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Packet Delivery Deadline time in 6LoWPAN Routing Header
draft-ietf-6lo-deadline-time-02

Abstract

This document specifies a new type for the 6LoWPAN routing header containing the delivery deadline time for data packets. The deadline time enables forwarding and scheduling decisions for time critical IoT M2M applications that need deterministic delay guarantees over constrained networks and operate within time-synchronized networks.

Status of This Memo

This Internet-Draft will expire on March 4, 2019.

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1. Introduction

Low Power and Lossy Networks (LLNs) are likely to be deployed for real time industrial applications requiring end-to-end delay guarantees [I-D.ietf-detnet-use-cases]. A Deterministic Network ("detnet") typically requires some data packets to reach their receivers within strict time bounds. Intermediate nodes use the deadline information to make appropriate packet forwarding and scheduling decisions to meet the time bounds.

The draft [I-D.ietf-roll-routing-dispatch] specifies the 6LoWPAN Routing Header (6LoRH), compression schemes for RPL routing (source routing) operation [RFC6554], header compression of RPL Packet Information [RFC6553], and IP-in-IP encapsulation. This document specifies a new Deadline-6LoRHE type for the 6LoWPAN Dispatch Page 1, so that the deadline time of data packets can be included within the 6LoWPAN routing header. This document also specifies handling of the deadline time when packets traverse through time-synchronized networks operating in different timezones or distinct reference

clocks. Time synchronization techniques need not be mandated by this specificiation. There are a number of standards available for this purpose, including IEEE 1588 [ieee-1588], IEEE 802.1AS [dot1AS-2011], IEEE 802.15.4-2015 TSCH [dot15-tsch], and more.

The Deadline-6LoRHE can be used in any time synchronized 6Lo network. A 6TiSCH network has been used to describe the implementation of the Deadline-6LoRHE, but this does not preclude its use in scenarios other than 6TiSCH. For instance, there is a growing interest in using 6lo over a BLE mesh network [I-D.ietf-6lo-blemesh] in industrial IoT. BLE mesh time synchronization is also being recently explored by the Bluetooth community. There are also cases under consideration in Wi-SUN.

2. Terminology

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 [RFC2119].

This document uses terminology consistent with the terminology used in [RFC6550] and [I-D.ietf-6tisch-terminology]. Also, in this document, the terms "expiration time", "delivery deadline time", and "deadline" are used interchangeably with the same meaning.

3. Deadline-6LoRHE

The Deadline-6LoRHE (see Figure 2) is an elective 6LoRH (i.e., a 6LoRHE [RFC8138]) that provides the Deadline Time (DT) for an IPv6 datagram in a compressed form. Along with the deadline, the header can include the packet Origination Time (OT), to enable a close estimate of the total delay incurred by a packet. The OT field is initialized by the sender using the current time at the outgoing network interface through which the packet is forwarded.

The deadline field contains the value of the delivery deadline time for the packet. The packet SHOULD be delivered to the Receiver before this time.

```
packet_deadline_time = packet_origination_time + max_delay
```

All nodes within the network SHOULD process the Deadline-6LoRHE in order to support delay-sensitive deterministic applications. The packet deadline time (DT) and origination time (OT) are represented in time units determined by a scaling parameter in the routing header. One of the time units is the Network ASN (Absolute Slot Number) which can be used in case of a time slotted synchronized

network (for instance a 6TiSCH network, where global time is maintained in the units of slot lengths of a certain resolution).

The delay experienced by packets in the network is a useful metric for network diagnostics and performance monitoring. Whenever the packets crosses into a network using a different reference clock, the Origination Time field is updated to represent the same Origination Time, but expressed using the reference clock of the interface into the new network. This is the same as the current time when the packet is transmitted into the new network, minus the delay already experienced by the packet, say 't'. In this way, within the newly entered network, the packet will appear to have originated 't' time units earlier with respect to the reference clock of the new network.

```
Origination Time in new network = current_time_in_new_network -
               delay_already_experienced_in_previous_network(s)
```

The following example illustrates the origination time calculation when a packet travels between three networks, each in a different time zone. 'x' can be 1,2 or 3.

TxA : Time of arrival of packet in the network 'x'

TxD : Departure time of packet in the network 'x'

Dx : Delay experienced by the packet in the previous network(s)

TZx : Indicates the time zone of network 'x'

As an illustration, we consider a packet traversing through three time synchronized networks along with numerical values as shown in Figure 1.

```
            TZ1                      TZ2                       TZ3
   T1A=0|                 |                             |
        |----    D1=100   |                             |
        |     \           |                             |
        |      \          |                             |
        |       \ T1D=100 |T2A=1000                     |
        |        -------->|-----             D2=400     |
        |                 |     \                       |
        |                 |      \                      |
        |                 |       \          T2D=1400   | T3A=5000
        |                 |         ------------------->|
        |                 |                             |
        v                 v                             v

      D = 0            D  = T1D-OT                  D = T2D-OT
                          = 100-0                     = 1400 - 900
                          = 100                       = 500 i.e. (D1 + D2)


    OT = T1A-D        OT  = T2A-D                 OT  = T3A-D
       = 0                = 1000-100                  = 5000 - 500
                          = 900                       = 4500
```

Figure 1: Origination Time update example

There are multiple ways that a packet can be delayed, including propagation delay and queuing delays. Sometimes there are processing delays as well. For the purpose of determining whether or not the deadline has already passed, these various delays are not distinguished.

4. Deadline-6LoRHE Format

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1|0|1| Length  |  6LoRH Type   |O|D| DTL | OTL | TU| EXP | Rsv |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      DT (variable length)     | OT(variable length)(optional) |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 2: Deadline-6LoRHE format

Length (5 bits): Length represents the total length of the Deadline-6LoRHE type measured in octets.

6LoRH Type: TBD

O flag (1bit): Indicates the presence of Origination Time field. '1' means the OT field is present, and '0' means it is absent.

D flag (1 bit): The 'D' flag, set by the Sender, indicates the action to be taken when a 6LR detects that the deadline time has elapsed. If 'D' bit is 1, then the 6LR MUST drop the packet if the deadline time is elapsed. If 'D' bit is 0, then the 6LR MAY ignore the deadline time and forward the packet.

DTL (3 bits): Length of DT field.

OTL (3 bits) : Length of OT field.

For example, DTL = 000 means the deadline time in the 6LoRHE is 1 octet (8 bits) long. Similarly, OTL = 111 means the origination time is 8 octets (64 bits) long.

TU (2 bits) : Indicates the time units for DT and OT fields

00 : Time represented in microseconds
01 : Time represented in seconds
10 : Network ASN
11 : Reserved

EXP (3 bits) : Multiplication factor expressed as exponent of 10.

The value of the DT field is multiplied by 10 to this power, to get the actual deadline time in the units represented by TU. The default value of EXP is 000, so that the DT field is unaffected.

Rsv (3 bits) : Reserved

DT Value (8..64-bit) : Deadline Time value

OT Value (8..64-bit) : Origination Time value

Whenever a sender initiates the IP datagram, it includes the Deadline-6LoRHE along with other 6LoRH information.

Example: Consider a 6TiSCH network with time-slot length of 10ms. Let the current ASN when the packet is originated be 54400, and the maximum allowable delay (max_delay) for the packet delivery is 1 second from the packet origination, then:

deadline_time = packet_origination_time + max_delay
= 55400 + 100 (in Network ASNs)
= 55500(Network ASNs)

Deadline-6LoRHE encoding with 'O' flag and 'D' flag set to 1:

DTL = 001, OTL = 001, TU = '10', EXP = 2, DT = 0x22B, OT = 0x22A

5. Deadline-6LoRHE in Three Network Scenarios

In this section, Deadline-6LoRHE operation is described for 3 network scenarios. Figure 3 depicts a constrained time-synchronized LLN that has two subnets N1 and N2, connected through LBRs [I-D.ietf-6lo-backbone-router] with different reference clock times T1 and T2.

```
                          +-------------------+
                          | Time Synchronized |
                          |      Network      |
                          +---------+---------+
                                    |
                                    |
                                    |
                     +--------------+--------------+
                     |                             |
                  +-----+                       +-----+
                  |     | Backbone              |     | Backbone
             o    |     | router                |     | router
                  +-----+                       +-----+
             o                  o               o
                 o    o   o               o  o   o  o   o  o
            o      LLN    o                 o  LLN   o  o
               o   o    o      o             o o o     o  o
         6LoWPAN Network (subnet N1)   6LoWPAN Network (subnet N2)
```

Figure 3: Intra-network Timezone Scenario

5.1. Scenario 1: Endpoints in the same DODAG (N1)

In scenario 1, shown in Figure 4, the Sender 'S' has an IP datagram to be routed to a Receiver 'R' within the same DODAG. For the route segment from Sender to 6LBR, the Sender includes a Deadline-6LoRHE by encoding the deadline time contained in the packet. Subsequently, each 6LR will perform hop-by-hop routing to forward the packet towards the 6LBR. Once 6LBR receives the IP datagram, it sends the packet downstream towards 'R'.

In case of a network running RPL non-storing mode, the 6LBR generates a IPv6-in-IPv6 encapsulated packet when sending the packet downwards to the Receiver [I-D.ietf-roll-useofrplinfo]. The 6LBR copies the Deadline-6LoRHE from the Sender originated IP header to the outer IP header. The Deadline-6LoRHE contained in the inner IP header is elided.

```
                              +-------+
                   ^          | 6LBR  |       |
                   |          |       |       |
                   |          +-------+       |
           Upward  |      (F)/      /| \      | Downward
           routing |     /  \      / |  \     | routing
                   |    /    \   (C) |  (D)   |
                   |  (A)    (B) /   | / |\   |
                   |  /|\     |\:   (E)  : R  |
                     S : :    :     / \       v
```

Figure 4: End points within same DODAG (subnet N1)

At the tunnel endpoint of the IPv6-in-IPv6 encapsulation, the Deadline-6LoRHE is copied back from the outer header to inner header, and the inner IP packet is delivered to 'R'.

5.2. Scenario 2: Endpoints in Networks with Dissimilar L2 Technologies.

In scenario 2, shown in Figure 5, the Sender 'S' (belonging to DODAG 1) has IP datagram to be routed to a Receiver 'R' over a time-synchronized IPv6 network. For the route segment from 'S' to 6LBR, 'S' includes a Deadline-6LoRHE. Subsequently, each 6LR will perform hop-by-hop routing to forward the packet towards the 6LBR. Once the Deadline Time information reaches the border router, the packet will be encoded as per the mechanism prescribed in the new time synchronized network. The specific data encapsulation mechanisms followed in the new network are beyond the scope of this document.

```
                              +----------------+
                              | Time           |
                              | Synchronized   |------R
                              | Network        |
                              +----------------+
                                      |
                                      |
                            ----------+-----------
                     ^                |
                     |            +---+---+
                     |            | 6LBR  |
            Upward   |            |       |
            routing  |            +------++
                     |        (F)/      /| \
                     |       /  \      / |  \
                     |      /    \   (C) |  (D)
                       :  (A)    (B) /   | / |\
                          /|\     |\:   (E)  ::
                         S : :    :     / \
                                       :   :
```

Figure 5: Packet transmission in Dissimilar L2 Technologies or Internet

For instance, the IP datagram could be routed to another time synchronized deterministic network using the mechanism specified in the In-band OAM [I-D.ietf-ippm-ioam-data], and then the deadline time would be updated according to the measurement of the current time in the new network.

5.3. Scenario 3: Packet transmission across different DODAGs (N1 to N2).

Consider the scenario depicted in Figure 6, in which the Sender 'S' (belonging to DODAG 1) has an IP datagram to be sent to Receiver 'R' belonging to another DODAG (DODAG 2). The operation of this scenario can be decomposed into combination of case 1 and case 2 scenarios. For the route segment from 'S' to 6LBR, 'S' includes the Deadline-6LoRHE. Subsequently, each 6LR will perform hop-by-hop operation to forward the packet towards the 6LBR. Once the IP datagram reaches 6LBR1 of DODAG1, it applies the same rule as described in Case 2 while routing the packet to 6LBR2 over a (likely) time synchronized wired backhaul. The wired side of 6LBR2 can be mapped to receiver of Case 2. Once the packet reaches 6LBR2, it updates the Deadline-6LoRHE by adding or subtracting the difference of time of DODAG2 and sends the packet downstream towards 'R'.

```
                    Time Synchronized Network
                  -+---------------------------+-
                   |                           |
      DODAG1   +---+---+                   +---+---+   DODAG2
               | 6LBR1 |                   | 6LBR2 |
               |       |                   |       |
               +-------+                   +-------+
           (F)/      /| \              (F)/      /| \
          /  \      / |  \            /  \      / |  \
         /    \   (C) |  (D)         /    \   (C) |  (D)
       (A)    (B) /   | / |\       (A)    (B) /   | / |\
       /|\     |\:   (E)  : :      /|\     |\:   (E)  : :
      S : :    :     / \          : : :    :     / \
                    :   :                       :   R
   Network N1, time zone T1      Network N2, time zone T2
```

Figure 6: Packet transmission in different DODAGs(N1 to N2)

Consider an example of a 6TiSCH network in which S in DODAG1 generates the packet at ASN 20000 to R in DODAG2. Let the maximum allowable delay be 1 second. The time-slot length in DODAG1 and DODAG2 is assumed to be 10ms. Once the deadline time is encoded in Deadline-6LoRHE, the packet is forwarded to 6LBR of DODAG1. Suppose the packet reaches 6LBR of DODAG1 at ASN 20030.

```
current_time = ASN at LBR * slot_length_value

remaining_time = deadline_time - current_time
= ((packet_origination_time + max_delay) - current time)
= (20000 + 100) - 20030
= 30 (in Network ASNs)
= 30 * 10^3 milliseconds.
```

Once the Deadline Time information reaches the border router, the packet will be encoded as per the mechanism prescribed in the new time synchronized network

6. IANA Considerations

This document defines a new 6LoWPAN Timestamp Header Type, and assigns a value (TBD) from the 6LoWPAN Dispatch Page1 number space.

6LoRH Type	Value
Deadline-6LoRHE	TBD

Figure 7: Deadline-6LoRHE type

7. Security Considerations

The security considerations of [RFC4944], [RFC6282] and [RFC6553] apply. Using a compressed format as opposed to the full in-line format is logically equivalent and does not create an opening for a new threat when compared to [RFC6550], [RFC6553] and [RFC6554].

8. Acknowledgements

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9. References

9.1. Normative References

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Appendix A. Changes after draft-ietf-6lo-deadline-time-01

This section lists the changes between draft-ietf-6lo-deadline-time revisions ...-01.txt and ...-02.txt.

- Replaced 6LoRHE description by reference to RFC 8138.
- Added figure to illustrate change to Origination Time when a packet crosses timezone boundaries.
- Clarified that use of 6tisch networks is descriptive, not normative.
- Clarified that In-Band OAM is used as an example and is not normative.
- Updated bibliographic citations.
- Alphabetized contributor names.

Appendix B. Changes between earlier versions

This section lists the changes between draft-ietf-6lo-deadline-time revisions ...-00.txt and ...-01.txt.

- Changed "SHOULD drop" to "MUST drop" a packet if the deadline is passed (see Section 4).
- Added explanatory text about how packet delays might arise. (see Section 3).

- Mentioned availability of time-synchronization protocols (see Section 1).   .
- Updated bibliographic citations.
- Alphabetized contributor names.
- Added this section.

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