Authors:
H. Wang   J. Dong   K. Talaulikar   T. Han
Huawei Technologies   *Huawei Technologies*   *Cisco Systems*   *Huawei Technologies*
R. Chen
ZTE Corporation

RFC 9723
BGP Colored Prefix Routing (CPR) for Services Based on Segment Routing over IPv6 (SRv6)

Abstract

This document describes a mechanism to advertise IPv6 prefixes in BGP that are associated with Color Extended Communities to establish end-to-end intent-aware paths for Segment Routing over IPv6 (SRv6) services. Such IPv6 prefixes are called "Colored Prefixes", and this mechanism is called "Colored Prefix Routing" (CPR). In SRv6 networks, the Colored Prefixes are the SRv6 locators associated with different intents. SRv6 services (e.g., SRv6 VPN services) with a specific intent could be assigned with SRv6 Segment Identifiers (SIDs) under the corresponding SRv6 locators, which are advertised as Colored Prefixes.

This operational methodology allows the SRv6 service traffic to be steered into end-to-end intent-aware paths based on the longest prefix matching of SRv6 Service SIDs to the Colored Prefixes. The existing IPv6 Address Family and Color Extended Community are reused to advertise IPv6 Colored Prefixes without new BGP extensions; thus, this mechanism is easy to interoperate and can be deployed incrementally in multi-Autonomous System (AS) networks that belong to the same trusted domain.

Status of This Memo

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1. Introduction

With the trend of using one common network to carry multiple types of services, each service type can have different requirements for the network. Such requirements are usually considered the "intent" of the service or customer, which is represented as an abstract notion called "color".

In network scenarios where the services are delivered across multiple Autonomous Systems (ASes), there is a need to provide the services with different end-to-end paths to meet the intent. [INTENTAWARE] describes the problem statements and requirements for inter-domain intent-aware routing.

The inter-domain path can be established using either Multi-Protocol Label Switching (MPLS) or the IP data plane. In MPLS-based networks, the usual inter-domain approach is to establish an end-to-end Label Switched Path (LSP) based on the mechanism defined in [RFC8277] (which is usually referred to as BGP-LU (BGP Labeled Unicast)). Each domain's ingress border node needs to perform label swapping for the end-to-end LSP, and impose the label stack that is used for the LSP within its own domain.

In IP-based networks, the IP reachability information can be advertised to network nodes in different domains using BGP, so that all the domain border nodes can obtain the routes to the IP prefixes of the destination nodes in other domains. With the introduction of SRv6 [RFC8402] [RFC8754] [RFC8986], BGP services are assigned with SRv6 Service SIDs [RFC9252], which are routable in the network according to its SRv6 locator prefix. Thus, the inter-domain path can be established simply based on the inter-domain routes to the prefix. Inter-domain LSPs based on the BGP-LU mechanism are not necessary for IPv6- and SRv6-based networks.

This document describes a mechanism to advertise IPv6 prefixes that are associated with the Color Extended Community to establish end-to-end intent-aware paths for SRv6 services. The color value in the Color Extended Community indicates the intent [RFC9256]. Such IPv6 prefixes are called "Colored Prefixes", and this mechanism is called Colored Prefix Routing (CPR). In SRv6 networks, the Colored Prefixes are the SRv6 locators associated with different intents. BGP services over SRv6 (e.g., SRv6 VPN services) [RFC9252] with specific intent could be assigned with SRv6 SIDs under the corresponding SRv6 locators, which are advertised as Colored Prefixes. This allows the SRv6 service traffic to be steered (as specified in [RFC9252]) into end-to-end intent-aware paths based on the longest prefix matching of SRv6 Service SIDs to the Colored Prefixes. In the data plane, the dedicated transport label or SID for the inter-domain path is not needed, resulting in smaller encapsulation overhead than with other options.

The existing IPv6 Address Family and Color Extended Community could be reused to advertise IPv6 Colored Prefixes without new BGP extensions; thus, this mechanism is easy to interoperate and can be deployed incrementally in multi-AS networks that belong to the same trusted domain (in the sense used by Section 8 of [RFC8402]).

2. BGP CPR

2.1. Colored Prefix Allocation

In SRv6 networks, an SRv6 locator needs to be allocated for each node. In order to distinguish N different intents, a Provider Edge (PE) node needs to be allocated with N SRv6 locators, each of which is associated a different intent that is identified by a color value. One way to achieve this is by splitting the base SRv6 locator of the node into N sub-locators, whereby these sub-locators are Colored Prefixes associated with different intents.

For example, a PE node is allocated with the base SRv6 Locator 2001:db8:aaaa:1::/64. In order to provide 16 different intents, this base SRv6 Locator is split into 16 sub-locators from 2001:db8:aaaa:1:0000::/68 to 2001:db8:aaaa:1:F000::/68; each of these sub-locators is associated with a different intent, such as low-delay, high-bandwidth, etc.

2.2. Colored Prefix Advertisement

After the allocation of Colored Prefixes on a PE node, routes to these Colored Prefixes need to be advertised both in the local domain and also to other domains using BGP, so that the BGP SRv6 services routes could be resolved using the corresponding CPR route.

In a multi-AS IPv6 network, the mechanism for IPv6 unicast routing as defined in [RFC2545] is used for the advertisement of the Colored Prefix routes, in which the Address Family / Subsequent Address Family (AFI/SAFI = 2/1) is used. The Color Extended Community [RFC9012] is carried with the Colored Prefix route with the color value indicating the intent [RFC9256]. The procedure of Colored Prefix advertisement is described using an example with the following topology:
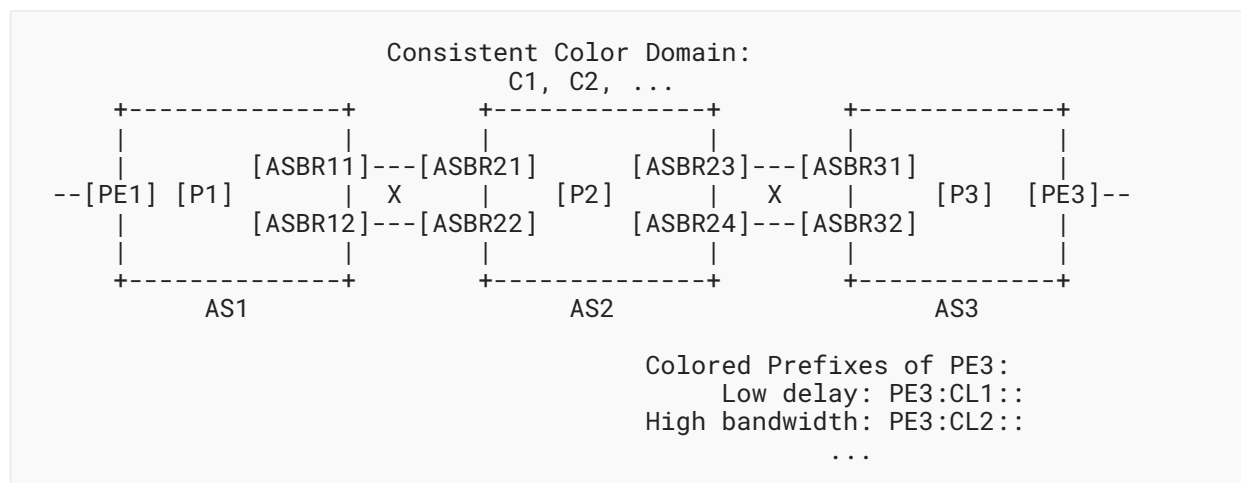
```
                      Consistent Color Domain:
                           C1, C2, ...
     +-------------+      +-------------+      +------------+
     |             |      |             |      |            |
     |     [ASBR11]---[ASBR21]     [ASBR23]---[ASBR31]      |
  --[PE1] [P1]     | X   |     [P2]    | X   |      [P3]  [PE3]--
     |     [ASBR12]---[ASBR22]     [ASBR24]---[ASBR32]      |
     |             |      |             |      |            |
     +-------------+      +-------------+      +------------+
          AS1                  AS2                  AS3

                                   Colored Prefixes of PE3:
                                       Low delay: PE3:CL1::
                                   High bandwidth: PE3:CL2::
                                                   ...
```

Figure 1: Example Topology for CPR Route Illustration

Assume PE3 is provisioned with two different Colored Prefixes CLP-1 and CLP-2 for two different intents such as "low-delay" and "high-bandwidth" respectively. In this example, It is assumed that the color representing a specific intent is consistent throughout all the domains.

- PE3 originates BGP IPv6 unicast (AFI/SAFI=2/1) route for the Colored Prefixes PE3:CL1:: and PE3:CL2::. Each route should carry the corresponding Color Extended Community C1 or C2. PE3 also advertises a route for the base SRv6 Locator prefix PE3:BL, and there is no Color Extended Community carried with this route.
- ASBR31 and ASBR32 receive the CPR routes of PE3, and advertise the CPR routes further to ASBR23 and ASBR24 with next-hop set to itself.

- ASBR23 and ASBR24 receive the CPR routes of PE3. Since the color-to-intent mapping in AS2 is consistent with that in AS3, the Color Extended Community in the received CPR routes are kept unchanged. ASBR23 and ASBR24 advertise the CPR routes further in AS2 with the next hop set to itself.
- The behavior of ASBR21 and ASBR22 are similar to the behavior of ASBR31 and ASBR32.
- The behavior of ASBR11 and ASBR12 are similar to the behavior of ASBR23 and ASBR24.

In normal cases, the color value in the Color Extended Community associated with the CPR route is consistent through all the domains, so that the Color Extended Community in the CPR routes is kept unchanged. In some special cases, one intent may be represented as a different color value in different domains. If this is the case, then the Color Extended Community in the CPR routes needs to be updated at the border nodes of the domains based on the color-mapping policy. For example, in AS1, the intent "low latency" is represented by the color "red", while the same intent is represented by color "blue" in AS2. When a CPR route is sent from AS1 to AS2, the Color Extended Community in the CPR routes needs to be updated from "red" to "blue" at the border nodes based on the color-mapping policy.

In network scenarios where some of the intermediate autonomous systems are MPLS based, the CPR routes may still be advertised using the IPv6 unicast address family (AFI/SAFI=2/1) in the MPLS-based intermediate domains; at the MPLS domain border nodes, some route resolution policy could be used to make the CPR routes resolve to intra-domain intent-aware MPLS LSPs. Another possible mechanism is to use the IPv6 LU address family (AFI/SAFI=2/4) to advertise the CPR routes in the MPLS domains, the detailed procedure is described in Section 7.1.2.1 of [SRv6-INTERWORK].

2.3. CPR to Intra-Domain Path Resolution

A domain border node that receives a CPR route can resolve the CPR route to an intra-domain color-aware path based on the tuple (N, C), where N is the next hop of the CPR route, and C is the Color Extended Community of the CPR route. The intra-domain color-aware path could be built with any of the following mechanisms:

- SRv6 Policy
- SR-MPLS Policy
- SRv6 Flex-Algo
- SR-MPLS Flex-Algo
- RSVP-TE

For example, if PE1 receives a CPR route to PE3:CL1:: with the color C1 and next hop ASBR11, it can resolve the CPR routes to an intra-domain SRv6 Policy based on the tuple (ASBR11, C1).

The intra-domain path resolution scheme could be based on any existing tunnel resolution policy, and new tunnel resolution mechanisms could be introduced if needed.

2.4. SRv6 Service Route Advertisement

For an SRv6 service that is associated with a specific intent, the SRv6 Service SID could be allocated under the corresponding Colored locator prefix. For example, on PE3 in the example topology, an SRv6 VPN service with the low-delay intent can be allocated with the SRv6 End.DT4 SID PE3:CL1:DT::, where PE3:CL1:: is the SRv6 Colored Prefix for low-delay service.

The SRv6 service routes are advertised using the mechanism defined in [RFC9252]. The inter-domain VPN Option C is used, which means the next hop of the SRv6 service route is set to the originating PE and is not changed. Since the intent of the service is embedded in the SRv6 service SID, the SRv6 service route does not need to carry the Color Extended Community.

2.5. SRv6 Service Steering

With the CPR routing mechanism, the ingress PE node that receives the SRv6 service routes follows the behavior of SRv6 shortest path forwarding (refer to Sections 5 and 6 of [RFC9252]). The SRv6 service SID carried in the service route is used as the destination address in the outer IPv6 header that encapsulates the service packet. If the corresponding CPR route has been received and installed, longest prefix matching of SRv6 service SIDs to the Colored Prefixes is performed. As a result of this prefix matching, the next hop found is an intra-domain color-aware path, which will be used for forwarding the SRv6 service traffic. This process repeats at the border node of each domain the packet traverses, until it reaches its destination.

3. Encapsulation and Forwarding Process

This section describes the encapsulation and forwarding process of data packets which are matched with the corresponding CPR route.

The topology of Figure 1 is used in each example.

3.1. CPR over SRv6 Intra-Domain Paths

Following is an illustration of the packet encapsulation and forwarding process of CPR over SRv6 Policy. The abstract representation of IPv6 and the Segment Routing Header (SRH) described in Section 6 of [RFC8754] is used.

PE3 is provisioned with a Colored Prefix PE3:CL1:: for "low-delay".

In AS1, the SRv6 Policy on PE1 for (ASBR11, C1) is represented with SID list <P1, ASBR11>.

In AS2, the SRv6 Policy on ASBR21 for (ASBR23, C1) is represented with the SID list <P2, ASBR23>.

In AS3, the SRv6 Policy on ASBR31 for (PE3, C1) is represented with the SID list <P3, PE3>.

C-pkt is the customer packet PE1 received from its attaching CE.

For packets that belong to an SRv6 VPN service associated with the SRv6 Service SID PE3:CL1.DT6, the packet encapsulation and forwarding process using H.Encaps.Red behavior [RFC8986] is shown as below:

```
PE1 ->P1:            (PE1, P1)(PE3:CL1.DT6, ASBR11; SL=2)(C-pkt)
P1 ->ASBR11:     (PE1, ASBR11)(PE3:CL1.DT6, ASBR11; SL=1)(C-pkt)
ASBR11->ASBR21:                      (PE1, PE3:CL1.DT6)(C-pkt)
ASBR21->P2: (ASBR21, P2)(ASBR23; SL=1)(PE1, PE3:CL1.DT6)(C-pkt)
P2->ASBR23:         (ASBR21, ASBR23)(PE1, PE3:CL1.DT6)(C-pkt)
ASBR23->ASBR31:                      (PE1, PE3:CL1.DT6)(C-pkt)
ASBR31->P3:     (ASBR31, P3)(PE3; SL=1)(PE1, PE3:CL1.DT6)(C-pkt)
P3->PE3:            (ASBR31, PE3)(PE1, PE3:CL1.DT6)(C-pkt)
```

Figure 2

In some autonomous systems, SRv6 Flex-Algo may be used to provide intent-aware intra-domain paths. The encapsulation is similar to the case with SRv6 Policy.

3.2.   CPR over MPLS Intra-Domain Paths

In network scenarios where some of the autonomous systems use the MPLS-based data plane, the CPR route can be resolved over a color-aware intra-domain MPLS LSP. Such an intra-domain MPLS LSP may be established using SR-MPLS Policy, SR-MPLS Flex-Algo, or RSVP-TE.

The encapsulation and forwarding of SRv6 service packets (which are actually IPv6 packets) over an intra-domain MPLS LSP is based on the MPLS mechanisms as defined in [RFC3031], [RFC3032] and [RFC8660]. The behavior is similar to that of IPv6 Provider Edge Routers (6PEs) [RFC4798].

In AS1, the SR-MPLS Policy on PE1 for (ASBR11, C1) is represented with the SID list <P1, ASBR11>.

In AS2, the SR-MPLS Flex-Algo on ASBR21 for (ASBR23, C1) is represented with SID list <ASBR23>.

In AS3, the SR-MPLS Policy on ASBR31 for (PE3, C1) is represented with SID list <P3, PE3>.

C-pkt is the customer packet PE-1 received from its attaching CE.

For packets that belong to an SRv6 VPN service associated with the SRv6 Service SID PE3:CL1.DT6, the packet encapsulation and forwarding process is shown as below:

```
PE1-> P1: Label-stack(P1, ASBR11)(PE1, PE3:CL1.DT6)(C-pkt)
P1->ASBR11:   Label-stack(ASBR11)(PE1, PE3:CL1.DT6)(C-pkt)
ASBR11->ASBR21:               (PE1, PE3:CL1.DT6)(C-pkt)
ASBR21->P2:   Label-stack(ASBR23)(PE1, PE3:CL1.DT6)(C-pkt)
P2->ASBR23:   Label-stack(ASBR23)(PE1, PE3:CL1.DT6)(C-pkt)
ASBR23->ASBR31:               (PE1, PE3:CL1.DT6)(C-pkt)
ASBR31->P3:   Label-stack(P3, PE3)(PE1, PE3:CL1.DT6)(C-pkt)
P3->PE3:        Label-stack(PE3)(PE1, PE3:CL1.DT6)(C-pkt)
```

Figure 3

4. Operational Considerations

The CPR mechanism can be used in network scenarios where multiple inter-connected ASes belong to the same operator, or where there is an operational trust model between the ASes of different operators which means they belong to the same trusted domain (in the sense used by Section 8 of [RFC8402]).

As described in Section 5 of [INTENTAWARE], inter-domain intent-aware routing may be achieved with a logical tunnel created by an SR Policy that applies to multiple ASes. In addition, service traffic with specific intent can be steered to the inter-domain SR Policy based on the intent signaled by Color Extended Community. An operator may prefer a BGP routing-based solution for the reasons described in [INTENTAWARE]. The operator may also consider the availability of an inter-domain controller for end-to-end intent-aware path computation. This document proposes an alternate solution to signal the intent with IPv6 Colored Prefixes using BGP.

When Colored Prefixes are assigned as sub-locators of the node's base SRv6 locator, the IPv6 unicast route of the base locator prefix is the prefix that covers all of the Colored locator prefixes. To make sure the Colored locator prefixes can be distributed to the ingress PE nodes along the border nodes, it is required that route aggregation be disabled for IPv6 unicast routes that carry the Color Extended Community.

With the CPR mechanism, at the prefix originator, each Colored Prefix is associated with one specific intent (i.e., color). In each domain, according to the color mapping policy, the same CPR route is always updated with the same color. The case where there are multiple copies of CPR routes with the same Colored Prefix but different Color Extended Community is considered a misconfiguration.

All the border nodes and the ingress PE nodes need to install the Colored locator prefixes in the RIB and FIB. For transit domains that support the CPR mechanism, the border nodes can use the tuple (N, C), where N is the next hop and C is the color, to resolve the CPR routes to intent-aware intra-domain paths. For transit domains that do not support the CPR mechanism, the border nodes would ignore the Color Extended Community and resolve the CPR routes over a best-effort intra-domain path to the next-hop N, while the CPR route will be advertised further to the downstream domains with only the next hop changed to itself. This allows the CPR routes to

resolve to intent-aware intra-domain paths in any autonomous systems that support the CPR mechanism, while the CPR routes can fall back to resolve over best-effort intra-domain paths in the legacy autonomous systems.

There may be multiple inter-domain links between the adjacent autonomous systems, and a border node BGP speaker may receive CPR routes from multiple peering BGP speakers in another domain via External BGP (EBGP). The local policy of a BGP speaker may take the attributes of the inter-domain links and the attributes of the received CPR routes into consideration when selecting the best path for specific Colored Prefixes to better meet the intent. The detailed local policy is outside the scope of this document. In a multi-AS environment, the policy of BGP speakers in different domains needs to be consistent.

In this document, the IPv6 Unicast Address Family is used for the advertisement of IPv6 Colored Prefixes. The primary advantage of this approach is the improved interoperability with legacy networks that lack support for intent-aware paths, and the facilitation of incremental deployment of intent-aware routing mechanisms. One potential concern arises regarding the need to separate Colored Prefixes from public IPv6 unicast routes. Because the IP prefixes and SRv6 locators of network infrastructure are usually advertised as part of the IP unicast routes, and appropriate filters are configured at the boundaries of network administration, this concern is not considered to be a significant issue. [RFC9602] allocates the prefix 5f00::/16 for SRv6 SIDs. By common agreement among participants in the trusted domain, the filters can be configured to by default drop all traffic from 5f00::/16 but permit the Colored Prefixes in use in these domains. The proposal in [BGP-CAR] provides a complementary solution that is also based on the notion of color indicating the intent and where the SRv6 Locator prefix itself signifies the intent; the difference is that a separate SAFI is used.

[BGP-CT] describes another mechanism for intent-aware routing, in which the SRv6 service SIDs are not directly associated with the intent (additional SRv6 transport SIDs are required to steer traffic to the inter-domain intent-aware paths), and an SRv6 operation similar to MPLS label swapping is needed on the border nodes of autonomous systems.

5. IANA Considerations

This document has no IANA actions.

6. Security Considerations

The mechanism described in this document provides an approach for inter-domain intent-aware routing based on existing BGP protocol mechanisms. The existing BGP IPv6 Unicast Address Family and existing Color Extended Community are reused without further BGP extensions. With this approach, the number of IPv6 Colored Prefixes advertised by PE nodes is proportionate to the number of intents it supports. This may introduce additional routes to the BGP IPv6 routing table. Because these are infrastructure routes, the number of Colored Prefixes is only a small portion of the total amount of IPv6 prefixes. Thus, the impact to the required routing table size is considered acceptable.

As the CPR routes are distributed across multiple ASes that belong to a trusted domain, the mapping relationship between the intent and the IPv6 Colored Prefixes are observable to BGP nodes in those ASes. It is possible for an on-path attacker in the trusted domain to identify packets associated with a particular intent.

The security considerations as described in [RFC4271], [RFC4272], and [RFC8754] apply to this document.

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Acknowledgements

Contributors

The following people contributed significantly to the content of this document and should be considered co-authors:

Xinjun Chen
Email: ifocus.chen@huawei.com

Jingrong Xie
Email: xiejingrong@huawei.com

Zhenqiang Li
Email: li_zhenqiang@hotmail.com

Authors' Addresses

Haibo Wang
Huawei Technologies
China
Email: rainsword.wang@huawei.com

Jie Dong
Huawei Technologies
China
Email: jie.dong@huawei.com

Ketan Talaulikar
Cisco Systems
India
Email: ketant.ietf@gmail.com

Tao Han
Huawei Technologies
China
Email: hantao@huawei.com

Ran Chen
ZTE Corporation
China
Email: chen.ran@zte.com.cn