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RFC 9376
Applicability of GMPLS for beyond 100 Gbit/s Optical Transport Network

Abstract

This document examines the applicability of using existing GMPLS routing and signaling mechanisms to set up Optical Data Unit-k (ODUk) Label Switched Paths (LSPs) over Optical Data Unit-Cn (ODUCn) links as defined in the 2020 version of ITU-T Recommendation G.709.

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Table of Contents

1. Introduction

The current GMPLS routing [RFC7138] and signaling [RFC7139] extensions support the control of the Optical Transport Network (OTN) signals and capabilities that were defined in the 2012 version of ITU-T Recommendation G.709 [ITU-T_G709_2012].

In 2016, a new version of ITU-T Recommendation G.709 was published: [ITU-T_G709_2016]. This version introduced higher-rate Optical Transport Unit (OTU) and Optical Data Unit (ODU) signals, termed "OTUCn" and "ODUCn", respectively, which have a nominal rate of n*100 Gbit/s. According to the definition in [ITU-T_G709_2016], OTUCn and ODUCn perform only the digital section-layer role, and ODUCn supports only ODUk clients. This document focuses on the use of existing GMPLS mechanisms to set up ODUk (e.g., ODUflex) Label Switched Paths (LSPs) over ODUCn links, independently from how these links have been set up.

Because [ITU-T_G709_2020] does not introduce any new features to OTUCn and ODUCn compared to [ITU-T_G709_2016], this document first presents an overview of the OTUCn and ODUCn signals in [ITU-T_G709_2020] and then analyzes how the current GMPLS routing and signaling mechanisms can be utilized to set up ODUk (e.g., ODUflex) LSPs over ODUCn links.

This document assumes that readers are familiar with OTN, GMPLS, and how GMPLS is applied in OTN. As such, this document doesn't provide any background pertaining to OTN that include links with capacities of 100 Gbit/s or less; this background could be found in documents such as [RFC7062] and [RFC7096]. This document provides an overview of the data plane primitives that enable links with capacities greater than 100 Gbit/s and analyzes the extensions that would be required in the current GMPLS routing and signaling mechanisms to support evolution in OTN.

2. OTN Terminology Used in This Document

FlexO: Flexible OTN information structure. This information structure usually has a specific bitrate and frame format that consists of overhead and payload, which are used as a group for the transport of an OTUCn signal.

LSP: Label Switched Path

MSI: Multiplex Structure Indicator. This structure indicates the grouping of the tributary slots in an OPU payload area that realizes a client signal, which is multiplexed into an OPU. The individual clients multiplexed into the OPU payload area are distinguished by the Tributary Port Number (TPN).

ODU: Optical Data Unit. An ODU has the frame structure and overhead, as defined in Figure 12-1 of [ITU-T_G709_2020]. ODUs can be formed in two ways: a) by encapsulating a single non-OTN client, such as SONET/SDH (Synchronous Optical Network / Synchronous Digital Hierarchy) or Ethernet, or b) by multiplexing lower-rate ODUs. In general, the ODU layer represents the path layer in OTN. The only exception is the ODUCn signal (defined below), which is defined to be a section-layer signal. In the classification based on bitrates of the ODU signals, ODUs are of two types: fixed rate and flexible rate. Flexible-rate ODUs, called "ODUflex", have a rate that is 239/238 times the bitrate of the client signal they encapsulate.

ODUC: Optical Data Unit-C. This signal has a bandwidth of approximately 100 Gbit/s and is of a slightly higher bitrate than the fixed rate ODU4 signal. This signal has the format defined in Figure 12-1 of [ITU-T_G709_2020]. This signal represents the building block for constructing a higher-rate signal called "ODUCn" (defined below).

ODUCn: Optical Data Unit-Cn, where Cn indicates the bitrate of approximately n*100 Gbit/s. This frame structure consists of "n" interleaved frame and multiframe synchronous instances of the ODUC signal, each of which has the format defined in Figure 12-1 of [ITU-T_G709_2020].

ODUflex: Optical Data Unit - flexible rate. An ODUflex has the same frame structure as a "generic" ODU but with a rate that is a fixed multiple of the bitrate of the client signal it encapsulates. [ITU-T_G709_2020] defines specific ODUflex containers that are required to transport specific clients such as 50GE, 200GE, 400GE, etc.

ODUk: Optical Data Unit-k, where k is one of {0, 1, 2, 2e, 3, 4}. The term "ODUk" refers to an ODU whose bitrate is fully specified by the index k. The bitrates of the ODUk signal for k = {0, 1, 2, 2e, 3, 4} are approximately 1.25 Gbit/s, 2.5 Gbit/s, 10 Gbit/s, 10.3 Gbit/s, 40 Gbit/s, and 100 Gbit/s, respectively.

OPUC: Optical Payload Unit-C. This signal has a payload of approximately 100 Gbit/s. This structure represents the payload area of the ODUC signal.

OPUCn: Optical Payload Unit-Cn, where Cn indicates that the bitrate is approximately n*100 Gbit/s. This structure represents the payload area of the ODUCn signal.

OTN: Optical Transport Network

OTUC: Optical Transport Unit-C. This signal has a bandwidth of approximately 100 Gbit/s. This signal forms the building block of the OTUCn signal defined below, which has a bandwidth of approximately n*100 Gbit/s.

OTUCn: Fully standardized Optical Transport Unit-Cn. This frame structure is realized by extending the ODUCn signal with the OTU layer overhead. The structure of this signal is illustrated in Figure 11-4 of [ITU-T_G709_2020]. Note that the term "fully standardized" is defined by ITU-T in Section 6.1.1 of [ITU-T_G709_2020].

OTUCn-M: This signal is an extension of the OTUCn signal introduced above. This signal contains the same amount of overhead as the OTUCn signal but contains a reduced amount of payload area. Specifically, the payload area consists of M tributary slots (each 5 Gbit/s), where M is less than 20*n, which is the number of tributary slots in the OTUCn signal.

PSI: Payload Structure Indicator. This is a 256-byte signal that describes the composition of the OPU signal. This field is a concatenation of the payload type (PT) and the Multiplex Structure Indicator (MSI) defined below.

TPN: Tributary Port Number. The tributary port number is used to indicate the port number of the client signal that is being transported in one specific tributary slot.

Detailed descriptions for some of these terms can be found in [ITU-T_G709_2020].

3. Overview of OTUCn/ODUCn in G.709

This section provides an overview of the OTUCn/ODUCn signals defined in [ITU-T_G709_2020]. The text in this section is purely descriptive and is not normative. For a full description of OTUCn/ODUCn signals, please refer to [ITU-T_G709_2020]. In the event of any discrepancy between this text and [ITU-T_G709_2020], that other document is definitive.

3.1. OTUCn

In order to carry client signals with rates greater than 100 Gbit/s, [ITU-T_G709_2020] takes a general and scalable approach that decouples the rates of OTU signals from the client rate. The new OTU signal is called "OTUCn", and this signal is defined to have a rate of (approximately) n*100 Gbit/s. The following are the key characteristics of the OTUCn signal:

- The OTUCn signal contains one ODUCn. The OTUCn and ODUCn signals perform digital section-layer roles only (see Section 6.1.1 of [ITU-T_G709_2020])
- The OTUCn signals are formed by interleaving n synchronous OTUC signals (which are labeled 1, 2, ..., n).
- Each of the OTUC instances has the same overhead as the standard OTUk signal in [ITU-T_G709_2020]. Note that the OTUC signal doesn't include the Forward Error Correction (FEC) columns illustrated in Figure 11-1 of [ITU-T_G709_2020]. The OTUC signal includes an ODUC.
- The OTUC signal has a slightly higher rate compared to the OTU4 signal (without FEC); this is to ensure that the OPUC payload area can carry an ODU4 signal.
- The combined signal OTUCn has n instances of OTUC overhead and n instances of ODUC overhead.

The OTUCn, ODUCn, and OPUCn signal structures are presented in a (physical) interface-independent manner, by means of n OTUC, ODUC, and OPUC instances that are marked #1 to #n.

OTUCn interfaces can be categorized as follows, based on the type of peer network element:

inter-domain interfaces: These types of interfaces are used for connecting OTN edge nodes to (a) client equipment (e.g., routers) or (b) hand-off points from other OTN. ITU-T Recommendation G709.1 [ITU-T_G709.1] specifies a flexible interoperable short-reach OTN interface over which an OTUCn (n >=1) is transferred, using bonded Flexible OTN information structure (FlexO) interfaces, which belong to a FlexO group.

intra-domain interfaces: In these cases, the OTUCn is transported using a proprietary (vendor-specific) encapsulation, FEC, etc. It is also possible to transport OTUCn for intra-domain links using FlexO.

3.1.1. OTUCn-M

The standard OTUCn signal has the same rate as the ODUCn signal. This implies that the OTUCn signal can only be transported over wavelength groups that have a total capacity of multiples of (approximately) 100 Gbit/s. Modern optical interfaces support a variety of bitrates per wavelength, depending on the reach requirements for the optical path. If the total rate of the ODUk LSPs planned to be carried over an ODUCn link is smaller than n*100 Gbit/s, it is possible to "crunch" the OTUCn, and the unused tributary slots are thus not transmitted. [ITU-T_G709_2020] supports the notion of a reduced-rate OTUCn signal, termed "OTUCn-M". The OTUCn-M signal is derived from the OTUCn signal by retaining all the n instances of overhead (one per OTUC instance) but with only M (M is less than 20*n) OPUCn tributary slots available to carry ODUk LSPs.

3.2. ODUCn

The ODUCn signal defined in [ITU-T_G709_2020] can be viewed as being formed by the appropriate interleaving of content from n ODUC signal instances. The ODUC frames have the same structure as a standard ODU in the sense that the frames have the same overhead and payload areas but have a higher rate since their payload area can embed an ODU4 signal.

The ODUCn is a multiplex section ODU signal and is mapped into an OTUCn signal, which provides the regenerator section layer. In some scenarios, the ODUCn and OTUCn signals will be coterminated, i.e., they will have identical source/sink locations (see Figure 1). In Figure 1, the term "OTN Switch" has the same meaning as that used in Section 3 of [RFC7138]. [ITU-T_G709_2020] allows for the ODUCn signal to pass through one or more digital regenerator nodes (shown as nodes B and C in Figure 2), which will terminate the OTUCn layer but will pass the regenerated (but otherwise untouched) ODUCn towards a different OTUCn interface where a fresh OTUCn layer will be initiated. This process is termed as "ODUCn regeneration" in Section 7.1 of [ITU-T_G872]. In this example, the ODUCn is carried by three OTUCn segments.

Specifically, the OPUCn signal flows through these regenerators unchanged. That is, the set of client signals, their TPNs, and tributary-slot allocations remains unchanged.

```
+--------+            +--------+
|        +------------+        |
| OTN    |------------| OTN    |
| Switch +------------+ Switch |
| A      |            | B      |
|        +------------+        |
+--------+            +--------+
    <--------ODUCn------->
     <-------OTUCn------>
```

Figure 1: ODUCn Signal

```
   +---------+         +--------+         +--------+         +--------+
   |         +--------+ |        |         |        +----------+        |
   | OTN     |--------| OTN    |         | OTN    |----------| OTN    |
   | Switch  +--------+ Regen  +---------+ Regen  +----------+ Switch |
   | A       |        | B      |         | C      |          | D      |
   |         +--------+        |         |        +----------+        |
   +---------+        +--------+         +--------+          +--------+

       <-------------------------ODUCn-------------------------->
        <---------------><----------------><------------------>
             OTUCn              OTUCn              OTUCn
```

Figure 2: ODUCn Signal - Multi-Hop

3.3. Tributary Slot Granularity

[ITU-T_G709_2012] introduced the support for 1.25 Gbit/s granular tributary slots in OPU2, OPU3, and OPU4 signals. [ITU-T_G709_2020] defined the OPUC with a 5 Gbit/s tributary slot granularity. This means that the ODUCn signal has 20*n tributary slots (of 5 Gbit/s capacity). The range of tributary port number (TPN) is 10*n instead of 20*n, which restricts the maximum client signals that could be carried over one single ODUC1.

3.4. Structure of OPUCn MSI with Payload Type 0x22

As mentioned above, the OPUCn signal has 20*n tributary slots (TSs) (each 5 Gbit/s). The OPUCn MSI field has a fixed length of 40*n bytes and indicates the availability and occupation of each TS. Two bytes are used for each of the 20*n tributary slots, and each such information structure has the following format (see Section 20.4.1 of [ITU-T_G709_2020]):

- The TS availability bit indicates if the tributary slot is available or unavailable.
- The TS occupation bit indicates if the tributary slot is allocated or unallocated.
- The tributary port number (14 bits) indicates the port number of the client signal that is being carried in this specific TS. A flexible assignment of tributary port to tributary slots is possible. Numbering of tributary ports is from 1 to 10*n.

The concatenation of the OPUCn payload type (PT) and the MSI field is carried over the overhead byte designated as PSI in Figure 15-6 of [ITU-T_G709_2020].

3.5. Client Signal Mappings

The approach taken by the ITU-T to map non-OTN client signals to the appropriate ODU containers is as follows:

- All client signals are mapped into an ODUj or ODUk (e.g., ODUflex) as specified in Section 17 of [ITU-T_G709_2020].
- The terms "ODUj" and "ODUk" are used in a multiplexing scenario, with ODUj being a low-order ODU that is multiplexed into ODUk, a high-order ODU. As Figure 3 illustrates, the ODUCn is also a high-order ODU into which other ODUs can be multiplexed. The ODUCn itself

cannot be multiplexed into any higher-rate ODU signal; it is defined to be a section-level signal.

- ODUflex signals are low-order signals only. If the ODUflex entities have rates of 100 Gbit/s or less, they can be transported over either an ODUk (k=1..4) or an ODUCn. For ODUflex connections with rates greater than 100 Gbit/s, ODUCn is required.
- ODU Virtual Concatenation (VCAT) has been deprecated. This simplifies the network and the supporting hardware since multiple different mappings for the same client are no longer necessary. Note that legacy implementations that transported sub-100 Gbit/s clients using ODU VCAT shall continue to be supported.

```
        Clients (e.g., SONET/SDH and Ethernet)

    |   |   |                           |   |   |
    |   |   |                           |   |   |
    |   |   |                           |   |   |
+---+---+---+----+                      |   |   |
|      OPUj      |                      |   |   |
+----------------+                      |   |   |
|      ODUj      |                      |   |   |
+----------------+----------------------+---+---+----------+
|                                                          |
|                       OPUk                               |
+----------------------------------------------------------+
|                                                          |
|                       ODUk       k in {0,1,2,2e,3,4,flex}|
+-------------------------+-----+--------------------------+
|                         |     |                          |
| OTUk, OTUk-SC, OTUk-V   |     |          OPUCn           |
+-------------------------+     +--------------------------+
                                |                          |
                                |          ODUCn           |
                                +--------------------------+
                                |                          |
                                |          OTUCn           |
                                +--------------------------+
```

Figure 3: Digital Structure of OTN Interfaces (from Figure 6-1 of [ITU-T_G709_2020])

4. GMPLS Implications and Applicability

4.1. TE Link Representation

Section 3 of [RFC7138] describes how to represent G.709 OTUk/ODUk with TE links in GMPLS. In the same manner, OTUCn links can also be represented as TE links. Figure 4 provides an illustration of a one-hop OTUCn TE link.

```
            +----------+                    +---------+
            |  OTN     |                    |  OTN    |
            |  Switch  +--------------------+  Switch |
            |  A       |                    |  B      |
            +----------+                    +---------+

                |<---------OTUCn Link---------->|

                |<---------TE Link------------->|
```

Figure 4: One-Hop OTUCn TE Link

It is possible to create TE links that span more than one hop by creating forward adjacencies (FAs) between non-adjacent nodes (see Figure 5). In Figure 5, nodes B and C are performing the ODUCn regeneration function described in Section 7.1 of [ITU-T_G872] and are not electrically switching the ODUCn signal from one interface to another. As in the one-hop case, multi-hop TE links advertise the ODU switching capability.

```
 +--------+         +--------+          +--------+         +---------+
 | OTN    |         |  OTN   |          |  OTN   |         |  OTN    |
 | Switch |<------->|  Regen |<-------->|  Regen |<------->|  Switch |
 | A      |  OTUCn  |  B     |   OTUCn  |  C     |  OTUCn  |  D      |
 +--------+  Link   +--------+   Link   +--------+  Link   +---------+

        |<-------------------- ODUCn Link -------------------->|

        |<---------------------- TE Link --------------------->|
```

Figure 5: Multi-Hop ODUCn TE Link

The two endpoints of a TE link are configured with the supported resource information (which may include whether the TE link is supported by an ODUCn, ODUk, or OTUk), as well as the link attribute information (e.g., slot granularity and list of available tributary slot).

4.2. GMPLS Signaling

Once the ODUCn TE link is configured, the GMPLS mechanisms defined in [RFC7139] can be reused to set up ODUk/ODUflex LSPs with no changes. As the resource on the ODUCn link that can be seen by the ODUk/ODUflex client signal is a set of 5 Gbit/s slots, the label defined in [RFC7139] is able to accommodate the requirement of the setup of an ODUk/ODUflex client signal over an ODUCn link. In [RFC7139], the OTN-TDM GENERALIZED_LABEL object is used to indicate how the lower-order (LO) ODUj signal is multiplexed into the higher-order (HO) ODUk link. In a similar manner, the OTN-TDM GENERALIZED_LABEL object is used to indicate how the ODUk signal is multiplexed into the ODUCn link. The ODUk signal type is indicated by Traffic Parameters. The IF_ID RSVP_HOP object provides a pointer to the interface associated with TE link; therefore, the two nodes terminating the TE link know (by internal/local configuration) the attributes of the ODUCn TE Link.

The TPN defined in [ITU-T_G709_2020] (where it is referred to as "tributary port #") for an ODUCn link has 14 bits while this field in [RFC7139] only has 12 bits, so some extension work will eventually be needed. Given that a 12-bit TPN field can support ODUCn links with up to n=400 (i.e., 40 Tbit/s links), this need is not urgent.

The example in Figure 6 illustrates the label format defined in [RFC7139] for multiplexing ODU4 onto ODUC10. One ODUC10 has 200 slots (each 5 Gbit/s), and twenty of them are allocated to the ODU4. With this label encoding, only 20 out of the 200 bits mask are non-zero, which is very inefficient. The inefficiency grows for larger values of "n", and an optimized label format may be desirable.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|        TPN = 3        |    Reserved     |      Length = 200     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 1 1 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 0 0 1 0 0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 0 0 0 0|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0 0 0 0 0 0 0 0|              Padding Bits(0)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 6: Label Format

4.3. GMPLS Routing

For routing, it is deemed that no extension to the current mechanisms defined in [RFC7138] is needed.

The ODUCn link, which is the lowest layer of the ODU multiplexing hierarchy involving multiple ODU layers, is assumed to have been already configured when GMPLS is used to set up ODUk over ODUCn; therefore, the resources that need to be advertised are the resources that are exposed by this ODUCn link and the ODUk multiplexing hierarchy on it. The 5 Gbit/s OPUCn time slots do not need to be advertised, while the 1.25 Gbit/s and 2.5 Gbit/s OPUk time slots need to be advertised using the mechanisms already defined in [RFC7138].

Since there is a 1:1 correspondence between the ODUCn and the OTUCn signal, there is no need to explicitly define a new value to represent the ODUCn signal type in the OSPF-TE routing protocol.

5. IANA Considerations

This document has no IANA actions.

6. Security Considerations

This document analyzes the applicability of protocol extensions in [RFC7138] and [RFC7139] for use in the 2020 version of ITU-T Recommendation G.709 [ITU-T_G709_2020] and finds that no new extensions are needed. Therefore, this document introduces no new security considerations to the existing signaling and routing protocols beyond those already described in [RFC7138] and [RFC7139]. Please refer to [RFC7138] and [RFC7139] for further details of the specific security measures. Additionally, [RFC5920] addresses the security aspects that are relevant in the context of GMPLS.

7. References

7.1. Normative References

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Appendix A. Possible Future Work

As noted in Section 4.2, the GMPLS TPN field defined in Section 6.1 of [RFC7139] is only 12 bits, whereas an ODUCn link could require up to 14 bits. Although the need is not urgent, future work could extend the TPN field in GMPLS to use the Reserved bits immediately adjacent. This would need to be done in a backward-compatible way.

Section 4.2 further notes that the current encoding of GMPLS labels can be inefficient for larger values of n in ODUCn. Future work might examine a more compact, yet generalized, label encoding to address this issue should it be felt, after analysis of the operational aspects, that the current encoding is causing problems. Introduction of a new label encoding would need to be done using a new pairing of LSP encoding type and Generalized Payload Identifier (G-PID) to ensure correct interoperability.

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