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Introducing Resource Awareness to SR Segments
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Abstract

This document describes a mechanism to allocate network resources to one or a set of Segment Routing Identifiers (SIDs). Such SIDs are referred to as resource-aware SIDs. The resource-aware SIDs retain their original forwarding semantics, with the additional semantics to identify the set of network resources available for the packet processing and forwarding action. The proposed mechanism is applicable to both segment routing with MPLS data plane (SR-MPLS) and segment routing with IPv6 data plane (SRv6).

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1. Introduction

The Segment Routing (SR) Architecture [RFC8402] specifies a mechanism to steer packets through an ordered list of segments. A segment is referred to by its Segment Identifier (SID). With SR, explicit source routing can be achieved without introducing per-path state into the network. The base SR specifications do not have the capability of identifying or reserving a set of network resources. Although a centralized controller can have a global view of network state and can provision different services using different SR paths, in data packet forwarding it still relies on the DiffServ QoS mechanism [RFC2474] [RFC2475] to provide coarse-grained traffic differentiation in the network. While such a mechanism may be sufficient for some types of services, other may require a set of dedicated network resources to achieve resource isolation in the same network. Also note the number of such services could be larger than the number of traffic classes available with DiffServ QoS.

Without needing to define new SID types, this document extends the SR paradigm by associating SIDs with network resource attributes, so that network resources can be allocated to one or a set of SIDs. Such SIDs are referred to as resource-aware SIDs. These resource-

aware SIDs retain their original functionality, with the additional semantics of identifying the set of network resources available for the packet processing action. Typical types of network resources include link bandwidth, buffers, and queues that are associated with class of service, scheduling weights or time cycles, and it is also possible to associate SR SIDs with other types of resources (e.g., the processing and storage resources). For a particular SR segment, multiple resource-aware SIDs can be allocated, each of which represents a subset of network resources allocated in the network to meet the requirements of one or a group of customers or services. Each subset of the network resources may be associated with one or multiple resource-aware SIDs. The allocation of network resources to segments can be done either via local configuration or via a centralized controller. Other approaches are possible such as use of a control plane signaling protocol, but they are out of the scope of this document.

An SR Policy that requires dedicated network resources can be composed of a list of resource-aware SIDs. This can be useful for service which requires dedicated network resources along the SR path. In addition, a subset of the network topology and resources (considered as a "virtual network") can be represented by a group of resource-aware SIDs that meet the connectivity and resource goals. The resources associated with each segment of the virtual network can be the same or different. The proposed mechanism is applicable to SR with both MPLS data plane (SR-MPLS) and IPv6 data plane (SRv6). The reader is expected to be familiar with the terminology in [RFC8402], [RFC8660] and [RFC8986].

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2. Segments with Resource Awareness

In the Segment Routing architecture [RFC8402], several types of segments are defined to represent either topological or service instructions. A topological segment can be a node segment or an adjacency segment. A service segment may be associated with specific service functions for service chaining purpose. This document introduces additional resource semantics to the existing types of SIDs. A resource-aware SID retains its original functionality, with the additional semantics of identifying a set of network resources allocated in the network for the packet processing action. A

resource-aware SID is considered local resource-aware if the associated network resource is allocated on a specific node in the network. A resource-aware SID is considered global resource-aware if the associated network resource is allocated on multiple nodes in the network. A local resource-aware SIDs may be allocated with a dedicated set of network resources, while for global resource-aware SIDs, a common set of network resources may be allocated to a group of resource-aware SIDs.

This section describes the mechanisms of using resource-aware SR SIDs to indicate the network resource information associated with the SR paths or virtual networks based on the two SR data plane instantiations: SR-MPLS and SRv6. The mechanisms to identify the forwarding path or network topology with SIDs as defined in [RFC8402] do not change. Aligning with the SR architecture, the control plane for resource-aware segments can be centralized, distributed, or hybrid. When resource-aware segments are associated with a virtual network, the control plane for distributing the resource-aware SIDs and the associated topology or Flexible-Algorithm can be based on [RFC4915], [RFC5120] and [RFC9350].

2.1. SR-MPLS

The MPLS instantiation of Segment Routing is specified in [RFC8660]. [RFC8402] specifies several type of SIDs, including the an IGP Adjacency Segment (Adj-SID), the IGP-Prefix Segment (Prefix-SID), and the IGP-Node Segment (Node-SID). It also introduces the BGP Peer Adjacency Segment (PeerAdj SID). These type of SIDs can be reused to represent both the topological instructions and the set of network resources allocated for packet processing following the instructions.

A resource-aware Adj-SID is a local resource-aware segment, it represents a subset of the network resources (e.g., bandwidth, buffer and queuing resources) on a given link, thus each resource-aware Adj-SID is associated with a subset of the link's traffic engineering (TE) capabilities and resources (known as TE attributes [RFC2702]).

For one IGP link, multiple resource-aware Adj-SIDs can be assigned, each of which is associated with a subset of the link resources allocated on the link. For one inter-domain link, multiple BGP PeerAdj SIDs may be assigned, each of which is associated with a subset of the link resources allocated on the inter-domain link. The resource-aware Adj-SIDs may be associated with a specific network topology and/or algorithm, so that it is used only for resource-aware SR paths computed within the topology and/or algorithm.

Note this per-segment resource allocation complies with the SR paradigm, which avoids introducing per-path state into the network. Several approaches can be used to partition and reserve the link resources, such as [FLEXE], logical sub-interfaces with reserved bandwidth, dedicated queues, etc. The detailed mechanism of link resource partitioning is out of scope of this document.

A resource-aware prefix-SID is a global resource-aware segment, it is associated with a network topology and/or algorithm which the attached node participates in. In addition, a resource-aware prefix-SID is allocated with a set of network resources (e.g., bandwidth, buffer and queuing resources) on all the nodes and links participating in the associated topology and/or algorithm. Such set of network resources can be used for forwarding packets which are encapsulated with this resource-aware prefix-SID, along the paths computed in the associated topology and/or algorithm.

Although it is possible that each resource-aware prefix-SID is allocated with a set of dedicated resources on every node and link in the associated topology and/or algorithm, the overhead of per-prefix resource reservation is usually considered unacceptable in both control plane signaling and data plane states, and it is likely some of the allocated resources will be wasted. It is RECOMMENDED that a common set of network resources be allocated by the network nodes and links participating in the topology and/or algorithm, and this common set of network resources is associated with a group of resource-aware Prefix-SIDs. Such a common set of network resources constitutes a resource group. For a given <topology, algorithm> tuple, there can be one or multiple resource groups. This way, a group of resource-aware prefix-SIDs which are associated with the same <topology, algorithm> tuple can share the set of network resources in a resource group. The association between the SR SIDs and a resource group can be provisioned using the management plane or a control plane.

The recommendation above helps to reduce the dynamics in per-prefix resource allocation and adjustment, so that the network resource can be allocated based on planning and does not have to rely on dynamic signaling. When the set of nodes and links that participate in a <topology, algorithm> tuple changes, the set of network resources allocated on specific nodes and links may need to be adjusted. When the set of network resources are locally configured on the network links, this means that the resources allocated to resource-aware Adj-SIDs on those links may have to be adjusted, and new TE attributes for the associated adj-SIDs re-advertised.

For one IGP prefix, multiple resource-aware prefix-SIDs can be allocated. Each resource-aware prefix-SID may be associated with a unique <topology, algorithm> tuple, in this case different <topology,

<algorithm> tuples can be used to distinguish the resource-aware prefix-SIDs of the same prefix. In another case, for one IGP prefix, multiple resource-aware prefix-SIDs may be associated with the same <topology, algorithm> tuple but different resource groups, then an additional control plane distinguisher needs to be introduced to distinguish different resource-aware prefix-SIDs associated with the same <topology, algorithm> but different resource groups. The first approach is simpler and does not require extensions to control plane protocols, while there can be scalability concerns when the number of resource groups is large, as it would require a large number of topologies or Flex-Algorithms. The second approach is more scalable, while it requires additional extensions to the control plane protocols. The exact control plane extensions are out of the scope of this document.

A group of resource-aware Adj-SID and resource-aware Prefix-SIDs can be used to construct the SID lists of an SR Policy, which can be used to steer the traffic to be forwarded along the explicit paths (either strict or loose) and processed using the set of network resources identified by the resource-aware SIDs.

In SR-MPLS packet forwarding, each resource-aware Adj-SID identifies both the next-hop of the node and the set of resources used for packet processing on the outgoing interface. Each resource-aware Prefix-SID identifies the path to the node which the prefix is attached to, and the set of network resources used for packet forwarding on the transit nodes along the path. The transit nodes use the resource-aware Prefix-SIDs to determine the next-hop of the packet and the set of associated local resources, then forward the packet to the next-hop using the set of local resources.

When the set of network resources allocated on the egress node also needs to be determined, it is RECOMMENDED that Penultimate Hop Popping (PHP) [RFC3031] be disabled, otherwise the inner service label needs to be used to infer the set of resources to be used for packet processing on the egress node of the SR path.

This mechanism requires the allocation of additional prefix-SIDs or adj-SIDs to identify different sets of network resources. As the number of resource groups increases, the number of SIDs would increase accordingly, while it should be noted that there is still no per-path state introduced into the network.

2.2. SRv6

[RFC8986] defines the SRv6 SID format (LOC:FUNCT:ARG) and the base set of SRv6 behaviors bound to the SRv6 SIDs. When the LOC (Locator) part of the SRv6 SIDs is routable, it leads to the node which instantiates the SID.

The approach of introducing resource-awareness to SRv6 is by firstly making the SRv6 Locators resource-aware. For one SRv6 node, multiple resource-aware SRv6 Locators can be assigned. A resource-aware Locator is associated with a network topology and/or algorithm in which the originating node participates, as well as a set of network resources (e.g., bandwidth, buffer, and queueing resources) on each node and the attached links participating in the same topology and/or algorithm. Then resource-aware SRv6 SIDs are allocated using the resource-aware SRv6 Locator as the prefix. The set of network resources allocated to the resource-aware SRv6 Locator are used in forwarding packets in which the resource-aware SRv6 SIDs are encoded as the destination IPv6 address.

Similar to the approach used with resource-aware prefix-SIDs in SR-MPLS, it is RECOMMENDED that a common set of network resources are allocated by the network nodes and links participating in a topology and/or algorithm, and this resource group is associated with a group of resource-aware Locators of the same topology and/or algorithm.

For one IGP link, multiple resource-aware SRv6 End.X SIDs can be allocated to identify different set of link resources allocated on the link. Each resource-aware End.X SID MUST use a resource-aware locator as its prefix. SRv6 SIDs for other types of behaviors MAY also be assigned as resource-aware SIDs, which can identify the set of network resources allocated by the node for executing the behavior.

A group of resource-aware SRv6 SIDs can be used to construct the SID lists of an SR Policy, which can be used to steer the traffic to be forwarded along the explicit paths (either strict or loose), and be processed using the set of network resources identified by the resource-aware SRv6 Locators and SIDs.

In SRv6 packet forwarding, the transit nodes uses the resource-aware Locator of the SRv6 SID carried in the destination IPv6 address field to determine the next-hop of the packet, and the associated set of network resources, then the packet is forwarded to the next-hop using the set of local resources in the resource group. On the segment endpoint nodes, the resource-aware End.X SID identifies both the next-hop and the set of resources used for packet processing on the outgoing interface of the node which instantiates the SID.

This mechanism requires the allocation of additional SRv6 Locators and SIDs to identify different set of network resources. As the number of resource groups increases, the number of SRv6 Locators and SIDs would increase accordingly, while it should be noted that there is still no per-path state introduced into the network.

3. Control Plane Considerations

The mechanism described in this document assumes the use of a centralized controller to collect the information about the network (configuration, state, routing databases, etc.) as well as the service information (traffic matrix, performance statistics, etc.) for the planning of network resources based on the service requirements. The centralized controller can also be used to instruct the network nodes to allocate the network resources and associate the resources to resource-aware SIDs. The resource-aware SIDs can be either explicitly provisioned by the controller, or can be dynamically allocated by network nodes. The distributed control plane is complementary to the centralized controller. When the resource-aware SIDs are locally configured or dynamically allocated, a distributed control plane can be used for the collection and distribution of the resource-aware SIDs among network nodes, together with the set of associated local network resource information. Then some of the network nodes can distribute the collected information to the centralized controller. The mechanisms as defined in [RFC8665][RFC8667][RFC9085][RFC9352][RFC9513] and [RFC9514] can be reused with possible extensions to improve the efficiency and scalability. The details are out of the scope of this document.

The support for a resource group and the information to associate packets to it MUST be aligned among the network nodes in that resource group, so as to ensure that packets are processed consistently within a resource group. This task can be accomplished via local configuration or via a centralized controller. Other approaches may be possible.

To indicate the support for a given resource group, a node needs to advertise the identifier of the resource group, the associated topology and algorithm, the resource-aware SIDs and potentially a set of TE attributes representing the resources allocated to it.

The controller is also responsible for the centralized computation and optimization of the SR paths taking the topology, algorithm and network resource constraints into consideration. The interaction between the controller and the network nodes can be based on Netconf/YANG [RFC6241][RFC7950][I-D.ietf-spring-sr-policy-yang], BGP SR Policy [I-D.ietf-idr-sr-policy-safi] or PCEP [RFC8664][RFC9603]. In some scenarios, extensions to some of these protocols may be needed

to improve the efficiency and scalability of the control plane, which are out of the scope of this document. Distributed computation of resource-aware SR paths is also possible, the topology, algorithm and/or resource constraints needs to be taken into consideration by network nodes. The distributed control plane may be based on [RFC4915], [RFC5120], [RFC9350] with necessary extensions.

When a network node is instructed to associate a SID with specific resources, its actions will depend on the operational mechanisms of the network. In some cases the association between SIDs and resources is configured on the individual network nodes, and the control plane (e.g. IGP) is used to distribute the SID information and the allocated resource information to the controller and the ingress nodes for TE constraint-based path computation. In network cases with SR and other TE mechanisms (such as RSVP-TE) co-existing in the network, the IGP advertisements of available resources may need to be updated to indicate that there has been a change to the available resources resulting from the instantiation of a new resource-aware SID, it is suggested such updates would be rate-limited. In still other cases the association between SIDs and network resources is provisioned by the central controller which is responsible for all TE management, then the distributed control plane does not need to take any additional action.

4. IANA Considerations

This document makes no request of IANA.

Note to RFC Editor: this section may be removed on publication as an RFC.

5. Security Considerations

The security considerations of segment routing in [RFC8402] [RFC8660] [RFC8754] and [RFC8986] are applicable to this document.

The resource-aware SIDs may be used for provisioning of SR paths or virtual networks to carry traffic with specific SLA requirements (such as latency). By disrupting the SLA of such traffic an attack can be directly targeted at the customer application, or can be targeted at the network operator by causing them to violate their SLA, triggering commercial consequences. Dynamic attacks of this sort are not something that networks have traditionally guarded against, and networking techniques need to be developed to defend against this type of attack. By rigorously policing ingress traffic and carefully provisioning network resources provided to such services, this type of attack can be prevented. However care needs to be taken when providing shared resources, and when the network needs to be reconfigured as part of ongoing maintenance or in response to a failure.

A compromised network node may choose not to allocate the necessary resources to a set of resource-aware SIDs, this may result in the expected SLA being disrupted due to lack of resource guarantee.

The details of the underlay network MUST NOT be exposed to third parties, to prevent attacks aimed at exploiting shared network resources.

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