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Flexible Candidate Path Selection of SR Policy
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Abstract

This document describes a flexible method for selecting candidate Segment Routing (SR) policy paths. Based on the real-time resource usage and forwarding quality of candidate paths, the head node can perform dynamic path switching among multiple candidate paths in the SR policy.

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1. Introduction

Segment Routing (SR) [RFC8402] is a source routing paradigm that explicitly indicates the forwarding path for packets at the ingress node. The ingress node steers packets into a specific path according to the Segment Routing Policy (SR Policy) as defined in [RFC9256].

An SR Policy may have multiple candidate paths that are provisioned or signaled [RFC9830] [RFC8664] from one of more sources. The tie-breaking rules defined in [RFC9256] result in determination of a single "active path" in a formal definition.

According to [RFC9256] the head node must use only the active candidate path for forwarding traffic that is being steered onto a specific policy, except for certain scenarios such as fast reroute where a backup candidate path may be used. A candidate path can be represented as a segment list or a set of segment lists. If a set of segment lists is associated with the active path of a policy, then the steering of traffic onto the different segment lists is per flow

and is based on weighted-ECMP (W-ECMP) according to the relative weight of each segment list.

According to the criteria for the validity of candidate paths described in Section 5 of [RFC9256], if there is a valid segment list in the active candidate path, the active candidate path is valid. When some segment lists of the active candidate path are not valid, the active candidate path may still be valid, but it might not continue to meet the actual forwarding requirements.

[I-D.karboubi-spring-sr-policy-eligibility] introduces the concept of an eligibility attribute at the candidate path level, not only at the time of the path computation, but also through topology and network changes to ensure that user intentions are preserved while carrying service traffic.

This document describes a method for setting the eligibility attribute, which can influence the selection of candidate paths. For specific preference rules, refer to [I-D.karboubi-spring-sr-policy-eligibility].

Based on real-time resource usage and the forwarding quality of candidate paths, the head node can dynamically adjust the eligibility attribute value, enabling it to dynamically switch traffic onto different paths among multiple candidate paths within the SR policy.

[RFC2386] provides valuable background on QoS-based routing, details some issues and requirements associated with QoS-based routing, and describes a framework for employing QoS-based routing within the Internet. This document describes an SR Policy mechanism where the traffic is switched between paths based on the resource status of the traversed path. However, it does not address the challenges related to dynamic distributed scheduling or resource reservation along intermediate paths. The document specifies the capability to switch to alternative paths within a strategy when the current path fails to satisfy designated link quality criteria, such as bandwidth, delay, or packet loss. In instances where a controller issues an SR Policy encompassing multiple paths, should a path's link quality not meet the established requirements, a switch to a backup path for forwarding is executed.

2. Terminology

The definitions of the basic terms are identical to those found in Segment Routing Policy Architecture [RFC9256].

3. Background Requirements

When some segment lists of the active candidate path are not valid, according to [RFC9256], if there is a valid segment list in the

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active candidate path, the active candidate path is still valid. But the paths of remaining segment lists may not meet the SR policy forwarding performance requirements, such as insufficient path bandwidth. Even if there are other candidate paths with lower preference that can meet the forwarding performance requirements in the SR policy, the traffic will continue to be forwarded along the original active candidate path.

As an example, consider the following SR Policy to illustrate the issues present in the current candidate path selection process in detail.

```
SR Policy POL1
Candidate Path CP1
  Preference 200
  Segment List 1 <SID1l...SID1i>, Weight 1
  Segment List 2 <SID2l...SID2j>, Weight 1
  Segment List 3 <SID3l...SID3k>, Weight 1
Candidate Path CP2
  Preference 100
  Segment List 4 <SID4l...SID4i>, Weight 1
  Segment List 5 <SID5l...SID5j>, Weight 1
  Segment List 6 <SID6l...SID6k>, Weight 1
```

There are two static candidate paths CP1 and CP2 in SR policy POL1. CP1 has a higher preference. Both candidate paths are composed of three static segment lists with the same weight. The path indicated by each segment list can carry traffic of 100Mbps bandwidth. When all Segment Lists in CP1 are valid, the effective bandwidth of the candidate path is 300Mbps.

Suppose the bandwidth of the actual traffic forwarded by the SR policy is between 100Mbps and 150Mbps. Because the traffic forwarded on the candidate path will share the load on the three segment list paths according to the weight value, the candidate path can meet the forwarding requirements. The traffic is forwarded on the three segment lists of the higher preference candidate paths of the SR policy.

When segment lists 1 and 2 in the high-preference candidate path CP1 are not valid, according to the candidate path validity criteria described in [RFC9256] Section 5, because segment list 3 in CP1 is still valid, the active candidate path CP1 is still valid. All traffic of SR policy POL1 will continue to be forwarded through the path of CP1. However, because segment list 3 can only forward 100Mbps traffic, over-bandwidth traffic will be discarded.

Of course, when the Segment List path fault is detected, the network device can report the detected fault information to the controller. The controller optimizes the forwarding path after receiving the

message. However, this interaction process is relatively long, and it is difficult to meet the requirement for fast switch-over.

When the quality of the high-preference candidate paths deteriorates, due to issues such as insufficient available bandwidth, increased end-to-end transmission delay, or segment lists that fail to meet service requirements, the same need arises. The goal is to switch traffic to other lower preference candidate paths within the SR policy that better satisfy the forwarding quality requirements.

To address this issue, this document proposes a new candidate path selection rule that defines resource thresholds and forwarding quality requirements for candidate paths.

If a candidate path does not satisfy the forwarding quality requirements, its eligibility attribute **MUST** be set to false. During the active candidate path(CP) selection process, the head-end **SHALL** use this eligibility attribute as an additional mandatory criterion, in conjunction with the rules defined in [RFC9256], Section 2.9. When a CP's eligibility attribute is false, it indicates that the path cannot forward traffic meeting the specified quality requirements and therefore **MUST NOT** be considered for active CP selection.

4. Flexible Candidate Path Selection Method

As described in [RFC9256], the candidate path selection process operates primarily on the candidate path Preference. A candidate path is selected when it is valid and it has the highest Preference value among all the valid candidate paths of the SR Policy.

[I-D.karboubi-spring-sr-policy-eligibility] introduces a new attribute at the candidate path level called Eligibility. Only candidate paths with Eligibility as true are considered as part of the active candidate path selection defined in [RFC9256].

This document describes using forwarding quality requirements and resource requirements of candidate paths as eligibility criteria for path selection.

A headend may be informed about the forwarding quality requirements of a candidate path for an SR Policy <Color, Endpoint> through various means, including configuration, PCEP, or BGP. The extensions of BGP and PCEP are described in [I-D.liu-idr-bgp-sr-policy-cp-threshold] and [I-D.liu-pce-sr-policy-cp-threshold].

When a candidate path fails to meet forwarding quality requirements, its Eligibility attribute **SHOULD** be set to false, thereby excluding it from active candidate path selection.

For candidate paths containing multiple segment lists:

- If a segment list fails to meet forwarding quality requirements, it SHOULD be excluded from forwarding operations.
- When all segment lists under a candidate path fail to meet forwarding quality requirements, the path's Eligibility attribute SHOULD be set to false, disqualifying it from active candidate path selection.

4.1. Threshold Parameters of Candidate Paths

The threshold parameters of candidate paths can include, but are not limited to, the following:

- * Jitter
- * Latency
- * Packet loss

Delay, jitter, and packet loss are thresholds at the segment list level.

When the jitter, delay, or packet loss of a valid segment list does not meet the specified threshold requirements, the segment list will be deemed not valid and will no longer participate in load sharing traffic.

- * Available bandwidth

The bandwidth threshold is the threshold at the candidate path level.

$$\text{CP available bandwidth} = \text{CP preset bandwidth} * (\text{Sum of weights of Segment Lists in Up state} / \text{Sum of all Segment List weights})$$

- * Actual bandwidth

The actual bandwidth refers to the sum of the actual available remaining bandwidth of each valid segment list in the candidate path.

Due to the different congestion conditions of each node on the forwarding path, the actual bandwidth that can forward service packets may differ from the preset bandwidth. By utilizing some measurement mechanisms, the actual minimum available bandwidth and actual minimum remaining bandwidth of all nodes along the

path can be obtained. The specific measurement mechanism is not within the scope of this document.

* Precision Availability Metrics (PAM)

Consider a candidate path of SR policy as a Service Level Objective (SLO) [RFC9543], based on the Precision Availability Metrics (PAM) defined in [RFC9544], determine whether the candidate path meets the forwarding requirements.

If segment list-level thresholds (such as latency, jitter, or packet loss) and candidate path-level thresholds (such as available bandwidth) are both specified, then when one or more segment lists in the candidate path fail to meet the segment list-level thresholds, this indicates that these segment lists cannot provide forwarding capabilities that meet the Service Level Agreement (SLA) requirements. These segment lists will be marked as unavailable and will no longer participate in packet forwarding. After excluding these segment lists, the candidate path should be re-verified to determine whether it still meets the forwarding quality requirements. If it does, traffic can continue to be forwarded along that candidate path.

For example, two threshold parameters, delay and available bandwidth, are specified for the candidate path with multiple segment lists. When the delay of a segment list exceeds the threshold, the following processing is performed:

- 1) Remove the segment list from the forwarding path.
- 2) Calculate the current available bandwidth of the CP based on the weight ratio of the remaining effective segment lists and the bandwidth of the CP.
- 3) Check whether the current available bandwidth of the CP still meets the bandwidth threshold requirements.

- * If the available bandwidth still meets the requirements, the candidate path still meets the forwarding quality

requirements, and the traffic is still forwarded along this candidate path.

- * Otherwise, set the Eligibility attribute of this CP to false. The system will then consider switching service traffic to another active candidate path with better forwarding quality.

If the candidate path does not specify any threshold parameters, select the primary candidate path according to the selection method defined in [RFC9256].

By default, there is no threshold parameter specified on the candidate path.

4.2. Rules for Setting the Eligibility Attribute

When a candidate path's current forwarding quality meets the specified threshold requirements, its Eligibility attribute MUST be set to true, indicating this path is valid for:

- * Traffic forwarding operations.
- * Active candidate path selection (per [RFC9256] selection methodology)

Conversely, when a candidate path fails to meet quality requirements, its eligibility attribute MUST be set to false.

For candidate paths without defined threshold parameters:

- * The eligibility attribute MUST default to true.
- * Primary path selection follows [RFC9256] procedures.

When multiple eligible candidate paths coexist in an SR policy:

- * Paths with Eligibility=false MUST NOT participate in active path selection.
- * Detailed behavior is specified in [I-D.karboubi-spring-sr-policy-eligibility].

4.3. Flexible Candidate Path Selection Process

The process of selecting the best candidate path for SR policy through the threshold parameter of the candidate path is as follows.

- 1) Configure the threshold parameters on the candidate path of the head node through manual configuration or controller distribution.
- 2) The head node monitors whether the available resources and forwarding quality of the SR policy candidate path exceed the thresholds. The forwarding quality of path can be obtained through active or passive performance measurement methods, such as ioAM [RFC9378], STAMP [I-D.ietf-spring-stamp-srpm], TWAMP [RFC5375], etc. The real-time quality data can be calculated by the controller and distributed to the head node, or calculated by the head node according to the network measurement data. The measurement method and quality data acquisition method are beyond the scope of this document.

- 3) According to the rules described in Section 4.2, when the available resources are less than the threshold, or the forwarding quality cannot meet the threshold requirements, the head node selects a new active candidate path.
- 4) After the fault on the old active candidate path is repaired or the forwarding quality improves, whether to revert to the previous active candidate path can be specified by the configuration. If fault recovery is required, start a wait timer for delayed recovery. When the timer expires and if the old active candidate path still meets the threshold requirements, the traffic will be switched back to the old higher preference candidate path.

To avoid frequent path switching (flapping), both over-threshold switching and fault recovery should be delayed. The interval of delay can be adjusted by configuration.

5. Use Cases of Flexible Candidate Path Selection

The example SR policy described in Section 3 is used in the sections that follow to illustrate how the flexible candidate path selection method switches between candidate paths.

SR policy POL1 has two candidate paths CP1 and CP2. The Preference of CP1 is 200, and the Preference of CP2 is 100. Both candidate paths are composed of three segment lists with the same weight.

5.1. Select the Best Path Based on End-to-End Delay

The quality requirement for the services carried on the SR policy is that the transmission delay must be less than 200ms. The bandwidth of the actual traffic forwarded by the SR policy is between 100Mbps and 150Mbps.

When the delay of Segment List 1 does not meet the requirements, the head node continues to check the available bandwidth of CP1. Due to segment list 2 only having 100Mbps bandwidth, it cannot meet the actual traffic forwarding requirements. CP1's Eligibility attribute is set to false, triggering the selection of CP2 as POL1's new active candidate path. The traffic forwarded by POL1 is switched to the path of CP2 for forwarding.

SR Policy POL1

 Candidate Path CP1

 Preference 200

 Delay threshold 200ms //Delay<=200ms

 Segment List 1 <SID11...SID1i>, Weight 1 //100M, Delay>1s

 Segment List 2 <SID21...SID2i>, Weight 1 //100M, Delay<100ms

 Candidate Path CP2

 Preference 100

```
Delay threshold 200ms //Delay<=200ms
Segment List 3 <SID31...SID3i>, Weight 1 //100M, Delay<100ms
Segment List 4 <SID41...SID4i>, Weight 1 //100M, Delay<100ms
```

5.2. Select the Best Path Based on Available Bandwidth

The preset bandwidth for both CP1 and CP2 is 300Mbps. Each segment list can carry a maximum of 100Mbps traffic. The quality requirement for service traffic is that the available bandwidth of the forwarding path must not be less than 150Mbps.

```
SR Policy POL1
Candidate Path CP1
  Preference 200
  Preset bandwidth 300Mbps
  Available bandwidth threshold 150Mbps
  Segment List 1 <SID11...SID1i>, Weight 1
  Segment List 2 <SID21...SID2j>, Weight 1
  Segment List 3 <SID31...SID3k>, Weight 1
Candidate Path CP2
  Preference 100
  Preset bandwidth 300Mbps
  Available bandwidth threshold 150Mbps
  Segment List 4 <SID41...SID4i>, Weight 1
  Segment List 5 <SID51...SID5j>, Weight 1
  Segment List 6 <SID61...SID6k>, Weight 1
```

First, take the available bandwidth as the threshold parameter of POL1. The threshold for configuring the available bandwidth is 150Mbps. When the available bandwidth of the candidate path is less than 150Mbps, perform path switching.

Normally, the three segment lists of CP1 and CP2 are valid. The available bandwidth of CP1 is 300Mbps, and the available bandwidth can meet the threshold requirements. CP1's Eligibility attribute is set to true, CP1 is selected as the active candidate path according to the Preference.

If the paths indicated by Segment List 1 and 2 fail, Segment List 1 and 2 become not valid, and the available bandwidth of CP1 becomes 100Mbps. Because the available bandwidth of CP1 is lower than the specified threshold, CP1 has failed to meet the forwarding quality requirements. CP1's Eligibility attribute is set to false. There is a need to reselect the active candidate path for POL1.

The three segment lists of the low-preference candidate path CP2 of POL1 are valid, and the available bandwidth can meet the threshold requirements. CP2's Eligibility attribute is set to true. CP2 is selected as the new active candidate path of POL1. The traffic forwarded by POL1 will be switched to the path of CP2 for forwarding.

5.3. Select the Best Path Based on Actual Bandwidth

In scenarios involving the actual available bandwidth measurement method for SRv6, as described in

[I-D.liu-ippm-srv6-bandwidth-measurement], the quality requirement for the services carried on the SR policy mandates that the actual available bandwidth of the forwarding path must exceed 80 Mbps. If traffic congestion occurs on a node in Segment List 1, resulting in a maximum forwarding capacity of only 50 Mbps for service traffic, and if Segment List 2 is either in a down state or has exceeded the delay threshold, Segment List 2 will not participate in load sharing traffic.

When the aggregate available bandwidth of CP1 falls below 80 Mbps:

- * CP1's eligibility attribute is set to false.
- * CP2's eligibility attribute is set to true (provided it meets forwarding requirements).
- * CP2 SHALL become POL1's new active candidate path.

SR Policy POL1

Candidate Path CP1

Preference 200

Preset bandwidth 200Mbps

Actual available bandwidth threshold 80Mbps

Segment List 1 <SID1l...SIDli>, Weight 1

(Actual available bandwidth is only 50Mbps.)

Segment List 2 <SID2l...SID2j>, Weight 1

(In Down state, or the delay has exceeded the threshold.)

Candidate Path CP2

Preference 100

Preset bandwidth 300Mbps

Actual available bandwidth threshold 80Mbps

Segment List 3 <SID4l...SID4i>, Weight 1 (100Mbps)

Segment List 4 <SID5l...SID5j>, Weight 1 (100Mbps)

Segment List 5 <SID6l...SID6k>, Weight 1 (100Mbps)

The traffic forwarded by POL1 will switch to the path of CP2 for forwarding.

6. IANA Considerations

This document has no IANA actions.

7. Security Considerations

[RFC8754] defines the notion of an SR domain and use of SRH within the SR domain. Procedures for securing an SR domain are defined the

section 5.1 and section 7 of [RFC8754]. This document does not impose any additional security challenges to be considered beyond security threats described in [RFC8754], [RFC8679] and [RFC8986].

The traffic switchover mechanism defined in this document, such as the ability to forcibly switch traffic from one control plane to another, may redirect traffic to an attacker's preset path. Additionally, switching traffic to another CP could overload network resources, leading to service unavailability or operational failures. Similarly, frequent flapping during switchovers may compromise network stability. Therefore, it is essential to ensure that this SR network operates within a trusted security domain while implementing safeguards like proper configuration and delayed switchback mechanisms to maintain secure SR Policy operation.

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