Authors: S. Hegde   W. Britto
         Juniper Networks Inc.   Juniper Networks Inc.
         R. Shetty   B. Decraene   P. Psenak
         Juniper Networks Inc.   Orange   Cisco Systems
         T. Li
         Juniper Networks Inc.

Flexible Algorithms: Bandwidth, Delay, Metrics and Constraints

Abstract

Many networks configure the link metric relative to the link
capacity. High bandwidth traffic gets routed as per the link
capacity. Flexible algorithms provides mechanisms to create
constraint based paths in IGP. This draft documents a generic metric
type and set of bandwidth related constraints to be used in Flexible
Algorithms.

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 RFC 2119 [RFC2119].

Status of This Memo

Table of Contents

1. Introduction

High bandwidth traffic such as residential internet traffic and
machine to machine elephant flows benefit from using high capacity
links. Accordingly, many network operators define a link's metric
relative to its capacity to help direct traffic to higher bandwidth
links, but this is no guarantee that lower bandwidth links will be
avoided, especially in failure scenarios. To ensure that elephant
flows are only placed on high capacity links, it would be useful to
explicitly exclude the high bandwidth traffic from utilizing links
below a certain capacity. Flex-Algorithm [I-D.ietf-lsr-flex-algo] is
defined as a set of parameters consisting of calculation-type,
metric-type and a set of constraints for allowing operators to have
more control over the network path computation. In this document, we
define further extensions to Flex-Algorithm that will allow
operators additional control over their traffic flow, especially
with respect to constraints about bandwidth.

Historically, IGPs have done path computation by minimizing the sum
of the link metrics along the path from source to destination. While
the metric has been administratively defined, implementations have
defaulted to a metric that is inversely proportional to link
bandwidth. This has driven traffic to higher bandwidth links and has
required manual metric manipulation to achieve the desired loading
of the network.

Over time, with the addition of different traffic types, the need
for alternate types of metrics has become clear. Flex-Algorithm
already supports using the minimum link delay and the
administratively assigned traffic-engineering metrics in path
computation. However, it is clear that additional metrics may be of
interest in different situations. A network operator may seek to
minimize their operational costs and thus may want a metric that
reflects the actual fiscal costs of using a link. Other traffic may
require low jitter, leading to an entirely different set of metrics.
With Flex-Algorithm, all of these different metrics, and more, could
be used concurrently on the same network.

In some circumstances, path computation constraints, such as administrative groups, can be used to ensure that traffic avoids particular portions of the network. These strict constraints are appropriate when there is an absolute requirement to avoid parts of the topology, even in failure conditions. If, however, the requirement is less strict, then using a high metric in a portion of the topology may be more appropriate.

This document defines a family of generic metrics that can carry various types of administratively assigned metrics. This document proposes standard metric-types which require specific standard document. This document also proposes user defined metric-types where specifics are not defined, so that administrators are free to assign semantics as they fit.

This document also specifies a new bandwidth based metric type to be used with Flex-Algorithm and other applications in Section Section 4. Additional Flexible Algorithm Definition (FAD) constraints are defined in Section Section 3 that allow the network administrator to preclude the use of low bandwidth links or high delay links.

Section Section 4.1 defines mechanisms to automatically calculate link metrics based on the parameters defined in the FAD and the advertised Maximum Link Bandwidth of each link. This is advantageous because administrators can change their criteria for metric assignment centrally, without individual modification of each link metric throughout the network.The procedures described in this document are intended to assign metric to the link based on total link capacity and they are not intended to update the metric based on actual traffic flow. Thus, the procedures described in this document are not a replacement to the capability of a centralized controller which has dynamic view of the network and provides real time bandwidth management or a distributed bandwidth management protocol.

2. Generic Metric Advertisement

IS-IS and OSPF advertise a metric for each link in their respective link state advertisements. Multiple metric types are already supported. Administratively assigned metrics are described in the original OSPF and IS-IS specifications. The Traffic Engineering Default Metric is defined in [RFC5305] and [RFC3630] and the Min Unidirectional delay metric is defined in [RFC8570] and [RFC7471]. Other metrics, such as jitter, reliability, and fiscal cost may be helpful, depending on the traffic class. Rather than attempt to enumerate all possible metrics of interest, this document specifies a generic mechanism for advertising metrics.

Each generic metric advertisement is on a per-link and per metric type basis. The metric advertisement consists of a metric type field and a value for the metric. The metric type field is assigned by the "IGP metric type" IANA registry. Metric types 0-127 are standard metric types as assigned by IANA. This document further specifies a user defined metric type space of metric types 128-255. These are user defined and can be assigned by an operator for local use.

Implementations MUST support sending and receiving generic metric sub-TLV in ASLA encodings as well as in the TLV 22/extended link LSA/TE-LSAs. The usage of generic metric by individual application is subjected to the same rules that apply to other link attributes defined in respective standards.

2.1. IS-IS Generic Metric sub-TLV

The IS-IS Generic Metric sub-TLV specifies the link metric for a given metric type. Typically, this metric is assigned by a network administrator. The Generic Metric sub-TLV is advertised in the TLVs/ sub-TLVs below:

   TLV-22 (Extended IS reachability) [RFC5305]

   TLV-222 (MT-ISN) [RFC5120]

   TLV-23 (IS Neighbor Attribute) [RFC5311]

   TLV-223 (MT IS Neighbor Attribute) [RFC5311]

   TLV-141 (inter-AS reachability information) [RFC5316]

   sub-TLV 16 (Application-Specific Link Attributes) of TLV
   22/222/23/223/141 [RFC8919]


```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Type       |    Length     |  metric-type  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Value                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

   Type :   TBD (To be assigned by IANA)
   Length: 4 octets
   metric-type: A value from the IGP metric-type registry
   Value : metric value range (0 - 16,777,215)
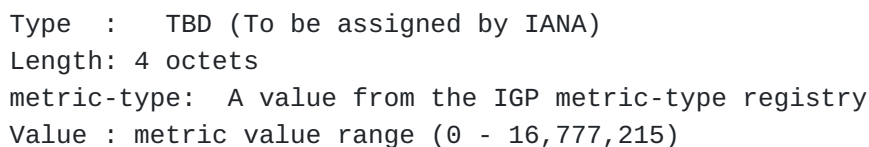
                Figure 1: IS-IS Generic Metric sub-TLV

The Generic Metric sub-TLV MAY be advertised multiple times. For a
particular metric type, the Generic Metric sub-TLV MUST be
advertised only once for a link when advertised in TLV 22,222,23,223
and 141. When Generic metric sub-TLV is advertised in ASLA, each
metric type MUST be advertised only once per-application for a link.
If there are multiple Generic Metric sub-TLVs advertised for a link
for same metric type (and same application in case of ASLA) in one
or more received LSPDUs, advertisement in the lowest numbered
fragment MUST be used and the subsequent ones MUST be ignored.

If the metric type indicates a standard metric type for which there
are other advertisement mechanisms (e.g., the IGP metric, the Min
Unidirectional Link Delay, or the Traffic Engineering Default
Metric, as of this writing), the Generic Metric advertisement MUST
be ignored.

A metric value of 0xFFFFFF is considered as maximum link metric and
a link having this metric value MUST NOT be considered during Flex-
algorithm calculations [I-D.ietf-lsr-flex-algo]. The link with
maximum generic metric value is not available for the use of
Flexible Algorithms but is availble for other usecases.

2.2. OSPF Generic Metric sub-TLV

The OSPF Generic Metric sub-TLV specifies the link metric for a
given metric type. Typically, this metric is assigned by a network
administrator. The Generic Metric sub-TLV is advertised in the TLVs
below:

   sub-TLV of the OSPF Link TLV of OSPF extended Link LSA [RFC7684].

   sub-TLV of TE Link TLV (2) of OSPF TE LSA [RFC3630].

   sub-TLV of the Router-Link TLV in the E-Router-LSA in OSPFv3
   [RFC8362].

   sub-sub-TLV of Application-Specific Link Attributes sub-TLV
   [RFC8920].

The Generic Metric sub-TLV is TLV type TBD (IANA), and is eight
octets in length.

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |             Type              |             Length            |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | metric-type   |             Reserved                         |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                            Value                             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+

   Type  :   TBD (To be assigned by IANA)
   Length: 8 octets
   metric-type = A value from the IGP metric type registry

   Value : metric value (0- 4,294,967,295)
```

Figure 2: OSPF Generic Metric sub-TLV

The Generic Metric sub-TLV MAY be advertised multiple times. For a
particular metric type, the Generic Metric sub-TLV MUST be
advertised only once for a link when advertised in OSPF Link TLV of
Extended Link LSA, Link TLV of TE LSA and sub-TLV of the Router-Link
TLV in the E-Router-LSA Router-Link TLV in OSPFv3. When Generic
Metric sub-TLV is advertised as sub-sub-TLV of ASLA, it MUST be
advertised only once per-application for a link. If there are
multiple Generic Metric sub-TLVs advertised for a link for the same
metric type in a received LSA, the first one MUST be used and the
subsequent ones MUST be ignored.

If the metric type indicates a standard metric type for which there
are other advertisement mechanisms (e.g., the IGP metric, the Min
Unidirectional Link Delay, or the Traffic Engineering Default
Metric, as of this writing), the Generic Metric advertisement MUST
be ignored.

A metric value of 0xFFFFFFFF is considered as maximum link metric
and a link having this metric MUST NOT be considered during Flex-
algorithm calculations [I-D.ietf-lsr-flex-algo].The link with
maximum generic metric value is not available for the use of
Flexible Algorithms but is availble for other use cases.

2.3. Generic Metric applicability to Flexible Algorithms Multi-domain/ Multi-area networks

Generic Metric can be used by Flex-Algorithms by specifying the
metric type in the Flexible Algorithm Definitions. When Flex-
Algorithms is used in a multi-area network, [I-D.ietf-lsr-flex-algo]
defines FAPM sub-TLV that carries the Flexible Algorithm specific
metric. Metric carried in FAPM will be equal to the metric to reach

the prefix for that Flex-Algorithm in its source area or domain.
When Flex-Algorithm uses Generic metric, the same procedures as
described in section 13 of [I-D.ietf-lsr-flex-algo] are used to send
and process FAPM sub-TLV.

3. FAD constraint sub-TLVs

In networks that carry elephant flows, directing an elephant flow
down a low-bandwidth link would be catastrophic. Thus, in the
context of Flex-Algorithm, it would be useful to be able to
constrain the topology to only those links capable of supporting a
minimum amount of bandwidth.

If the capacity of a link is constant, this can already be achived
through the use of administrative groups. However, when a Layer 3
link is actually a collection of Layer 2 links (LAG/Layer 2 Bundle),
the link bandwidth will vary based on the set of active constituent
links. This could be automated by having an implementation vary the
advertised administrative groups based on bandwidth, but this seems
unnecessarily complex and expressing this requirement as a direct
constraint on the topology seems simpler. This is also advantageous
if the minimum required bandwidth changes, as this constraint would
provide a single centralized, coordinated point of control.

To implement this idea, this document defines a new Exclude Minimum
Bandwidth constraint. When this constraint is advertised in a FAD, a
link will be pruned from the Flex-Algorithm topology if the link's
advertised Maximum Link Bandwidth is below the advertised Minimum
Bandwidth value.

Similarly, this document defines a Exclude Maximum Link Delay
constraint. Delay is an important consideration in High Frequency
Trading applications, networks with transparent L2 link recovery, or
in satellite networks, where link delay may fluctuate. Mechanisms
already exist to measure the link delay dynamically and advertised
it in the IGP. Networks that employ dynamic link delay measurement,
may want to exclude links that have a delay over a given threshold.

3.1. IS-IS FAD constraint sub-TLVs

3.1.1. IS-IS Exclude Minimum Bandwidth sub-TLV

IS-IS Flex-Algorithm Exclude Minimum Bandwidth sub-TLV (FAEMB) is a
sub-TLV of the IS-IS FAD sub-TLV. It has the following format:
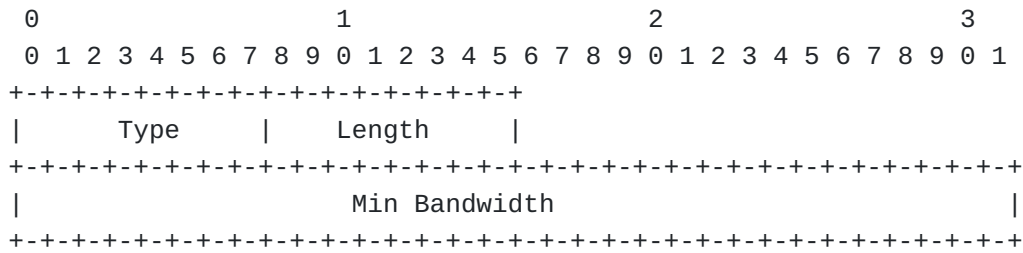
```
    0                   1                   2                   3
    0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |     Type      |    Length     |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                     Min Bandwidth                             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   where:
```

   Type: TBA

   Length: 4 octets.

   Min Bandwidth: The link bandwidth is encoded in 32 bits in IEEE
floating point format. The units are bytes per second.

                    Figure 3: IS-IS FAEMB sub-TLV

The FAEMB sub-TLV MUST appear at most once in the FAD sub-TLV. If it
appears more than once, the IS-IS FAD Sub-TLV MUST be ignored by the
receiver.

The Minimum bandwidth advertised in FAEMB sub-TLV MUST be compared
with Maximum Link Bandwidth advertised in sub-sub-TLV 9 of ASLA sub-
TLV [RFC8919]. If L-Flag is set in the ASLA sub-TLV, the Minimum
bandwidth advertised in FAEMB sub-TLV MUST be compared with Maximum
Link Bandwidth as advertised by the sub-TLV 9 of the TLV
22/222/23/223/141 [RFC5305] as defined in [RFC8919] Section 4.2.

If the Maximum Link Bandwidth is lower than the Minimum link
bandwidth advertised in FAEMB sub-TLV, the link MUST be excluded
from the Flex-Algorithm topology. If a link does not have the
Maximum Link Bandwidth advertised but the FAD contains this sub-TLV,
then that link MUST NOT be excluded from the topology based on the
Minimum Bandwidth constraint.

3.1.2. IS-IS Exclude Maximum Delay sub-TLV

IS-IS Flex-Algorithm Exclude Maximum Delay sub-TLV (FAEMD) is a sub-
TLV of the IS-IS FAD sub-TLV. It has the following 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
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |     Type      |    Length     |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |                   max link delay              |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
where:

   Type: TBD

   Length: 3 octets

   Max link delay: Maximum link delay in microseconds

                    Figure 4: IS-IS FAEMD sub-TLV

The FAEMD sub-TLV MUST appear only once in the FAD sub-TLV. If it
appears more than once, the IS-IS FAD Sub-TLV MUST be ignored by the
receiver.

The Maximum link delay advertised in FAEMD sub-TLV MUST be compared
with Min Unidirectional Link Delay advertised in sub-sub-TLV 34 of
ASLA sub-TLV [RFC8919]. If L-Flag is set in the ASLA sub-TLV, the
Maximum link delay advertised in FAEMD sub-TLV MUST be compared with
Min Unidirectional Link Delay as advertised by the sub-TLV 34 of the
TLV 22/222/23/223/141 [RFC8570] as defined in [RFC8919] Section 4.2.

If the Min Unidirectional Link Delay value is higher than the
Maximum link delay advertised in FAEMD sub-TLV, the link MUST be
excluded from the Flex-Algorithm topology. If a link does not have
the Min Unidirectional Link Delay advertised but the FAD contains
this sub-TLV, then that link MUST NOT be excluded from the topology
based on the Maximum Delay constraint.

3.2. OSPF FAD constraint sub-TLVs

3.2.1. OSPF Exclude Minimum Bandwidth sub-TLV

OSPF Flex-Algorithm Exclude Minimum Bandwidth sub-TLV (FAEMB) is a
sub-TLV of the OSPF FAD TLV. It has the following 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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |          Type                 |            Length             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                       Min Bandwidth                          |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
where:

   Type: TBD

   Length: 4 octets.

   Min Bandwidth: link bandwidth is encoded in 32 bits in IEEE
floating point format. The units are bytes per second.

                    Figure 5: OSPF FAEMB sub-TLV

The FAEMB sub-TLV MUST appear only once in the FAD sub-TLV. If it
appears more than once, the OSPF FAD TLV MUST be ignored by the
receiver. The Maximum Link Bandwidth as advertised in Extended Link
TLV in the Extended Link Opaque LSA in OSPFv2 [RFC7684] or as a sub-
TLV of the Router-Link TLV in the E-Router-LSA Router-Link TLV in
OSPFv3 [RFC8362] MUST be compared against the Minimum bandwidth
advertised in FAEMB sub-TLV. If the link bandwidth is lower than the
Minimum bandwidth advertised in FAEMB sub-TLV, the link MUST be
excluded from the Flex-Algorithm topology. If a link does not have
the Maximum Link Bandwidth advertised but the FAD contains this sub-
TLV, then that link MUST be included in the topology and proceed to
apply further pruning rules for the link.

3.2.2. OSPF Exclude Maximum Delay sub-TLV

   OSPF Flex-Algorithm Exclude Maximum Delay sub-TLV (FAEMD) is a sub-
   TLV of the OSPF FAD TLV. It has the following 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Type                        |      Length                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Max Delay              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
where:
```

    Type: TBD

    Length: 3 octets

    Max link delay: Maximum link delay in microseconds

                    Figure 6: OSPF FAEMD sub-TLV

The FAEMD sub-TLV MUST appear only once in the OSPF FAD TLV. If it
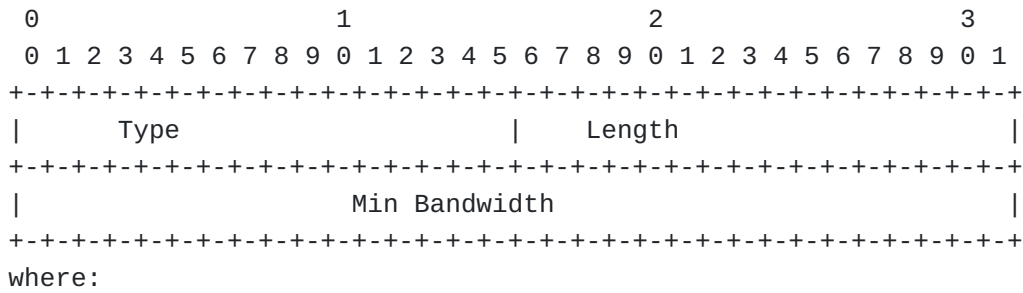appears more than once, the OSPF FAD TLV MUST be ignored by the
receiver. The Min Unidirectional Link Delay as advertised by sub-
sub-TLV 12 of ASLA sub-TLV [RFC8920], MUST be compared against the
Maximum delay advertised in FAEMD sub-TLV. If the Min Unidirectional
Link Delay is higher than the Maximum delay advertised in FAEMD sub-
TLV, the link MUST be excluded from the Flex-Algorithm topology If a
link does not have the Min Unidirectional Link Delay advertised but
the FAD contains this sub-TLV, then then that link MUST NOT be
excluded from the topology based on the Maximum Delay constraint.

4. Bandwidth Metric Advertisement

Historically, IGP implementations have made default metric
assignments based on link bandwidth. This has proven to be useful,
but has suffered from having different defaults across
implementations and from the rapid growth of link bandwidths. With
Flex-Algorithm, the network administrator can define a function that
will produce a metric for each link have each node automatically
compute each link's metric based its bandwidth.

This document defines a new standard metric type for this purpose
called the "Bandwidth Metric". The Bandwidth Metric MAY be
advertised in the Generic Metric sub-TLV with the metric type set to
"Bandwidth Metric". IS-IS and OSPF will advertise this new type of
metric in their link advertisements. Bandwidth metric is a link
attribute and for advertisement and processing of this attribute for
Flex-algorithm purposes, MUST follow the the section 12 of
[I-D.ietf-lsr-flex-algo]

Flex-Algorithm uses this metric type by specifying the bandwidth
metric as the metric type in a FAD TLV. A FAD TLV may also specify
an automatic computation of the bandwidth metric based on a links

advertised bandwidth. An explicit advertisement of a link's
bandwidth metric using the Generic Metric sub-TLV overrides this
automatic computation. The automatic bandwidth metric calculation
sub-TLVs are advertised in FAD TLV and these parameters are
applicable to applications such as Flex-algorithm that make use of
the FAD TLV.

4.1. Automatic Metric Calculation

Networks which are designed to be highly regular and follow uniform
metric assignment may want to simplify their operations by
automatically calculating the bandwidth metric. When a FAD
advertises the metric type as Bandwidth Metric and the link does not
have the Bandwidth Metric advertised, automatic metric derivation
can be used with additional FAD constraint advertisements as
described in this section.

If a link's bandwidth changes, then the delay in learning about the
change may create the possibility of micro-loops in the topology.
This is no different from the IGP's susceptibility to micro-loops
during a metric change. The micro-loop avoidance procedures
described in [I-D.bashandy-rtgwg-segment-routing-uloop] can be used
to avoid micro-loops when the automatic metric calculation is
deployed.

Computing the metric between adjacent systems based on bandwidth
becomes more complex in the face of parallel adjacencies. If there
are parallel adjacencies between systems, then the bandwidth between
the systems is the sum of the bandwidth of the parallel links. This
is somewhat more complex to deal with, so there is an optional mode
for computing the aggregate bandwidth.

4.1.1. Automatic Metric Calculation Modes

4.1.1.1. Simple Mode

In simple mode, the Maximum Link Bandwidth of a single Layer 3 link
is used to derive the metric. This mode is suitable for deployments
that do not use parallel Layer 3 links. In this case, the
computation of the metric is straightforward. If a layer 3 link is
composed of a layer 2 bundle, then the link bandwidth is the sum of
the bandwidths of the working components and may vary with layer 2
link failures.

4.1.1.2. Interface Group Mode

The simple mode of metric calculation may not work well when there
are multiple parallel layer 3 interfaces between two nodes. Ideally,
the metric between two systems should be the same given the same
bandwidth, whether the bandwidth is provided by parallel layer 2

links or parallel layer 3 links. To address this, in Interface Group
Mode, nodes MUST compute the aggregate bandwidth of all parallel
adjacencies, MUST derive the metric based on the aggregate
bandwidth, and MUST apply the resulting metric to each of the
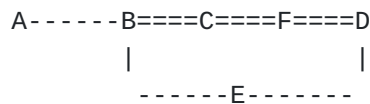parallel adjacencies.

```
    A------B====C====F====D
          |            |
           ------E-------
```

                    Figure 7: Parallel interfaces

For exmple, in the above diagram, there are two parallel links
between B->C, C->F, F->D. Let us assume the link bandwidth is
uniform 10Gbps on all links and the metric for each link will be the
same. Traffic from B to D will be forwarded B->E->D. Since the
bandwidth is higher on the B->C->F->D path, the metric for that path
should be lower, and that path should be selected. Interface Group
Mode is preferred in cases where there are parallel layer 3 links.

In the interface group mode, every node MUST identify the set of
parallel links between a pair of nodes based on IGP link
advertisements and MUST consider cumulative bandwidth of the
parallel links while arriving at the metric of each link.

4.1.2. Automatic Metric Calculation Methods

In automatic metric calculation for simple and interface group mode,
Maximum Link Bandwidth of the links is used to derive the metric.
There are two types of automatic metric derivation methods.

    1. Reference bandwidth method

    2. Bandwidth thresholds method

4.1.2.1. Reference Bandwidth method

In many networks, the metric is inversely proportional to the link
bandwidth. The administrator or implementation selects a reference
bandwdith and the metric is derived by dividing the reference
bandwidth by the advertised Maximum Link Bandwidth. Advertising the
reference bandwidth in the FAD constraints allows the metric
computation to be done automatically. Centralized control of this
reference bandwidth simplifies management in the case that the
reference bandwidth changes. In order to ensure that small bandwidth
changes do not change the link metric, it is useful to define the
granularity of the bandwidth that is of interest. The link bandwidth
will be truncated to this granularity before deriving the metric.

For example,

    reference bandwidth = 1000G

    Granularity = 20G

    The derived metric is 10 for link bandwidth in the range 100G to
    119G

4.1.2.2. Bandwidth Thresholds method

The reference bandwidth approach described above provides a uniform
metric value for a range of link bandwidths. In certain cases there
may be a need to define non-proportional metric values for the
varying ranges of link bandwidth. For example, bandwidths from 10G
to 30G are assigned metric value 100, bandwidth from 30G to 70G get
a metric value of 50, and bandwidths greater than 70G have a metric
of 10. In order to support this, a staircase mapping based on
bandwidth thresholds is supported in the FAD. This advertisement
contains a set of threshold values and associated metrics.

4.1.3. IS-IS FAD constraint sub-TLVs for automatic metric calculation

4.1.3.1. Reference Bandwidth sub-TLV

This section provides FAD constraint advertisement details for the
reference bandwidth method of metric calculation as described in
Section 4.1.2.1. The Flexible Algorithm Definition Reference
Bandwidth Sub-TLV (FADRB Sub-TLV) is a Sub-TLV of the IS-IS FAD sub-
TLV. It has the following 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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |     Type      |     Length    |     Flags     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                    Reference Bandwidth                       |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                    Granularity Bandwidth                     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

   Type: TBD

   Length: 9 octets.
   Reference Bandwidth: Bandwidth encoded in 32 bits in IEEE floating
                        format. The units are in bytes per second.
   Granularity Bandwidth: Bandwidth encoded in 32 bits in IEEE floati
                        format. The units are in bytes per second.

Flags:

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

      G-flag: when set, interface group Mode MUST be used to derive t

      Metric calculation: (Reference_bandwidth) /
                          (Total_link_bandwidth -
                          (Modulus of(Total_link_bandwidth,granulari

                    Figure 8: IS-IS FADRB sub-TLV

Granularity Bandwidth value ensures that the metric does not change
when there is a small change in the link bandwidth. The IS-IS FADRB
Sub-TLV MUST NOT appear more than once in an IS-IS FAD sub-TLV. If
it appears more than once, the IS-IS FAD sub-TLV MUST be ignored by
the receiver. If a Generic Metric sub-TLV with Bandwidth metric type
is advertised for a link, the Flex-Algorithm calculation MUST use
the advertised Bandwidth Metric, and MUST NOT use the automatically
derived metric for that link.

4.1.3.2. Bandwidth Thresholds sub-TLV

This section provides FAD constraint advertisement details for the
Bandwidth Thresholds method of metric calculation as described in
Section 4.1.2.2. The Flexible Algorithm Definition Bandwidth
Threshold Sub-TLV (FADBT Sub-TLV) is a Sub-TLV of the IS-IS FAD sub-
TLV. It has the following 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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |     Type      |     Length     |       Flags     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                 Bandwidth Threshold 1                       |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                 Threshold Metric 1         |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                 Bandwidth Threshold 1                       |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                 Threshold Metric 2         |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                 Bandwidth Threshold 2                       |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                              .....
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                 Threshold Metric n-1       |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                 Bandwidth Threshold n-1                     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                 Threshold Metric n         |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

    where:

    Type: TBD

    Length: 1 + n*7 octets. Here n is equal to number of Threshold
            Metrics specified. n MUST be greater than or equal to 1.

    Flags:

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

        G-flag: when set, interface group Mode MUST be used to derive
                total link bandwidth.

        Staircase bandwidth threshold and associated metric values.
        Bandwidth Threshold 1: Minimum Link Bandwidth is encoded in
                               32 bits in IEEE floating point format.
                               The units are bytes per second.
        Bandwidth Threshold 2: Maximum Link Bandwidth is encoded in
                               32 bits in IEEE floating point format.
                               The units are bytes per second.

Threshold Metric 1 : metric value range (1 - 4,261,412,864)

Figure 9: IS-IS FADBT sub-TLV

When G-flag is set, the cumulative bandwidth of the parallel links
is computed as described in section Section 4.1.1.2. If G-flag is
not set, the advertised Maximum Link Bandwidth is used.

When the computed link bandwidth is less than Bandwidth Threshold 1,
the MAX_METRIC value of 4,261,412,864 MUST be assigned as the
Bandwidth Metric on the link during Flex-Algorithm SPF calculation.

When the computed link bandwidth is greater than or equal to
Bandwidth Threshold 1 and less than Bandwidth Threshold 1, Threshold
Metric 1 MUST be assigned as the Bandwidth Metric on the link during
Flex-Algorithm SPF calculation.

Similarly, when the computed link bandwidth is greater than or equal
to Bandwidth Threshold 1 and less than Bandwidth Threshold 2,
Threshold Metric 2 MUST be assigned as the Bandwidth Metric on the
link during Flex-Algorithm SPF calculation.

In general, when the computed link bandwidth is greater than or
equal to Bandwidth Threshold X AND less than Bandwidth Threshold
X+1, Threshold Metric X MUST be assigned as the Bandwidth Metric on
the link during Flex-Algorithm SPF calculation.

Finally, when the computed link bandwidth is greater than or equal
to Bandwidth Threshold n, then Threshold Metric n MUST be assigned
as the Bandwidth Metric on the link during Flex-Algorithm SPF
calculation.

The IS-IS FADBT Sub-TLV MUST NOT appear more than once in an IS-IS
FAD sub-TLV. If it appears more than once, the IS-IS FAD sub-TLV
MUST MUST stop participating in such flex-algorithm.

A FAD MUST NOT contain both FADBT sub-TLV and FADRB sub-TLV. If both
these sub-TLVs are advertised in the same FAD for a Flexible
Algorithm, the FAD MUST be ignored by the receiver.

If a Generic Metric sub-TLV with Bandwidth metric type is advertised
for a link, the Flex-Algorithm calculation MUST use the Bandwidth
Metric advertised on the link, and MUST NOT use the automatically
derived metric for that link.

4.1.4. OSPF FAD constraint sub-TLVs for automatic metric calculation
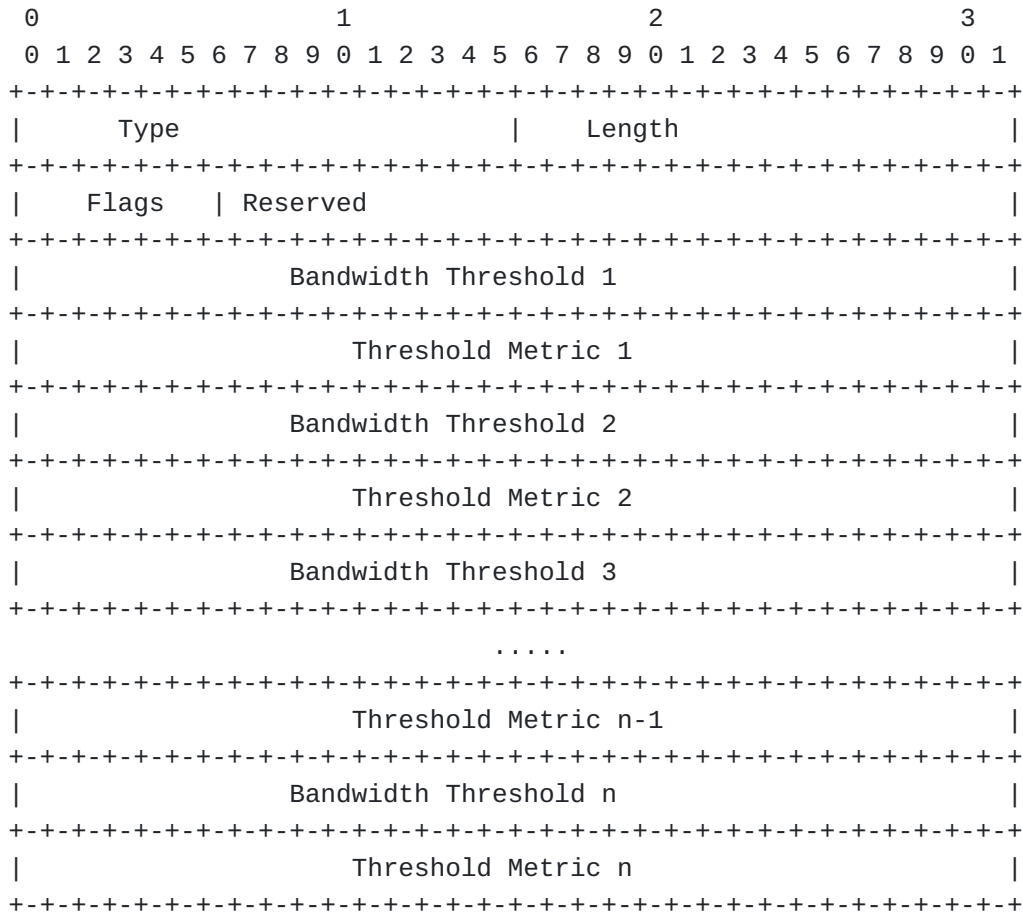
4.1.4.1. Reference Bandwidth sub-TLV

The Flexible Algorithm Definition Reference Bandwidth Sub-TLV (FADRB
Sub-TLV) is a Sub-TLV of the OSPF FAD TLV. It has the following
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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Type                     |           Length              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Flags   |      Reserved                                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Reference Bandwidth                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Granularity Bandwidth                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

   Type: TBD

   Length: 14 octets.
   Reference Bandwidth: Bandwidth encoded in 32 bits in
                        IEEE floating point format.
                        The units are in bytes per second.
   Granularity Bandwidth: Bandwidth encoded in 32 bits in
                        IEEE floating point format.
                        The units are in bytes per second.

Flags:

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

    G-flag: when set, interface group Mode MUST be used
            to derive total link bandwidth.

    Metric calculation: (Reference_bandwidth) /
                        (Total_link_bandwidth -
                        (Modulus of
                            (Total_link_bandwidth, Granularity_bw))

                    Figure 10: OSPF FADRB sub-TLV

Granularity Bandwidth value is used to ensure that the metric does
not change when there is a small change in the link bandwidth. The
OSPF FADRB Sub-TLV MUST NOT appear more than once in an OSPF FAD
TLV. If it appears more than once, the OSPF FAD TLV MUST be ignored

by the receiver. If a Generic Metric sub-TLV with Bandwidth metric
type is advertised for a link, the Flex-Algorithm calculation MUST
use the advertised Bandwidth Metric on the link, and MUST NOT use
the automatically derived metric for that link.

4.1.4.2. Bandwidth Threshold sub-TLV

The Flexible Algorithm Definition Bandwidth Thresholds Sub-TLV
(FADBT Sub-TLV) is a Sub-TLV of the OSPF FAD TLV. It has the
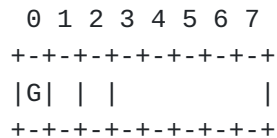following format:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Type                     |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Flags   | Reserved                                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Bandwidth Threshold 1                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Threshold Metric 1                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Bandwidth Threshold 2                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Threshold Metric 2                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Bandwidth Threshold 3                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                                .....
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Threshold Metric n-1                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Bandwidth Threshold n                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Threshold Metric n                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

where:

   Type: TBD

   Length: 2 + n*8 octets. Here n is equal to number of
   Threshold Metrics specified.
         n MUST be greater than or equal to 1.

   Flags:

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

      G-flag: when set, interface group Mode MUST be used to
             derive total link bandwidth.

      Staircase bandwidth threshold and associated metric values.
      Bandwidth Threshold 1: Minimum Link Bandwidth is

```
                            encoded in 32 bits in IEEE
                            floating point format.
                            The units are bytes per second.
Bandwidth Threshold 2: Maximum Link Bandwidth is encoded in
                            32 bits in IEEE floating point format.
                            The units are bytes per second.
Threshold Metric 1 : metric value range (1 - 4,294,967,296)
```

Figure 11: OSPF FADBT sub-TLV

When G-flag is set, the cumulative bandwidth of the parallel links is computed as described in section [Section 4.1.1.2](). If G-flag is not set, the advertised Maximum Link Bandwidth is used.

When the computed link bandwidth is less than Bandwidth Threshold 1 , the MAX_METRIC value of 4,294,967,296 MUST be assigned as the Bandwidth Metric on the link during Flex-Algorithm SPF calculation.

When the computed link bandwidth is greater than or equal to Bandwidth Threshold 1 and less than Bandwidth Threshold 1, Threshold Metric 1 MUST be assigned as the Bandwidth Metric on the link during Flex-Algorithm SPF calculation.

Similarly, when the computed link bandwidth is greater than or equal to Bandwidth Threshold 1 and less than Bandwidth Threshold 2, Threshold Metric 2 MUST be assigned as the Bandwidth Metric on the link during Flex-Algorithm SPF calculation.

In general, when the computed link bandwidth is greater than or equal to Bandwidth Threshold X AND less than Bandwidth Threshold X+1, Threshold Metric X MUST be assigned as the Bandwidth Metric on the link during Flex-Algorithm SPF calculation.

Finally, when the computed link bandwidth is greater than or equal to Bandwidth Threshold n, then Threshold Metric n MUST be assigned as the Bandwidth Metric on the link during Flex-Algorithm SPF calculation.

The IS-IS FADBT Sub-TLV MUST NOT appear more than once in an IS-IS FAD sub-TLV. If it appears more than once, the IS-IS FAD sub-TLV MUST stop participating in such flex-algorithm.

A FAD MUST NOT contain both FADBT sub-TLV and FADRB sub-TLV. If both these sub-TLVs are advertised in the same FAD for a Flexible Algorithm, the FAD MUST be ignored by the receiver.

If a Generic Metric sub-TLV with Bandwidth metric type is advertised for a link, the Flex-Algorithm calculation MUST use the Bandwidth Metric advertised on the link, and MUST NOT use the automatically derived metric for that link.

5. Bandwidth metric considerations

This section specifies the rules of deriving the Bandwidth Metric if
and only if the winning FAD for the Flex-Algorithm specifies the
metric-type as "Bandwidth Metric".

   1. If the the Generic Metric sub-TLV with Bandwidth metric type
   is advertised for the link as described in Section 4, it MUST be
   used during the Flex-Algorithm calculation.

   2. If the Generic Metric sub-TLV with Bandwidth metric type is
   not advertised for the link and the winning FAD for the Flex-
   Algorithm does not specify the automatic bandwidth metric
   calculation (as defined in Section 4.1), the Bandwidth Metric is
   considered as not being advertised for the link.

   3. If the Generic Metric sub-TLV with Bandwidth metric type is
   not advertised for the link and the winning FAD for the Flex-
   Algorithm specifies the automatic bandwidth metric calculation
   (as defined in Section 4.1), the Bandwidth Metric metric MUST be
   automatically calculated as per the procedures defined in
   Section 4.1. If the Bandwidth Metric can not be calculated due to
   lack of Flex-Algorithm specific ASLA advertisement of sub-sub-TLV
   9 [RFC8919], or in case of IS-IS, in presence of the L-Flag in
   the Flex-Algorithm specific ASLA advertisement the lack of sub-
   TLV 9 in the TLV 22/222/23/223/141 [RFC5305], the Bandwidth
   Metric is considered as not being advertised for the link.

6. Calculation of Flex-Algorithm paths

Two new additional rules are added to the existing rules in the
Flex-rules specified in sec 13 of [I-D.ietf-lsr-flex-algo].

   6. Check if any exclude FAEMB rule is part of the Flex-Algorithm
   definition. If such exclude rule exists and the link has Maximum
   Link Bandwidth advertised, check if the link bandwidth satisfies
   the FAEMB rule. If the link does not satisfy the FAEMB rule, the
   link MUST be pruned from the computation.

   7. Check if any exclude FAEMD rule is part of the Flex-Algorithm
   definition. If such exclude rule exists and the link has Min
   Unidirectional link delay advertised, check if the link delay
   satisfies the FAEMD rule. If the link does not satisfy the FAEMD
   rule, the link MUST be pruned from the computation.

7. Backward Compatibility

8. Security Considerations

TBD

9. IANA Considerations

9.1. IGP Metric-Type Registry

IGP Metric-type Registry is updated to include another column
specifying whether the pariticular metric-type is allowed in the
generic-metric sub-TLV or not.

```
   Type Description               Reference          Allowed in gen
   ----------------------------------------------------------------
    0    IGP Metric               [RFC-ietf-lsr-flex-algo-25]
                                  Section 5.1
    1    Min Unidirectional       [RFC-ietf-lsr-flex-algo-25]
         Link Delay as defined    Section 5.1
         in [RFC8570,
             Section 4.2],and
             [RFC7471, Section 4.2]

    2    Traffic Engineering Default [RFC-ietf-lsr-flex-algo-25]
         Metric as defined in      Section 5.1
            [RFC5305,Section 3.7],
            and [RFC3630, Section 2.5.5]
   3(TBA) Bandwidth Metric        [RFC-ietf-lsr-flex-algo-bw-con

 128-255(TBA) User defined metric  [RFC-ietf-lsr-flex-algo-bw-con-04]
```

Figure 12: IANA IGP Metric-Type Registry

9.2. IS-IS Sub-Sub-TLVs for Flexible Algorithm Definition Sub-TLV

Type: 6(TBA)

Description: IS-IS Exclude Minimum Bandwidth sub-TLV

Reference: This document [Section 3.1.1](#)

Type: 7 (TBA)

Description: IS-IS Exclude Maximum Delay sub-TLV

Reference: This document [Section 3.1.2](#)

Type: 8 (TBA)

Description: IS-IS Reference Bandwidth sub-TLV

Reference: This document [Section 4.1.3.1](#)

Type: 9(TBA)

Description: IS-IS Threshold Metric sub-TLV

Reference: This document [Section 4.1.3.2](#)

9.3. OSPF Sub-TLVs for Flexible Algorithm Definition Sub-TLV

Type:6 (TBA)

Description: OSPF Exclude Minimum Bandwidth sub-TLV

Reference: This document [Section 3.2.1](#)

Type: 7(TBA)

Description: OSPF Exclude Maximum Delay sub-TLV

Reference: This document [Section 3.2.2](#)

Type: 8(TBA)

Description: OSPF Reference Bandwidth sub-TLV

Reference: This document [Section 4.1.4.1](#)

Type: 9 (TBA)

Description: OSPF Threshold Metric sub-TLV

Reference: This document [Section 4.1.4.2](#)

9.4. IS-IS Sub-TLVs for TLVs Advertising Neighbor Information

Type:17 (TBA)

Description: Generic metric

Reference: This document [Section 2.1](#)

9.5. Sub-sub-TLV Codepoints for Application-Specific Link Attributes

Type: 17 (TBA)

Description: Generic metric

Reference: This document [Section 2.1](#)

9.6. OSPFv2 Extended Link TLV Sub-TLVs

Type: 25(TBA)

Description: Generic metric

Reference: This document Section 2.2

9.7. Types for sub-TLVs of TE Link TLV (Value 2)

Type: 36 (TBA)

Description: Generic metric

Reference: This document Section 2.2

9.8. OSPFv3 Extended-LSA Sub-TLVs

Type: 34 (TBA)

Description: Generic metric

Reference: This document Section 2.2

10. Acknowledgements

Many thanks to Chris Bowers, Krzysztof Szarcowitz, Julian Lucek, Ram Santhanakrishnan, Ketan Talaulikar for discussions and inputs.

11. Contributors

1. Salih K A

Juniper Networks

salih@juniper.net

12. References

12.1. Normative References

[I-D.ietf-lsr-flex-algo] Psenak, P., Hegde, S., Filsfils, C., Talaulikar, K., and A. Gulko, "IGP Flexible Algorithm", Work in Progress, Internet-Draft, draft-ietf-lsr-flex-algo-26, 17 October 2022, <https://datatracker.ietf.org/doc/html/draft-ietf-lsr-flex-algo-26>.

[RFC2119]   Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC3630]   Katz, D., Kompella, K., and D. Yeung, "Traffic Engineering (TE) Extensions to OSPF Version 2", RFC 3630, DOI 10.17487/RFC3630, September 2003, <https://www.rfc-editor.org/info/rfc3630>.

[RFC5305] Li, T. and H. Smit, "IS-IS Extensions for Traffic
           Engineering", RFC 5305, DOI 10.17487/RFC5305, October
           2008, <https://www.rfc-editor.org/info/rfc5305>.

[RFC7684] Psenak, P., Gredler, H., Shakir, R., Henderickx, W.,
           Tantsura, J., and A. Lindem, "OSPFv2 Prefix/Link
           Attribute Advertisement", RFC 7684, DOI 10.17487/RFC7684,
           November 2015, <https://www.rfc-editor.org/info/rfc7684>.

[RFC8362] Lindem, A., Roy, A., Goethals, D., Reddy Vallem, V., and
           F. Baker, "OSPFv3 Link State Advertisement (LSA)
           Extensibility", RFC 8362, DOI 10.17487/RFC8362, April
           2018, <https://www.rfc-editor.org/info/rfc8362>.

[RFC8919] Ginsberg, L., Psenak, P., Previdi, S., Henderickx, W.,
           and J. Drake, "IS-IS Application-Specific Link
           Attributes", RFC 8919, DOI 10.17487/RFC8919, October
           2020, <https://www.rfc-editor.org/info/rfc8919>.

[RFC8920] Psenak, P., Ed., Ginsberg, L., Henderickx, W., Tantsura,
           J., and J. Drake, "OSPF Application-Specific Link
           Attributes", RFC 8920, DOI 10.17487/RFC8920, October
           2020, <https://www.rfc-editor.org/info/rfc8920>.

12.2. Informative References

[I-D.bashandy-rtgwg-segment-routing-uloop]
           Bashandy, A., Filsfils, C., Litkowski, S., Decraene, B.,
           Francois, P., and P. Psenak, "Loop avoidance using
           Segment Routing", Work in Progress, Internet-Draft,
           draft-bashandy-rtgwg-segment-routing-uloop-14, 18
           December 2022, <https://datatracker.ietf.org/doc/html/
           draft-bashandy-rtgwg-segment-routing-uloop-14>.

[RFC5120] Przygienda, T., Shen, N., and N. Sheth, "M-ISIS: Multi
           Topology (MT) Routing in Intermediate System to
           Intermediate Systems (IS-ISs)", RFC 5120, DOI 10.17487/
           RFC5120, February 2008, <https://www.rfc-editor.org/info/
           rfc5120>.

[RFC5311] McPherson, D., Ed., Ginsberg, L., Previdi, S., and M.
           Shand, "Simplified Extension of Link State PDU (LSP)
           Space for IS-IS", RFC 5311, DOI 10.17487/RFC5311,
           February 2009, <https://www.rfc-editor.org/info/rfc5311>.

[RFC5316] Chen, M., Zhang, R., and X. Duan, "ISIS Extensions in
           Support of Inter-Autonomous System (AS) MPLS and GMPLS
           Traffic Engineering", RFC 5316, DOI 10.17487/RFC5316,
           December 2008, <https://www.rfc-editor.org/info/rfc5316>.

[RFC7471] Giacalone, S., Ward, D., Drake, J., Atlas, A., and S.
           Previdi, "OSPF Traffic Engineering (TE) Metric
           Extensions", RFC 7471, DOI 10.17487/RFC7471, March 2015,
           <https://www.rfc-editor.org/info/rfc7471>.

[RFC8570] Ginsberg, L., Ed., Previdi, S., Ed., Giacalone, S., Ward,
           D., Drake, J., and Q. Wu, "IS-IS Traffic Engineering (TE)
           Metric Extensions", RFC 8570, DOI 10.17487/RFC8570, March
           2019, <https://www.rfc-editor.org/info/rfc8570>.

Authors' Addresses

Shraddha Hegde
Juniper Networks Inc.
Exora Business Park
Bangalore 560103
KA
India

Email: shraddha@juniper.net

William Britto A J
Juniper Networks Inc.

Email: bwilliam@juniper.net

Rajesh Shetty
Juniper Networks Inc.

Email: mrajesh@juniper.net

Bruno Decraene
Orange

Email: bruno.decraene@orange.com

Peter Psenak
Cisco Systems

Email: ppsenak@cisco.com

Tony Li
Juniper Networks Inc.

Email: tony.li@tony.li