DetNet Enhanced Data Plane

Abstract

   Aiming at providing the bounded latency to DetNet services, DetNet
   data plane is required to be enhanced. This document provides a
   method to extend DetNet data plane by introducing the Bounded
   Latency Information (BLI), which facilitates DetNet transit nodes to
   guarantee the bounded latency transmission in data plane.

Requirements Language

   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 .

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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   material or to cite them other than as "work in progress."

   This Internet-Draft will expire on 12 January 2023.

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1. Introduction

DetNet [RFC8655] provides the capability to carry specified unicast or multicast data flows with extremely low data loss rates and bounded end-to-end latency within a network domain. Three primary goals of DetNet QoS are defined in section 3.1 of [RFC8655]:

  *Minimum and maximum end-to-end latency from source to
   destination, timely delivery, and bounded jitter (packet delay
   variation) derived from these constraints.

  *Packet loss ratio under various assumptions as to the operational
   states of the nodes and links.

  *An upper bound on out-of-order packet delivery. It is worth
   noting that some DetNet applications are unable to tolerate any
   out-of-order delivery.

To fulfill the goals of DetNet QoS, DetNet architecture [RFC8655] defines a DetNet data plane protocol stack, which includes DetNet forwarding and service sub-layers. Specifically, DetNet data plane

framework [RFC8938] specifies two metadata of flow identity and sequence number to be encoded in data plane. Flow-ID is used for identification of the flow or aggregate flow to decide the DetNet traffic treatment and PREOF in both sub-layers. At the same time, sequence number is only used for PREOF in service sub-layer.

For IP DetNet data plane, [RFC8939] specifies a method of using 6-tuple to identify DetNet flows. Management and control information defined in DetNet YANG module [I-D.ietf-detnet-yang] is used to select the forwarding outgoing interface and next hop. It is stated that the allocation of system resources and provisioning of related parameters is used for DetNet traffic treatment. However, [RFC8939] doesn't further specify the related parameters used in data plane.

In [RFC8964], DetNet Control Word (d-CW), DetNet service label (S-Label), and DetNet MPLS forwarding label(s) (F-Label) are defined for the MPLS-based DetNet data plane encapsulation, where the first two information is mainly used for the DetNet service sub-layer functions, the last information is used for the DetNet forwarding sub-layer functions. DetNet controller plane takes the responsibility to provision both flow identification information and the flow-specific resources needed to provide traffic treatment to meet each flow's service requirements. There is no specification in MPLS DetNet data plane to empower the packet treatment capabilities.

There are also other specifications of DetNet data planes such as [RFC9023], [RFC9024], [RFC9025], [RFC9037], and [RFC9056]. These documents specifies the DetNet data planes and interworking technologies of one type of network operating over another sub-network in order to extend the DetNet service range. However, these documents do not introduce new procedure or process, but to follow the specifications defined in [RFC8939] and [RFC8964].

To meet the requirements for large-scale deterministic networks and support the bounded latency objective specified in [I-D.liu-detnet-large-scale-requirements], DetNet data plane is required to be enhanced in the following aspects:

  *Explicit inclusion of the metadata used for traffic treatment, especially for bounded latency and jitter, when considering the support of DetNet flows scalability in large scale DetNet networks

  *Compatibility to different options of queuing, shaping, policing or any other underlying network technologies, in order to provide bounded latency

  *Minimize the end-to-end delay difference of multiple forwarding paths that are used for packet replication and elimination

*DetNet data plane processing of DetNet flow coexists with the
    non-DetNet flows

   This documents provides a method to extend DetNet data plane by
   introducing Bounded Latency Information (BLI), which facilitates
   DetNet transit nodes to guarantee the bounded latency transmission
   in data plane. The resources include the QoS mechanisms, scheduling
   mechanisms, or any other mechanisms from underlying network layer so
   as to support bounded latency. This document also proposes a format
   of bounded latency information and its encapsulations on DetNet data
   planes.

2. Terminology and Conventions

2.1. Requirement Language

   The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT",
   "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and
   "OPTIONAL" in this document are to be interpreted as described in
   BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all
   capitals, as shown here.

2.2. Terminology

   The abbreviations used in this document are:

   BLI: Bounded Latency Information

   PREOF: Packet Replication, Elimination, and Ordering Functions

3. Design of DetNet Enhanced Data Plane

   In order to support the enhanced traffic treatment functions, such
   as bounded latency, DetNet data plane is enhanced by carrying a new
   defined metadata information in DetNet service packets: Bounded
   Latency Information (BLI).

   DetNet uses either one or combination of QoS related and resource
   allocation technologies to ensure the end-to-end bounded latency.
   [I-D.ietf-detnet-bounded-latency] introduces a set of scheduling
   mechanisms can be used to assure the bounded latency. [I-D.stein-
   srtsn] uses a single stack data structure to provide a unified
   approach to forwarding and deadline based scheduling. Noted that in
   most scheduling process, an ancillary information is required to be
   transmitted between DetNet nodes to facilitate local scheduling. In
   this document, this ancillary information is named bounded latency
   information. Bounded latency information is transmitted across
   multiple DetNet transit nodes and used by the DetNet forwarding sub-
   layer.

To cope with a variety of scheduling mechanisms and transfer
different information in a uniform format in data plane, the bounded
latency information is abstracted and classified into two
categories: requirement and resource.

3.1. Category 1: Requirement

Bounded latency information in the requirement category may include
the information like the end-to-end delay budget, local delay
budget, local deadline, delay variation budget, local delay
variation budget etc. For example, end-to-end delay budget describes
the upper bounded latency value of DetNet flow in network. Then
DetNet node may use this information to determine the packet
priority or which queue can be used to transmit this packet. Local
delay budget is a variation of end-to-end delay budget when multiple
DetNet nodes may have same or different delay budget time of each in
DetNet network. Deadline is straightforward to indicate how much
time is left for this packet to meet the upper bounded latency
requirement. Similar practice in 6LoWPANs is given by [RFC9034]. The
usage of this information is similar to the delay budget information
when DetNet node decides the priority or queue for the packet
forwarding. Delay variation [I-D.mohammadpour-detnet-bounded-delay-
variation] is another deterministic goal required by DetNet and
should be considered in scheduling process when it is required.
Priority can also be a type of requirement. DetNet application may
assign its priority by different meanings and formats, which may not
be equivalently fulfilled by existing QoS priority.

3.2. Category 2: Resource

Bounded latency information in the resource category includes the
information like cycle ID, queue ID, and time slot ID etc. Since
cycles, queues, or time slots are the real resources can be
allocated for DetNet flow, they are named as the time resource ID.
For example, time resource ID can represent a cycle ID when cyclic
queuing mechanism is used on DetNet node. Time resource ID can also
represent a queue ID when queue based scheduling mechanism is
locally used on DetNet node. Time resource ID can represent a time
slot ID too, when a time slot based mechanism like [RFC9030] is
used.

4. Data Field of Bounded Latency Information

This section introduces the data field of bounded latency
information in DetNet data plane. The format of the data field is
shown as follows.

```
+---------------+------------+------------+------------+
|  BLI Type     |   Format   |    Flag    |  Reserved  |
+---------------+------------+------------+------------+
|                                                     ~
~         Bounded Latency Information (variable size)  ~
~                                                     |
+-----------------------------------------------------+
```
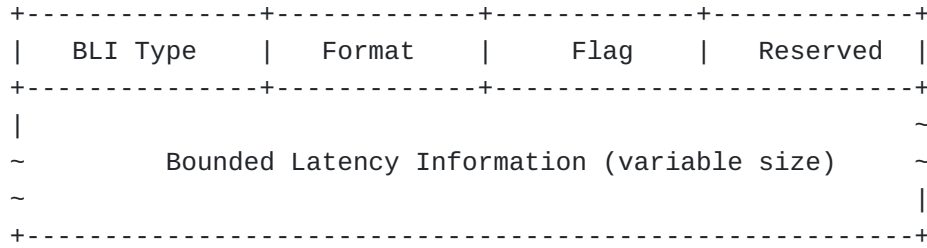
Figure 1: Data Field of Bounded Latency Information

where:

*Bounded Latency Information Type: 8-bit identifier to represent
the type of bounded latency information. A new registry is
expected to be created and the value is assigned by IANA. Table 1
lists the value of BLI Type and the corresponding Bounded Latency
Information defined so far,

```
+----------------+----------------------------------------+
| BLI Type Value |        Bounded Latency Information      |
+----------------+----------------------------------------+
|        0       |                Reserved                 |
+----------------+----------------------------------------+
|        1       |             Time resource ID            |
+----------------+----------------------------------------+
|        2       |                Priority                 |
+----------------+----------------------------------------+
|        3       |          End-to-end delay budget        |
+----------------+----------------------------------------+
|        4       |            Local delay budget           |
+----------------+----------------------------------------+
|        5       |            End-to-end deadline          |
+----------------+----------------------------------------+
|        6       |              Local deadline             |
+----------------+----------------------------------------+
|        7       |    End-to-end delay variation budget    |
+----------------+----------------------------------------+
|        8       |      Local delay variation budget       |
+----------------+----------------------------------------+
```

Table 1: Bounded Latency Information Type and Value

*Format: 8-bit value to indicate the format of bounded latency
information. For example, the format could be 16-bit unsigned
integer, 32-bit unsigned integer, PTP or NTP timestamp, and other
pre-configured formats. Table 2 lists the value of Format and the
corresponding Format defined so far,

```
+---------------+-------------------------+
| Format Value  |          Format         |
+---------------+-------------------------+
|       1       | 32-bit unsigned Integer |
+---------------+-------------------------+
|       2       | 16-bit unsigned Integer |
+---------------+-------------------------+
|       3       |  8-bit unsigned Integer |
+---------------+-------------------------+
|       4       |   PTP 80-bit Timestamp  |
+---------------+-------------------------+
|       5       |   PTP 64-bit Timestamp  |
+---------------+-------------------------+
|       6       |   NTP 64-bit Timestamp  |
+---------------+-------------------------+
|       7       |   NTP 32-bit Timestamp  |
+---------------+-------------------------+
```

Table 2: Format

Bounded Latency Information Type and Format are used together to
specify the type, length and format of the bounded latency
information.

   Reserved: Reserved for future usage.

   Time resource ID: the identifier to indicate the underlying
   resources used for bounded latency. The format is 32-bit unsigned
   integer with Format Value 1.

   Priority: QoS priority of the DetNet service packet. As six bits
   of the Differentiated Services Field [RFC2474] are used as a
   codepoint (DSCP), the format of priority is 8-bit unsigned
   integer with Format Value 3.

   End-to-end delay budget: the end-to-end delay requirement of
   DetNet service packet. The format is 32-bit unsigned Integer with
   Format Value 1.

   Local delay budget: the per hop delay requirement of DetNet
   service packet on this network node. The format is 32-bit
   unsigned Integer with Format Value 1.

   End-to-end deadline: the time when the packet must arrive at the
   final destination or exit the DetNet network. This time is

usually the birth time plus the end-to-end delay budget. The
format is the timestamp with proper length.

Local deadline: the time when the packet must exit this network
node. The format is the timestamp with proper length.

End-to-end delay variation budget: the end-to-end delay variation
requirement of DetNet service packet. The format is 8-bit or 16-
bit unsigned Integer with Format Value 3 or Format Value 2.

Local delay variation budget: the per hop delay variation
requirement of DetNet service packet on this network node. The
format is 8-bit or 16-bit unsigned Integer with Format Value 3 or
Format Value 2.

*Flags: 8 bits of flags. A new registry "Bounded Latency Flags" is
expected to be created. At the writing time, all flags are unused
and undefined.

```
 0 1 2 3 4 5 6 7
+-+-+-+-+-+-+-+-+
|U U U U U U U U|
+-+-+-+-+-+-+-+-+
```

Figure 2: Flag

*Reserved: Keeps zero when it is not specified.

*Bounded Latency Information: indicates the bounded latency
information used for local scheduling processing. Table 1 shows
the bounded latency information type and the corresponding
values. The bounded latency information is different depending on
the type of bounded latency information.

5. Encapsulation of Bounded Latency Information

BLI data field can be encapsulated in different DetNet data planes.

5.1. DetNet Data Plane of IP

For IPv6 based DetNet data plane, the data field of bounded latency
information is recommended to be carried in IPv6 Extension Header
Options, called Bounded Latency Information Option, shown in the
following Figure.

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2
                                +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                | Option Type   | Opt Data Len  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   BLI Type    |    Format     |    Flag       |   Reserved    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                              ~
~          Bounded Latency Information (variable size)         ~
~                                                              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
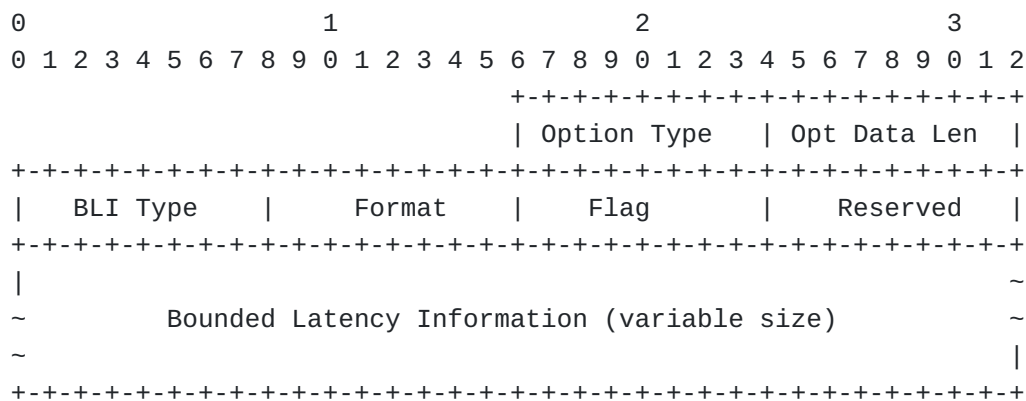
Figure 3: Bounded Latency Information Option

   *Option Type: 8-bit identifier of the type of option. Value TBD by
    IANA; the highest-order 3 bits of this field is 001 to skip over
    this option and continue processing the header if the processing
    IPv6 node does not recognize the Option Type and to permit the
    Option Data may change en route to the destination of packet.

   *Opt Data Len: 8-bit unsigned integer. Length of the Option Data
    field of this option, in octets.

   *For Bounded Latency Information data field, see section 4 for
    details.

Bounded latency information data field is encapsulated in either
IPv6 Hop-by-Hop Options header or IPv6 Destination Options header
depending on the processing happens at each hop or at the last hop.
More than one bounded latency information can appear in one Bounded
Latency Information Option. The Option Data Length and the Format
are used to locate every bounded latency information. The
encapsulation of Bounded Latency Information Option is shown in
Figure 4 and Figure 5.

```
+--------------------------------------+
|           DetNet App-Flow            |
|         (Original IP) Packet         |
+--------------------------------------+
|        UDP/GRE/IPSec... Header       |
+--------------------------------------+
|            Other IPv6 EHs            |
+--------------------------------------+
|     IPv6 Hop-by-Hop Options Header   |
|  (Bounded Latency Information Option) |
+--------------------------------------+
|             IPv6 Header              |
+--------------------------------------+
|              Data-Link               |
+--------------------------------------+
|              Physical                |
+--------------------------------------+
```
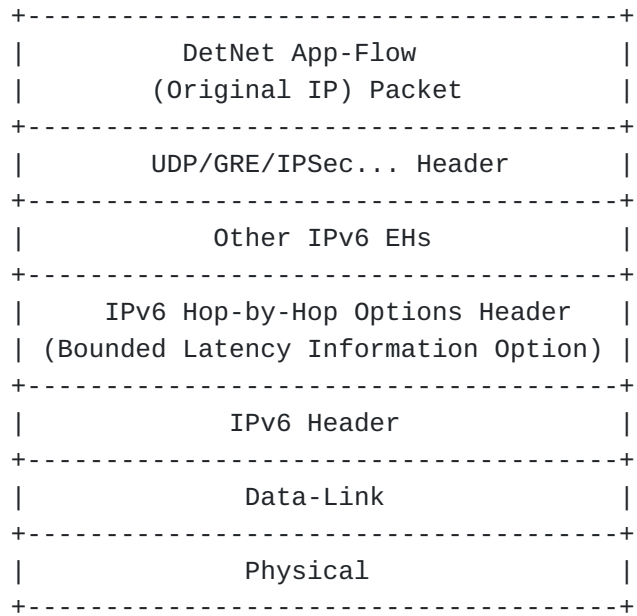
   Figure 4: Encapsulation of BLI Option in IPv6 Hop-by-Hop Options
   Headers

```
+--------------------------------------+
|           DetNet App-Flow            |
|         (Original IP) Packet         |
+--------------------------------------+
|        UDP/GRE/IPSec... Header       |
+--------------------------------------+
|     IPv6 Destination Options Header  |
|  (Bounded Latency Information Option) |
+--------------------------------------+
|            Other IPv6 EHs            |
+--------------------------------------+
|             IPv6 Header              |
+--------------------------------------+
|              Data-Link               |
+--------------------------------------+
|              Physical                |
+--------------------------------------+
```

   Figure 5: Encapsulation of BLI Option in IPv6 Destination Options
   Headers

5.2. DetNet Data Plane of MPLS

   An MPLS extension header is proposed in [I-D.song-mpls-extension-
   header]. An MPLS Extension Header (EH) encapsulated with the format
   of bounded latency information is called Bounded Latency Information
   Extension Header (BLIEH) and shown in Figure 6.

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     NH       |     HLEN      |      EXT      |    Reserved   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   BLI Type   |     Format    |      Flag     |    Reserved   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                             ~
~          Bounded Latency Information (variable size)        ~
~                                                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

     Figure 6: Bounded Latency Information Extension Header

      *NH: 8-bit indicator for the Next Header. This field identifies
       the type of the EH immediately following this EH.

      *HLEN: 8-bit unsigned integer for the Extension Header Length in
       4-octet units, not including the first 4 octets.

      *EXT: 8-bit optional type extension.

   The encapsulation of bounded latency information in MPLS extension
   headers with MPLS label stack is shown in the following figure. More
   than one BLI can be carried in one Bounded Latency Information
   Extension Header (BLIEH).

 0                               31
+--------+--------+--------+--------+  \
|                                   |  |
~       MPLS Label Stack            ~  |
|                                   |  |
+--------+--------+--------+--------+  |
|      EH Indicator (TBD)           |  > MPLS Label Stack
+--------+--------+--------+--------+  |  (extended with EHI)
|                                   |  |
~       MPLS Label Stack            ~  |
|                                   |  |
+--------+--------+--------+--------+ <
| Header of Extension Headers (HEH) |  |
+--------+--------+--------+--------+  |
|                                   | > MPLS EH Fields
~ Extension Header (EH)  with BLI  ~  |  (new)
|                                   |  |
+--------+--------+--------+--------+ <
|                                   |  |
~     Upper Layer Headers/Payload   ~  > MPLS Payload
|                                   |  |  (as is)
+--------+--------+--------+--------+  /
```
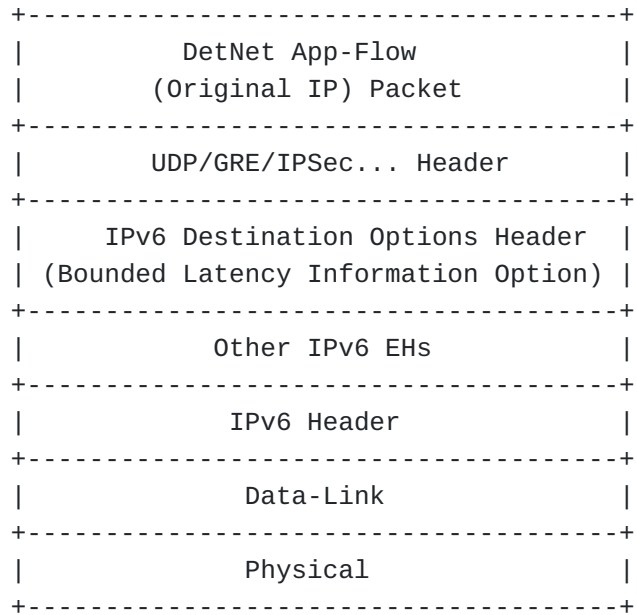
Figure 7: MPLS Encapsulation of Bounded Latency Information
Extension Header

5.3. DetNet Data Plane of MPLS over UDP/IP

This document describes a DetNet IP encapsulation that includes the
bounded latency information based on the DetNet MPLS over UDP/IP
data plane [RFC9025], i.e., leveraging the MPLS-over-UDP technology.
The bounded latency guarantee capable DetNet IP encapsulation builds
on encapsulating DetNet PW over an IP/UDP tunnel [RFC7510]. It is
noted that the format of MPLS Bounded Latency Extension Header
(BLIEH) after UDP header is the same with the format of MPLS Bounded
Latency Extension Header (BLIEH) defined in section 5.2, as well as
without using any MPLS forwarding labels. The encapsulation of
bounded latency information in DetNet Data Plane of MPLS over UDP/IP
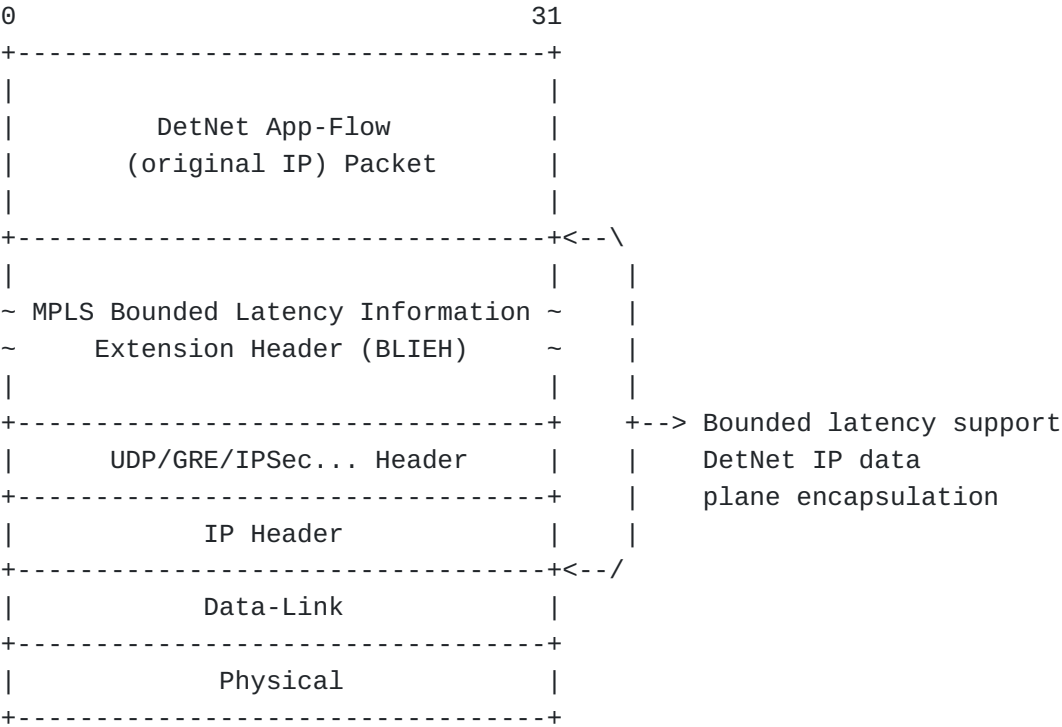is shown in the following figure.

```
0                                 31
+---------------------------------+
|                                 |
|          DetNet App-Flow        |
|       (original IP) Packet      |
|                                 |
+---------------------------------+<--\
|                                 |   |
~ MPLS Bounded Latency Information ~   |
~     Extension Header (BLIEH)    ~   |
|                                 |   |
+---------------------------------+   +--> Bounded latency support
|      UDP/GRE/IPSec... Header    |   |    DetNet IP data
+---------------------------------+   |    plane encapsulation
|            IP Header            |   |
+---------------------------------+<--/
|            Data-Link            |
+---------------------------------+
|             Physical            |
+---------------------------------+
```

Figure 8: IPv6 extension option of bounded latency

6. IANA Considerations

6.1. New Destination Options and Hop-by-Hop Options

IANA is requested to allocate a value of "Destination Options and
Hop-by-Hop Options" under "Internet Protocol Version 6 (IPv6)
Parameters" registry. The suggested value is:

```
+------+-----+-----+-------+--------------------+-----------+
| Hex  | act | chg | rest  |    Description     | Reference |
+------+-----+-----+-------+--------------------+-----------+
| TBD  | 00  |  1  | TBD   |     BLI Option     | This I-D  |
+------+-----+-----+-------+--------------------+-----------+
```

     Bounded Latency Information Option

6.2. New Type of MPLS Extension Header

   IANA is requested to allocate a 8-bit indicator for the Next Header
   to the Bounded Latency Extension Header.

6.3. New Subregistry of Bounded Latency Information Type

   IANA is requested to define a new subregistry of "Bounded Latency
   Information Type" for the "Bounded Latency Information Option" under
   "Internet Protocol Version 6 (IPv6) Parameters" registry.

   This new subregistry will include the following registries:

```
+-----------------+----------------------------------+-----------+
| Suggested Value |             Meaning              | Reference |
+-----------------+----------------------------------+-----------+
|       TBD       |             Reserved             | This I-D  |
+-----------------+----------------------------------+-----------+
|       TBD       |          Time resource ID        | This I-D  |
+-----------------+----------------------------------+-----------+
|       TBD       |             Priority             | This I-D  |
+-----------------+----------------------------------+-----------+
|       TBD       |       End-to-end delay budget    | This I-D  |
+-----------------+----------------------------------+-----------+
|       TBD       |         Local delay budget       | This I-D  |
+-----------------+----------------------------------+-----------+
|       TBD       |         End-to-end deadline       | This I-D  |
+-----------------+----------------------------------+-----------+
|       TBD       |          Local deadline          | This I-D  |
+-----------------+----------------------------------+-----------+
|       TBD       |End-to-end delay variation budget| This I-D  |
+-----------------+----------------------------------+-----------+
|       TBD       |   Local delay variation budget   | This I-D  |
+-----------------+----------------------------------+-----------+
```

     Bounded Latency Information Type

7. Security Considerations

   TBD

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