High Availability

The goal of any high availability solution is to ensure that all network services are resilient to failure. Such a solution aims to provide continuous access to network resources by addressing the potential causes of downtime through functionality, design, and best practices. The core of the Cisco Catalyst SD-WAN high availability solution is achieved through a combination of three factors:

- Functional hardware device redundancy. The basic strategy consists of installing and provisioning redundant hardware devices and redundant components on the hardware. These devices are connected by a secure control plane mesh of Datagram Transport Layer Security (DTLS) connections among themselves, which allows for rapid failover should a device fail or otherwise become unavailable. A key feature of the Cisco Catalyst SD-WAN control plane is that it is established and maintained automatically, by the Cisco IOS XE Catalyst SD-WAN devices and software themselves.
- Robust network design.
- Software mechanisms ensure rapid recovery from a failure. To provide a resilient control plane, the Cisco Catalyst SD-WAN Overlay Management Protocol (OMP) regularly monitors the status of all Cisco IOS XE Catalyst SD-WAN devices in the network and automatically adjusts to changes in the topology as devices join and leave the network. For data plane resiliency, the Cisco Catalyst SD-WAN software implements standard protocol mechanisms, specifically Bidirectional Forwarding Detection (BFD), which runs on the secure IPsec tunnels between routers.

Recovery from a failure is a function of the time it takes to detect the failure and then repair or recover from it. The Cisco Catalyst SD-WAN solution provides the ability to control the amount of time to detect a failure in the network. In most cases, repair of the failure is fairly instantaneous.

Hardware Support of High Availability

A standard best practice in any network setup is to install redundant hardware at all levels, including duplicate parallel routers and other systems, redundant fans, power supplies and other hardware components within these devices, and backup network connections. Providing high availability in the Cisco Catalyst SD-WAN solution is no different. A network design that is resilient in the face of hardware failure should include redundant Cisco SD-WAN Validators, Cisco SD-WAN Controllers, and routers and any available redundant hardware components.

Recovery from the total failure of a hardware component in the Cisco Catalyst SD-WAN overlay network happens in basically the same way as in any other network. A backup component has been preconfigured, and it is able to perform all necessary functions by itself.

Robust Network Design

In addition to simple duplication of hardware components, the high availability of a Cisco Catalyst SD-WAN network can be enhanced by following best practices to design a network that is robust in the face of failure. In one such network design, redundant components are spread around the network as much as possible. Design practices include situating redundant Cisco SD-WAN Validators and Cisco SD-WAN Controllers at dispersed geographical locations and connecting them to different transport networks. Similarly, the routers at a local site can connect to different transport networks and can reach these networks through different NATs and DMZs.

Software Support of High Availability

The Cisco Catalyst SD-WAN software support for high availability and resiliency in the face of failure is provided both in the control plane, using the standard DTLS protocol and the proprietary Cisco Catalyst SD-WAN Overlay Management Protocol (OMP), and in the data plane, using the industry-standard protocols BFD, BGP, OSPF, and VRRP.

Control Plane Software Support of High Availability

The Cisco Catalyst SD-WAN control plane operates in conjunction with redundant components to ensure that the overlay network remains resilient if one of the components fails. The control plane is built on top of DTLS or TLS connections between the Cisco devices, and it is monitored by the Cisco Catalyst SD-WAN OMP protocol, which establishes peering sessions (similar to BGP peering sessions) between pairs of Cisco SD-WAN Controllers and routers, and between pairs of Cisco SD-WAN Controllers. These peering sessions allow OMP to monitor the status of the Cisco devices and to share the information among them so that each device in the network has a consistent view of the overlay network. The exchange of control plane information over OMP peering sessions is a key piece in the Cisco Catalyst SD-WAN high availability solution:

- Cisco SD-WAN Controllers quickly and automatically learn when a Cisco SD-WAN Validator or a router joins or leaves the network. They can then rapidly make the necessary modifications in the route information that they send to the routers.
- Cisco SD-WAN Validator quickly and automatically learn when a device joins the network and when a Cisco SD-WAN Controller controller leaves the network. They can then rapidly make the necessary changes to the list of Cisco SD-WAN Controller IP addresses that they send to routers joining the network.
- Cisco SD-WAN Validators learn when a domain has multiple Cisco SD-WAN Controllers and can then provide multiple Cisco SD-WAN Controller addresses to routers joining the network.
- Cisco SD-WAN Controllers learn about the presence of other Cisco SD-WAN Controllers, and they all automatically synchronize their route tables. If one Cisco SD-WAN Controller fails, the remaining systems take over management of the control plane, simply and automatically, and all routers in the network continue to receive current, consistent routing and TLOC updates from the remaining Cisco SD-WAN Controllers.

A highly available Cisco Catalyst SD-WAN network contains two or more Cisco SD-WAN Controllers in each domain. A Cisco Catalyst SD-WAN domain can have up to eight Cisco SD-WAN Controllers, and each Cisco IOS XE Catalyst SD-WAN device, by default, connects to two of them.

Let's look at the redundancy provided by each of the Cisco Catalyst SD-WAN hardware devices in support of network high availability.

Recovering from a Failure in the Control Plane

The combination of hardware component redundancy with the architecture of the Cisco Catalyst SD-WAN control plane results in a highly available network, one that continues to operate normally and without interruption when a failure occurs in one of the redundant control plane components. Recovery from the total failure of a Cisco SD-WAN Controller, Cisco SD-WAN Validator, or router in the Cisco Catalyst SD-WAN overlay network happens in basically the same way as the recovery from the failure of a regular router or server on the network: A preconfigured backup component is able to perform all necessary functions by itself.

In the Cisco Catalyst SD-WAN solution, when a network device fails and a redundant device is present, network operation continues without interruption. This is true for all Cisco devices, Cisco SD-WAN Validators, Cisco SD-WAN Controllers, and routers. No user configuration is required to implement this behavior; it happens automatically. The OMP peering sessions running between Cisco devices ensure that all the devices have a current and accurate view of the network topology.

Let's examine failure recovery device by device.

Data Plane Software Support for High Availability

For data plane resiliency, the Cisco Catalyst SD-WAN software implements the standard BFD protocol, which runs automatically on the secure IPsec connections between routers. These IPsec connections are used for the data plane, and for data traffic, and are independent of the DTLS or TLS tunnels used by the control plane. BFD is used to detect connection failures between the routers. It measures data loss and latency on the data tunnel to determine the status of the devices at either end of the connection.

BFD is enabled, by default, on connections between Cisco IOS XE Catalyst SD-WAN devices and Cisco vEdge devices. BFD sends Hello packets periodically (by default, every 1 second) to determine whether the session is still operational. If a certain number of the Hello packets are not received, BFD considers that the link has failed and brings the BFD session down (the default dead time is 3 seconds). When BFD sessions go down, any route that points to a next hop over that IPsec tunnel is removed from the forwarding table (FIB), but it is still present in the route table (RIB).

In the Cisco Catalyst SD-WAN software, you can adjust the Hello packet and dead time intervals. If the timers on the two ends of a BFD link are different, BFD negotiates to use the lower value.

Using Affinity to Manage Network Scaling

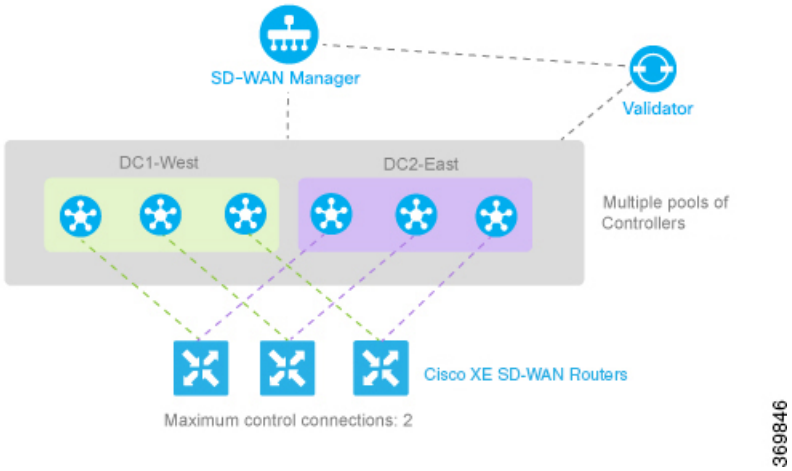
In the Cisco Catalyst SD-WAN overlay network, all Cisco IOS XE Catalyst SD-WAN devices and Cisco vEdge devices establish control connections to Cisco SD-WAN Controllers, to ensure that the routers are always able to properly route data traffic across the network. As networks increase in size, with routers at thousands of sites and with Cisco SD-WAN Controllers in multiple data centers managing the flow of control and data traffic among routers, network operation can be improved by limiting the number of Cisco SD-WAN Controllers that a router can connect to. When data centers are distributed across a broad geography, network operation can also be better managed by having routers establish control connections only with the Cisco SD-WAN Controllers collocated in the same geographic region.

Establishing affinity between Cisco SD-WAN Controllers and Cisco IOS XE Catalyst SD-WAN devices allows you to control the scaling of the overlay network, by limiting the number of Cisco SD-WAN Controllers that a Cisco IOS XE Catalyst SD-WAN device can establish control connections. When you have redundant routers in a single data center, affinity allows you to distribute the Cisco IOS XE Catalyst SD-WAN device control connections across the Cisco SD-WAN Controllers.

Similarly, when you have multiple data centers in the overlay network, affinity allows you to distribute the control connections between edge devices and the Cisco SD-WAN Controller, across all data centers. This way, a Cisco IOS XE Catalyst SD-WAN device has controller redundancy and data center redundancy. If the

link between a Cisco IOS XE Catalyst SD-WAN device and any one of the data centers goes down, the Cisco SD-WAN Controllers in the other data center are available to continue servicing the overlay network.

The following figure illustrates this scenario, showing three Cisco SD-WAN Controllers in each of the two data centers. Each of the three Cisco IOS XE Catalyst SD-WAN devices establishes a control connection to one controller in the West data center and one in the East data center.



You might think of the scenario in the figure above as one where there are redundant data centers in the same region of the world, such as in the same city, province, or country.

For an overlay network that spans a larger geography, such as across continents, you can use affinity so the Cisco IOS XE Catalyst SD-WAN devices establish control connections with data centers in their geographic region and only connect to more distant regions should their closer data centers become unavailable.

- Cisco Catalyst SD-WAN Validator Redundancy, on page 4
- Cisco Catalyst SD-WAN Manager Server Redundancy, on page 6
- Cisco Catalyst SD-WAN Controller Redundancy, on page 9
- Cisco IOS XE Catalyst SD-WAN Device Redundancy, on page 10
- High Availability, on page 11
- Configure Affinity Between Cisco Catalyst SD-WAN Controllers and Cisco IOS XE Catalyst SD-WAN Device, on page 11

Cisco Catalyst SD-WAN Validator Redundancy

The Cisco SD-WAN Validator performs two key functions in the Cisco Catalyst SD-WAN overlay network:

- Authenticates and validates all Cisco SD-WAN Controllers and routers that attempt to join the Cisco Catalyst SD-WAN network.
- Orchestrates the control plane connections between the Cisco SD-WAN Controllers and routers, thus enabling Cisco SD-WAN Controller and routers to connect to each other in the Cisco Catalyst SD-WAN network.

The Cisco SD-WAN Validator runs as a VM on a network server.

Having multiple Cisco SD-WAN Validators ensures that one of them is always available whenever a Cisco device such as a router or a Cisco SD-WAN Controller is attempting to join the network.

Configuration of Redundant Cisco Catalyst SD-WAN Validators

A vEdge Cloud router learns that it is acting as a Cisco SD-WAN Validator from its configuration. In the **system vbond** configuration command, specify the local IP address of the Cisco SD-WAN Validator and include the **local** keyword. Other Cisco IOS XE Catalyst SD-WAN devices use the **system vbond** configuration command without the **local** keyword to specify the IP address or DNS hostname of the Cisco SD-WAN Validator that those devices can connect to in order to join the overlay network and discover the other control components to establish control connections with

On Cisco SD-WAN Controllers, Cisco SD-WAN Managers and Cisco IOS XE Catalyst SD-WAN devices, when the network has only a single Cisco SD-WAN Validator, you can configure the Cisco SD-WAN Validator either as an IP address or as a host name (such as vbond.cisco.com) using the **system vbond** command. When the network has two or more Cisco SD-WAN Validators and they must all be reachable, you should use a DNS host name to specify the Cisco Catalyst SD-WAN Validators. If the DNS name resolves to multiple IP addresses, the Cisco IOS XE Catalyst SD-WAN device tries each Cisco Catalyst SD-WAN Validator address sequentially until it forms a successful connection.

Note that even if your Cisco Catalyst SD-WAN network has only a single Cisco SD-WAN Validator, it is recommended as a best practice that you specify a DNS host name rather than an IP address in the **system vbond** configuration command, because this results in a scalable configuration. Then, if you add additional Cisco SD-WAN Validators to your network, you do not need to change the configurations on any of the routers or other devices in your network.

Note When configuring redundant Cisco SD-WAN Validators, ensure the following:

- If there is an IP host mapping for both public and private IPs of vBond, verify that both private and public IPs exists. Also, confirm that these IPs are associated with their respective private and public colors.
- Only include IPs that the device can reach over the designated color (internet/public or MPLS/private). If an address is not reachable, the edge may attempt it and time out, impacting performance.

Recovering from a Cisco Catalyst SD-WAN Validator Failure

In a network with multiple Cisco SD-WAN Validators, if one of them fails, the other Cisco SD-WAN Validators simply continue operating and are able to handle all requests by Cisco devices to join the network. From a control plane point of view, each Cisco SD-WAN Validator maintains permanent DTLS connections to each of the Cisco SD-WAN Controllers in the network.

Note however, that there are no connections between the Cisco SD-WAN Validators themselves. As long as one Cisco SD-WAN Validator is present in the domain, the Cisco Catalyst SD-WAN network is able to continue operating without interruption, because Cisco SD-WAN Controllers and routers are still able to locate each other and join the network.

Because Cisco SD-WAN Validators never participate in the data plane of the overlay network, the failure of any Cisco SD-WAN Validator has no impact on data traffic. Cisco SD-WAN Validators communicate with routers when the routers are first joining the network. The joining router establishes a transient DTLS connection with a Cisco SD-WAN Validator to learn the IP address of a Cisco SD-WAN Controller. When the Cisco IOS XE Catalyst SD-WAN device configuration lists the Cisco SD-WAN Validator address as a DNS name, the router tries each of the Cisco SD-WAN Validators in the list, one by one, until it is able to establish a DTLS connection. This mechanism allows a router to always be able to join the network, even after one of a group of Cisco SD-WAN Validators has failed.

Cisco Catalyst SD-WAN Manager Server Redundancy

The Cisco SD-WAN Manager servers comprise a centralized network management system that enables configuration and management of the Cisco devices in the overlay network. It also provides a real-time dashboard into the status of the network and network devices. The Cisco SD-WAN Manager servers maintain permanent communication channels with all Cisco IOS XE Catalyst SD-WAN devices in the network. Over these channels, the Cisco SD-WAN Manager servers provide new software images as part of a software upgrade process. From each network device, the Cisco SD-WAN Manager servers receive various status information that is displayed on the Cisco SD-WAN Manager **Monitor** > **Overview** page.

Note In Cisco SD-WAN Release 20.6.1 and earlier releases, the status information is available on the **Dashboard** > **Main Dashboard** page.

The Cisco SD-WAN Manager can be deployed in two basic ways, either standalone or by clustering. A cluster consists of three or six Cisco SD-WAN Manager servers, and each Cisco SD-WAN Manager server in a cluster is referred to as a Cisco SD-WAN Manager instance.

Cisco IOS XE Catalyst SD-WAN devices are load-balanced among the Cisco SD-WAN Manager instances.

The Cisco SD-WAN Manager cluster is designed such that the cluster remains operational if one of the devices in that cluster fails.

The purpose of an Cisco SD-WAN Manager is scale. It provides a level of redundancy against a single Cisco SD-WAN Manager failure, but it does not protect against a cluster-level failure. For high availability, a standby cluster should be deployed in the event of a cluster failure or connectivity failure to the site where the Cisco SD-WAN Manager cluster resides. See more information about Disaster Recovery

See Recommended Computing Resources for your specific release to get vCPU, RAM, storage requirements, and number of control components required for your deployment.

A Cisco SD-WAN Manager cluster consists of the following architectural components:

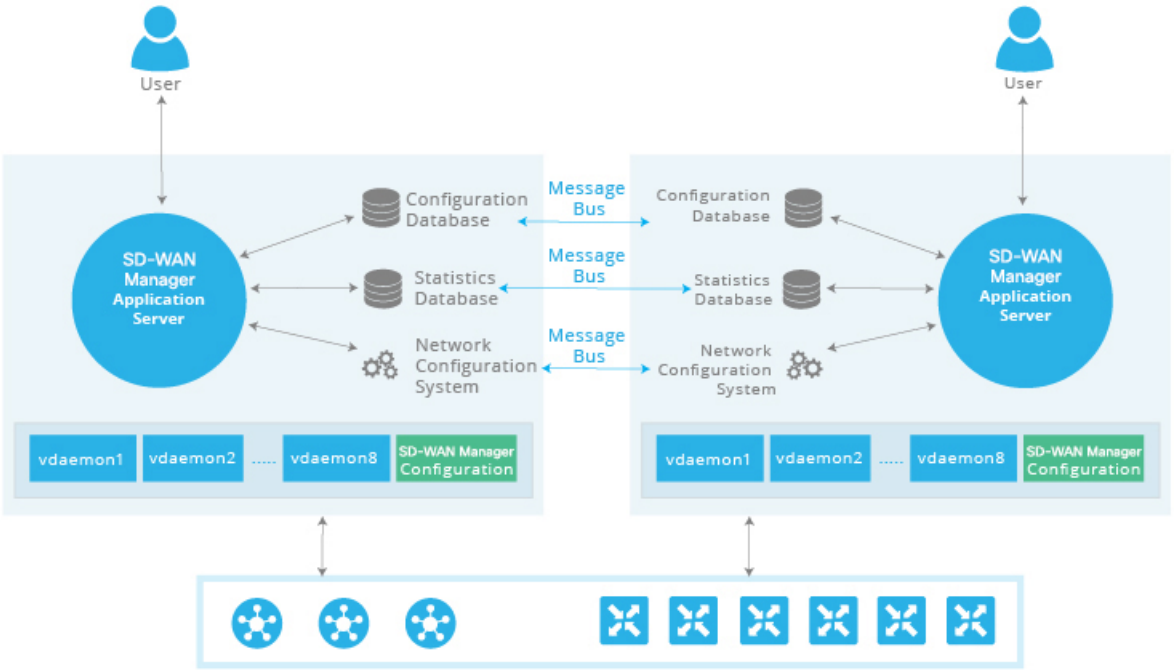
- Application server—This provides a web server for user sessions. Through these sessions, a logged-in user can view a high-level dashboard summary of networks events and status, and can drill down to view details of these events. A user can also manage network serial number files, certificates, software upgrades, device reboots, and configuration of the Cisco SD-WAN Manager cluster itself from the Cisco SD-WAN Manager application server.
- Configuration database—Stores the inventory and state and the configurations for all Cisco IOS XE Catalyst SD-WAN devices.
- Network configuration system—Stores all configuration information, policies, templates, certificates, and more.
- Statistics database—Stores the statistics information collected from all Cisco devices in the overlay network.
- Message server—Communication bus among the different Cisco SD-WAN Manager instances. This bus is used to share data and coordinate operations among the Cisco SD-WAN Manager instances in the cluster.

The Statistics database and Configuration database services must run on an odd number of Cisco SD-WAN Manager instances in a cluster, with a minimum of three. For these databases to be writeable, there must be a quorum of Cisco SD-WAN Manager instances running and they should be in sync. A quorum is a simple majority. For example, if you have a cluster of three Cisco SD-WAN Manager instances running these databases, then two must be running and in sync to have a majority.

Note that from Cisco SD-WAN Release 20.6.1, persona-based cluster configuration is used. A persona defines what services runs on a Cisco SD-WAN Manager server.

For more information, see Add a Cisco Catalyst SD-WAN Manager Server to a Cluster.

The following figure shows the interaction between Cisco SD-WAN Manager instances in a cluster, although a minimum of three devices is required. The figure illustrates the Cisco SD-WAN Manager services that synchronize between the Cisco SD-WAN Manager instances. Also in this figure, you see that each Cisco SD-WAN Manager instance resides on a virtual machine (VM). The VM can have from one to eight cores, with a Cisco Catalyst SD-WAN software process (vdaemon) running on each core. In addition, the VM stores the actual configuration for the Cisco SD-WAN Manager server itself.



The Cisco SD-WAN Manager cluster implements an active-active architecture in the following way:

- Each Cisco SD-WAN Manager instance in the cluster is an independent processing node.
- All control sessions between the Cisco SD-WAN Manager application servers are load balanced. All the controller sessions—the sessions between the Cisco SD-WAN Manager instances and the Cisco Catalyst SD-WAN Controllers, the sessions between the Cisco SD-WAN Manager instances and the Cisco Catalyst SD-WAN Validators are arranged in a full-mesh topology.
- The configuration and statistics databases can be replicated across Cisco SD-WAN Manager instances, and these databases can be accessed and used by all the Cisco SD-WAN Manager instances.

- If one of the Cisco SD-WAN Manager instances in the cluster fails or otherwise becomes unavailable, the network management services that are provided by the Cisco SD-WAN Manager server are still fully available across the network.

The message server among the Cisco SD-WAN Manager instances in the cluster allows all the instances to communicate using an out-of-band network. This design, which leverages a third vNIC on the Cisco SD-WAN Manager VM, avoids using WAN bandwidth for management traffic.

The following are the design considerations for a Cisco SD-WAN Manager cluster:

- A Cisco SD-WAN Manager cluster should only consist of three or six Cisco SD-WAN Manager instances.

  All members of a Cisco SD-WAN Manager cluster must be located in the same data center (database replication between cluster members requires four ms or less of delay between them). The cluster interface IP address of all members of the Cisco SD-WAN Manager cluster should be in the same subnet.
- From Cisco SD-WAN Release 20.6.1 onwards, a cluster supports:
  - three compute+data nodes,
  - three compute+data nodes and 3 data nodes,
  - three compute nodes and three data nodes are only supported by an upgrade from an existing deployment.

Note Data nodes should be added to the cluster only after a 3-node cluster with compute+data is added.

See the Cluster Management chapter in the *Cisco Getting Started Guide* for more information about deploying and managing the Cisco SD-WAN Manager instances of a cluster.

The main purpose of an Cisco SD-WAN Manager cluster is scale. It does provide a level of redundancy against a single Cisco SD-WAN Manager instance failure, but it does not protect against a cluster-level or data center location failure, so disaster recovery is also needed.

Cisco Catalyst SD-WAN Manager Disaster Recovery

Should an active standalone Cisco SD-WAN Manager node or cluster become unavailable at one data center site, disaster recovery can minimize disruption and fail management traffic over to another standalone Cisco SD-WAN Manager node or cluster at a different data center site.

Note that the failure of the Cisco SD-WAN Manager impacts only the ability to configure, upgrade, and receive statistics, and does not affect data plane traffic.

The following disaster recovery methods are available:

- **Manual** (Cisco SD-WAN Manager standalone or cluster): The backup SD-WAN Manager server or SD-WAN Manager cluster is kept shutdown in cold standby state.

  Regular backups of the active database are taken, and if the primary SD-WAN Manager or SD-WAN Manager cluster goes down, the standby SD-WAN Manager or SD-WAN Manager cluster is brought up manually and the backup database restored on it.
- **Administrator-triggered failover** (Cisco SD-WAN Manager standalone or cluster): The administrator-triggered disaster recovery switchover option can be configured on a cluster starting in Cisco SD-WAN Release 19.2.1 or on a single node starting in version Cisco SD-WAN Release 20.5.1.

Data is replicated automatically between the primary and secondary Cisco SD-WAN Manager nodes/clusters. When needed, a switchover is manually performed to the secondary Cisco SD-WAN Manager node/cluster.

See the Disaster Recovery chapter for more information.

Cisco Catalyst SD-WAN Manager Backups

In a Cisco cloud-managed SD-WAN overlay, Cisco takes regular snapshots of the Cisco SD-WAN Manager virtual machines for recovery due to a catastrophic failure or corruption. Another snapshot can be taken before any scheduled activity. In on-premise deployments, it is your responsibility to take regular snapshots of the Cisco SD-WAN Manager virtual machine and follow the example of frequency and retention that is followed by Cisco.

It is also recommended that regular backups for the configuration database should be taken and stored securely off-site. The greater the time between the backup and when it is needed for a recovery, the greater the risk that data might be lost.

Perform configuration database backups often. Use the following command to create a configuration database backup file:

```
request nms configuration-db backup path <path>
```

Cisco Catalyst SD-WAN Controller Redundancy

Cisco Catalyst SD-WAN Controller Redundancy

The Cisco SD-WAN Controllers are the central orchestrators of the control plane. They have permanent communication channels with all the Cisco devices in the network. Over the DTLS or TLS connections between the Cisco SD-WAN Controllers and Cisco SD-WAN Validators and between pairs of Cisco SD-WAN Controllers, the devices regularly exchange their views of the network, to ensure that their route tables remain synchronized. The Cisco SD-WAN Controllers pass accurate and timely route information over DTLS or TLS connections to Cisco IOS XE Catalyst SD-WAN devices.

A highly available Cisco Catalyst SD-WAN network contains two or more Cisco SD-WAN Controllers in each domain. A Cisco Catalyst SD-WAN domain can have up to 12 Cisco SD-WAN Controllers, and each router, by default, connects to two of them. When the number of Cisco SD-WAN Controllers in a domain is greater than the maximum number of controllers that a domain's routers are allowed to connect to, the Cisco Catalyst SD-WAN software load-balances the connections among the available Cisco SD-WAN Controllers.

While the configurations on all the Cisco SD-WAN Controllers must be functionally similar, the control policies must be identical. This is required to ensure that, at any time, all Cisco IOS XE Catalyst SD-WAN devices receive consistent views of the network. If the control policies are not absolutely identical, different Cisco SD-WAN Controllers might give different information to a Cisco IOS XE Catalyst SD-WAN device, and the likely result will be network connectivity issues.

Note To reiterate, the Cisco Catalyst SD-WAN overlay network works properly only when the control policies on all Cisco SD-WAN Controllers are identical. Even the slightest difference in the policies will result in issues with the functioning of the network.

To remain synchronized with each other, the Cisco SD-WAN Controllers establish a full mesh of DTLS or TLS control connections, as well as a full mesh of OMP sessions, between themselves. Over the OMP sessions, the Cisco SD-WAN Controllers advertise routes, TLOCs, services, policies, and encryption keys. It is this exchange of information that allows the Cisco SD-WAN Controllers to remain synchronized.

You can place Cisco SD-WAN Controllers anywhere in the network. For availability, it is highly recommended that the Cisco SD-WAN Controllers be geographically dispersed.

Each Cisco SD-WAN Controller establishes a permanent DTLS connection to each of the Cisco SD-WAN Validators. These connections allow the Cisco SD-WAN Validators to track which Cisco SD-WAN Controllers are present and operational. So, if one of the Cisco SD-WAN Controller fails, the Cisco SD-WAN Validator does not provide the address of the unavailable Cisco SD-WAN Controller to a router that is just joining the network.

To reiterate, the Cisco Catalyst SD-WAN overlay network works properly only when the control policies on all Cisco SD-WAN Controllers are identical. Even the slightest difference in the policies result in issues with the functioning of the network.

Recovering from a Cisco Catalyst SD-WAN Controller Failure

The Cisco SD-WAN Controllers are the primary controllers of the network. To maintain this control, they maintain permanent DTLS connections to all the Cisco SD-WAN Validators and Cisco IOS XE Catalyst SD-WAN devices and Cisco vEdge devices. These connections allow the Cisco SD-WAN Controllers to be constantly aware of any changes in the network topology. When a network has multiple Cisco SD-WAN Controllers:

- There is a full mesh of OMP sessions among the Cisco SD-WAN Controllers.
- Each Cisco SD-WAN Controller has a permanent DTLS connection to each Cisco SD-WAN Validator.
- The Cisco SD-WAN Controllers have permanent TLS or DTLS connections to the Cisco IOS XE Catalyst SD-WAN devices and Cisco vEdge devices.

If one of the Cisco SD-WAN Controllers fails, the other Cisco SD-WAN Controllers seamlessly take over handling control of the network. The remaining Cisco SD-WAN Controllers are able to work with Cisco IOS XE Catalyst SD-WAN devices and Cisco vEdge devices joining the network and are able to continue sending route updates to the routers. As long as one Cisco SD-WAN Controller is present and operating in the domain, the Cisco Catalyst SD-WAN network may continue operating without interruption.

Cisco IOS XE Catalyst SD-WAN Device Redundancy

The Cisco IOS XE Catalyst SD-WAN device is commonly used in two ways in the Cisco Catalyst SD-WAN network: to be the Cisco Catalyst SD-WAN routers at a branch site, and to create a hub site that branch routers connect to.

A branch site can have two or more Cisco IOS XE Catalyst SD-WAN devices for redundancy. Each of the router maintains the following connections:

- A secure control plane connection, via a TLS or DTLS connection, with one or more Cisco SD-WAN Controllers in its domain.
- A secure data plane connection with the other routers.

Because both the routers receive the same routing information from the Cisco SD-WAN Controllers, each one is able to continue to route traffic if one fails, even if they are connected to different transport providers.

When using Cisco IOS XE Catalyst SD-WAN devices and Cisco vEdge devices in a hub site, you can provide redundancy by installing two hub routers. The branch routers need to connect to each of the hub routers by using SD-WAN IPsec data plane tunnels.

You can also have Cisco IOS XE Catalyst SD-WAN device provide redundancy by configuring multiple tunnel interfaces on a single router. Each tunnel interface can go through the same or different firewalls, service providers, and network clouds.

Recovering from a Cisco IOS XE Catalyst SD-WAN Device Failure

The route tables on Cisco IOS XE Catalyst SD-WAN devices and Cisco vEdge devices are populated by OMP routes received from the Cisco SD-WAN Controllers. For a site or branch with redundant routers, the route tables on both routers remain synchronized, so if either of the routers fail, the other one continues to be able to route data traffic to its destination.

High Availability

Table 1: Feature History

Feature name	Release information	Description
Controller Group Redundancy Management	Cisco IOS XE Catalyst SD-WAN Release 17.18.1a Cisco Catalyst SD-WAN Manager Release 20.18.1	Cisco IOS XE Catalyst SD-WAN devices ensure consistent connectivity by connecting to SD-WAN Controllers specified in their Control Group list. They maintain redundancy by switching to alternate SD-WAN Controllers within or across groups if the primary controllers become unavailable.

Configure Affinity Between Cisco Catalyst SD-WAN Controllers and Cisco IOS XE Catalyst SD-WAN Device

One way to manage network scale is to configure affinity between Cisco SD-WAN Controllers and Cisco IOS XE Catalyst SD-WAN devices. To do this, you place each Cisco SD-WAN Controller into a controller group, and then you configure which group or groups a Cisco IOS XE Catalyst SD-WAN device can establish control connections with. The controller groups are what establishes the affinity between Cisco SD-WAN Controllers and Cisco IOS XE Catalyst SD-WAN device.

Configure Controller Group Identifier on Cisco Catalyst SD-WAN Controllers

To participate in affinity, each Cisco SD-WAN Controller must be assigned a controller group identifier:

```
vSmart(config)#system controller-group-id number
```

The identifier number can be from 0 through 100.

For Cisco SD-WAN Controllers in the same data center, they can have the same controller group identifier or different identifiers:

- If the Cisco SD-WAN Controllers have the same controller group identifier, a Cisco IOS XE Catalyst SD-WAN device establishes a control connection to any one of them. If that Cisco SD-WAN Controller becomes unreachable, the router simply establishes a control connection with another one of the controllers in the data center. As an example of how this might work, if one Cisco SD-WAN Controller becomes unavailable during a software upgrade, the Cisco IOS XE Catalyst SD-WAN device immediately establishes control connections and an OMP session with another Cisco SD-WAN Controller, and the router's network operation is not interrupted. This network design provides redundancy among Cisco SD-WAN Controllers in a data center.
- If the Cisco SD-WAN Controllers have different controller group identifiers, a Cisco IOS XE Catalyst SD-WAN device can use one controller as the preferred and the other as backup. As an example of how this might work, if you are upgrading the Cisco SD-WAN Controller software, you can upgrade one controller group at a time. If a problem occurs with the upgrade, a Cisco IOS XE Catalyst SD-WAN device establishes control connections and an OMP session with the Cisco SD-WAN Controllers in the second, backup controller group, and the router's network operation is not interrupted. When the Cisco SD-WAN Controller in the first group again becomes available, the Cisco IOS XE Catalyst SD-WAN device switches its control connections and OMP session back to that controller. This network design, while offering redundancy among the Cisco SD-WAN Controllers in a data center, also provides additional fault isolation.

Configure Affinity on Cisco IOS XE Catalyst SD-WAN Device

For a Cisco IOS XE Catalyst SD-WAN device to participate in affinity, you configure the Cisco SD-WAN Controllers that the router is allowed to establish control connections with. By default, you can establish two OMP sessions and two control connections per TLOC.

Configure Cisco Catalyst SD-WAN Controller Groups

Configuring the Cisco SD-WAN Controllers that the router is allowed to establish control connections is a two-part process:

- At the system level, configure a single list of the controller group identifiers that are present in the overlay network.
- For each tunnel interface, you can choose to restrict which controller group identifiers the tunnel interface can establish control connections with. To do this, configure an exclusion list.

At a system level, configure the identifiers of the Cisco SD-WAN Controller groups:

```
ISR4331(config)#system controller-group-list numbers
```

List the Cisco SD-WAN Controller group identifiers that any of the tunnel interfaces on the Cisco IOS XE Catalyst SD-WAN device might want to establish control connections with. It is recommended that this list contain the identifiers for all the Cisco SD-WAN Controller groups in the overlay network.

If you want a specific tunnel interface to establish control connections to only a subset of all the Cisco SD-WAN Controller groups, configure the group identifiers to exclude:

```
ISR4331(config-interface-GigabitEthernets0/0/1)#tunnel-interface exclude-controller-group-list
 numbers
```

```
ISR4331(config-sdwan)# interface GigabitEthernets0/0/1 tunnel-interface
exclude-controller-group-list numbers
```

This command lists the identifiers of the Cisco SD-WAN Controller groups that this particular tunnel interface should not establish control connections with, when a Cisco SD-WAN Controller is available in configured controller groups. Ensure that the controller groups in this list are a subset of the controller groups that are configured with the **system controller-group-list** command.

To display the controller groups configured on a Cisco IOS XE Catalyst SD-WAN device, use the **show sdwan running-config system** command.

Configure Maximum Number of Control Connections

By default, the maximum number of control connections that each tunnel interface can establish is the same as the maximum number of OMP sessions that is configured on the Cisco IOS XE Catalyst SD-WAN device. The default value for Maximum OMP sessions (MOS) is 2.

Configuring the maximum number of control connections for a tunnel interface for a Cisco IOS XE Catalyst SD-WAN device is a two-part process:

- At the system level, configure the MOS that the Cisco IOS XE Catalyst SD-WAN device can establish to Cisco SD-WAN Controllers.
- If a tunnel interface needs to connect to a different number Cisco SD-WAN Controllers than the configured MOS value, configure the maximum number of control connections that the tunnel can establish to Cisco SD-WAN Controllers,

Note If Max Control Connections (MCC) is not configured on a tunnel interface, its default value is the same as the MOS value.

Effectively, the maximum number of control connections a tunnel interface in a Cisco IOS XE Catalyst SD-WAN device can establish is determined by the following formula:

Max Control Connections for tunnel interface in VPN 0 = MIN(MOS, MCC)

To modify the maximum number of OMP sessions, enter the following command:

```
Device (Config)# system max-omp-sessions number
```

A Cisco IOS XE Catalyst SD-WAN device establishes OMP sessions as follows:

- The device, not the individual tunnel interfaces, establishes OMP sessions with Cisco SD-WAN Controllers.
- When different tunnel interfaces on a router connect to the same Cisco SD-WAN Controller, the device creates a single OMP session with the Cisco SD-WAN Controller and the different tunnel interfaces use this single OMP session.

Note When each tunnel interface connects to the same set of Cisco SD-WAN Controllers, a Cisco IOS XE Catalyst SD-WAN device has the total number of OMP sessions equal to the configured maximum number of OMP sessions. However, if each tunnel interface connects to a different Cisco SD-WAN Controller (because of an excluded controller list), the total number of OMP sessions on the device is higher than the configured maximum number of OMP sessions,

Use the following command to modify the maximum number of control connections for a tunnel interface:

```
Device(config)#sdwan interface interface-name tunnel-interface max-control-connections
number
```

The number of control connections can be from 0 through 100. The default value is the maximum number of OMP sessions that is configured with the **system max-omp-sessions** command.

To display the actual number of control connections for each tunnel interface, use the **show sdwan control affinity config** command.

To display a list of the Cisco SD-WAN Controllers that each tunnel interface has established control connections with, use the **show sdwan control affinity status** command.

How Cisco IOS XE Catalyst SD-WAN Device manage controller group connections

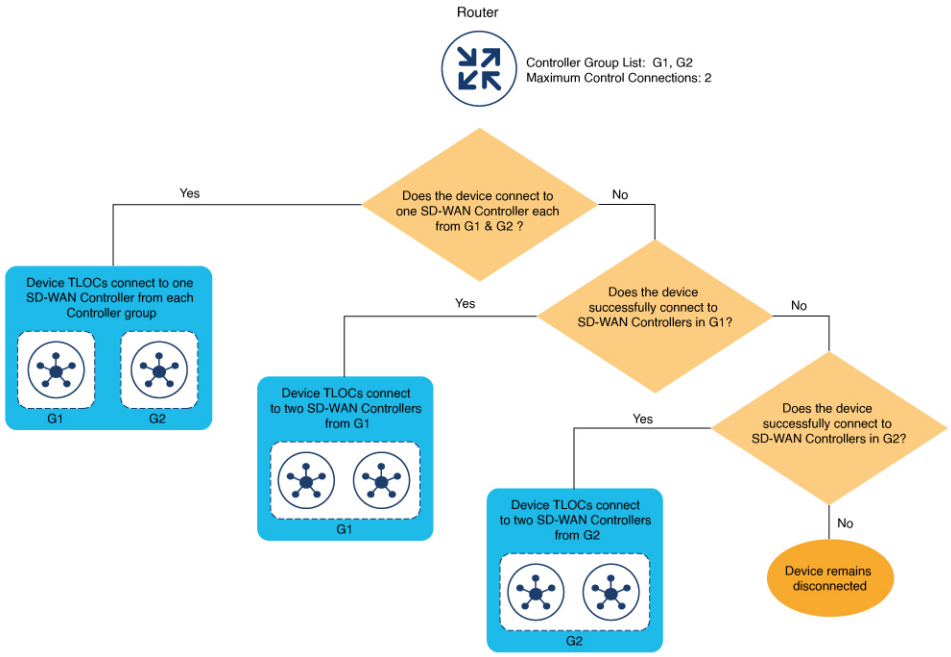
Minimum supported releases: Cisco IOS XE Catalyst SD-WAN Release 17.18.1a and Cisco Catalyst SD-WAN Manager Release 20.18.1

Controller group aware Cisco IOS XE Catalyst SD-WAN devices

Controller group aware Cisco IOS XE Catalyst SD-WAN device is a type of device that connects only to the Cisco SD-WAN controller groups specified in their Control Group List (CGL).

When a Cisco SD-WAN controller or a controller group becomes unavailable, the device attempts to connect to the next available SD-WAN controller or controller group listed in its CGL. If all SD-WAN controllers in the CGL are unavailable, the device remains disconnected until the SD-WAN controllers become available for reconnection.

Figure 1: Example: Controller group aware connection

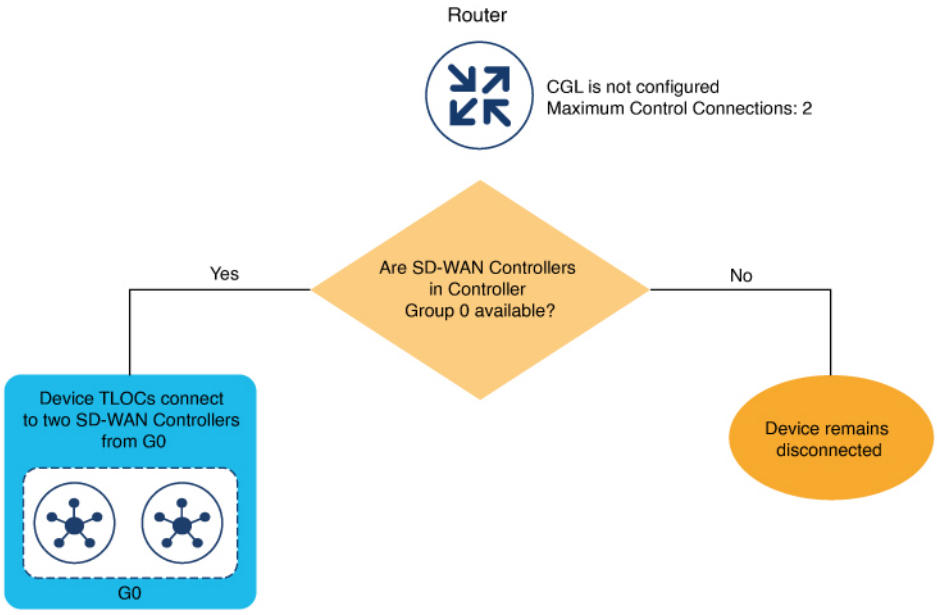


Controller group unware Cisco IOS XE Catalyst SD-WAN devices

A Controller group unaware Cisco IOS XE Catalyst SD-WAN device is a type of device that operates without a configured controller group list.

It connects exclusively to controller groups that are not assigned to any controller group lists. These SD-WAN controllers are categorized under gontroller group 0 and are also referred to as the default group. When the SD-WAN controllers in controller group 0 are unavailable the controller group unaware device remains disconnected until the SD-WAN controllers become available for reconnection.

Figure 2: Example: Controller group unware connection



How controller groups maintain redundancy

Controller groups maintain redundancy by enabling Cisco Catalyst SD-WAN devices to establish connections with SD-WAN Controllers based on the device's maximum controller connections (MCC) value. For instance, if the MCC is set to 2, the device consistently connects with two controllers per TLOC.

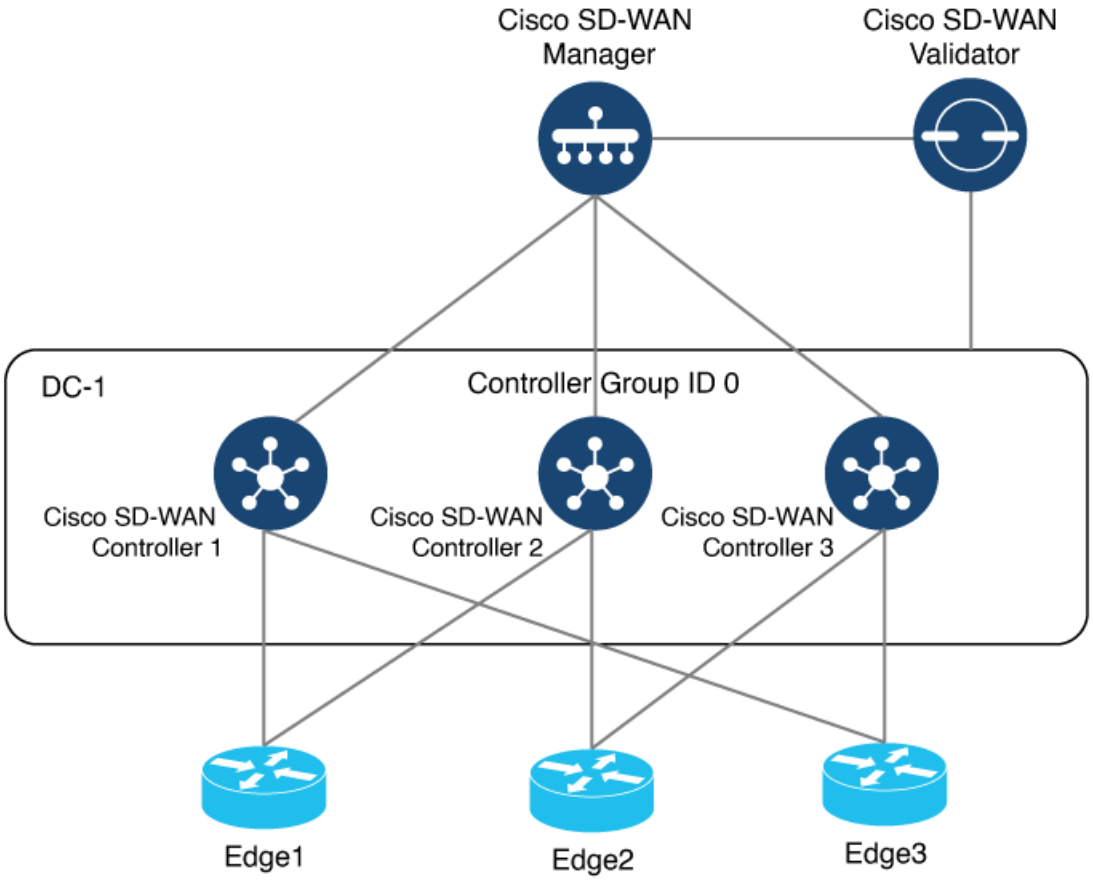
Intra and inter controller group redundancy

When a SD-WAN controller within a configured controller group at a specific location goes down, the device selects another SD-WAN controller from the same controller group and location to maintain redundancy. This process is called intra-controller group redundancy.

If intra controller group redundancy is not possible because the SD-WAN controllers in the same controller group or location are either down or unreachable, the device redirects the connection to a SD-WAN controller from other locations. This is known as inter-controller group redundancy.

Configure Affinity for Cisco Catalyst SD-WAN Controllers on Single Data Center

In a Cisco Catalyst SD-WAN overlay network that has multiple Cisco SD-WAN Controllers, each tunnel interface in a Cisco IOS XE Catalyst SD-WAN device establishes control connections to two Cisco SD-WAN Controllers. This default behavior provides controller redundancy, so there is no need to configure affinity.



In the topology that is shown in the figure above, there are three Cisco SD-WAN Controllers in Data Center DC-1, all of which belong to default controller group 0. A Cisco IOS XE Catalyst SD-WAN device selects two Cisco SD-WAN Controllers, which are identified as its assigned Cisco SD-WAN Controllers. Each tunnel interface of the Cisco IOS XE Catalyst SD-WAN device connects to these assigned Cisco SD-WAN Controllers. When a tunnel interface connects to its assigned Cisco SD-WAN Controllers, that tunnel interface is said to be in *equilibrium*.

Note If exclude-controller-group-list is configured on a tunnel interface, that tunnel interface may have different Cisco SD-WAN Controllers assigned to it.

However, if you want to connect the Cisco IOS XE Catalyst SD-WAN device only to a subset of the Cisco SD-WAN Controllers in a data center, you can use affinity. Place the Cisco SD-WAN Controllers in different controller groups, and then configure the Cisco IOS XE Catalyst SD-WAN device with a list of controller groups that it can connect to. This design provides redundant control connections to the Cisco SD-WAN Controller and provides fault isolation among the Cisco SD-WAN Controller groups in the same data center.

In the topology that is shown in the figure above, assume that you want edge devices to connect to Cisco SD-WAN Controllers as follows:

- Edge1 connects only to Cisco SD-WAN Controller 1 and Cisco SD-WAN Controller 2
- Edge2 connects only to Cisco SD-WAN Controller 2 and Cisco SD-WAN Controller 3

- Edge3 connects only to Cisco SD-WAN Controller 1 and Cisco SD-WAN Controller 3

To achieve these connections, configure Cisco SD-WAN Controller 1 with controller group ID 1:

```
vSmart(config)# system controller-group-id 1
```

To verify the configuration, use the **show running-config** command:

```
vSmart# show running-config system
system
 description         "vSmart in data center 1"
 host-name           vSmart
 gps-location latitude 37.368140
 gps-location longitude -121.913658
 system-ip           172.16.255.19
 site-id             100
 controller-group-id 1
 organization-name   "Cisco"
 clock timezone America/Los_Angeles
```

Use the following commands to configure the other Cisco SD-WAN Controllers:

```
vSmart2(config)# system controller-group-id 2
```

```
vSmart3(config)# system controller-group-id 3
```

In this example, each Cisco SD-WAN Controller in the data center is added to its own controller group. Alternatively, you can add multiple Cisco SD-WAN Controllers to the same controller group.

Note When Cisco SD-WAN Controllers are assigned to controller groups, we recommend that you assign controller groups for all Cisco SD-WAN Controllers in the overlay network.

Next, because you want Edge1 to connect only to Cisco SD-WAN Controller 2 and Cisco SD-WAN Controller 3, configure Edge1 as follows:

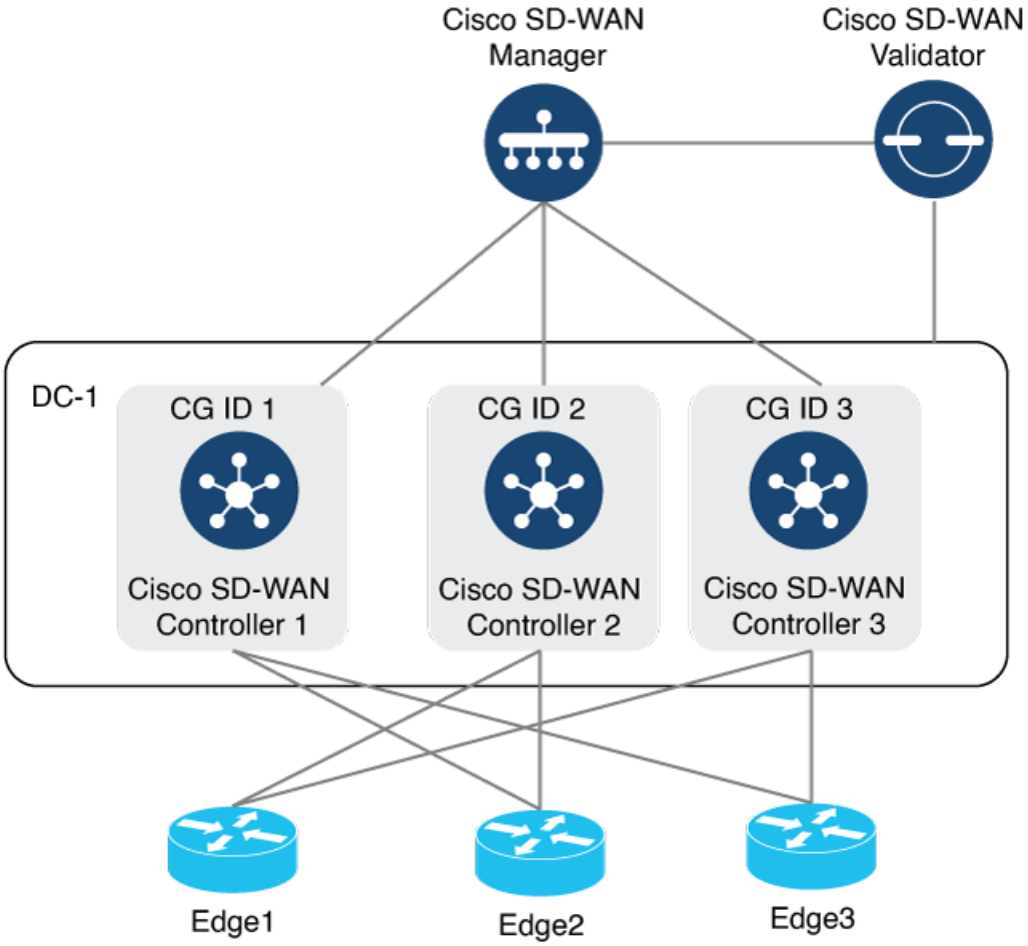
```
Edge1(config)# system controller-group-list 2 3
```

Configure Edge2 to connect only to Cisco SD-WAN Controller 1 and Cisco SD-WAN Controller 2:

```
Edge2(config)# system controller-group-list 1 2
```

Configure Edge3 to connect only to Cisco SD-WAN Controller 1 and Cisco SD-WAN Controller 3:

```
Edge3(config)# system controller-group-list 1 3
```



To display the control connections with the Cisco SD-WAN Controllers, use the **show [sdwan] control connections** command. The last column on the output, **Controller Group ID**, lists the Cisco SD-WAN Controller group that a router is in.

```
Edge1# show sdwan control connections

                                                  PEER                PEER                                                                CONTROLLER

PEER    PEER PEER            SITE    DOMAIN PEER           PRIV  PEER           PUB                                                          GROUP
TYPE    PROT SYSTEM IP       ID      ID     PRIVATE IP     PORT  PUBLIC IP      PORT  ORGANIZATION    LOCAL COLOR     PROXY STATE UPTIME      ID
-------------------------------------------------------------------------------------------------------------------------------------------
vsmart  tls  172.16.255.27   200     1      10.0.12.27     23456 10.0.12.27     23456 Cisco           default         No    up     0:00:18:34 3
vsmart  tls  172.16.255.20   200     1      10.0.12.20     23456 10.0.12.20     23456 Cisco           default         No    up     0:00:18:33 2
vmanage tls  172.16.255.22   200     0      10.0.12.22     23656 10.0.12.22     23656 Cisco           default         No    up     0:00:18:34 0
```

To display the maximum number of control connections allowed on the router, use the **show sdwan control local-properties** command. The last line of the output lists the maximum controllers. The following is the abbreviated output for this command:

```
Edge1# show sdwan control local-properties
personality                     vedge
sp-organization-name            Cisco
organization-name               Cisco
root-ca-chain-status            Installed
root-ca-crl-status              Not-Installed

certificate-status              Installed
certificate-validity            Valid
...
```

```
                  PUBLIC      PUBLIC PRIVATE     PRIVATE  PRIVATE                    MAX   RESTRICT/           LAST         SPI TIME    NAT  VM
INTERFACE         IPv4        PORT   IPv4        IPv6     PORT    VS/VM COLOR   STATE CNTRL CONTROL/     LR/LB  CONNECTION   REMAINING   TYPE CON
 REG
                                                                                        STUN                                              PRF
 IDs
-------------------------------------------------------------------------------------------------------------------------------------------------

GigabitEthernet1  10.1.15.15  12386  10.1.15.15  ::       12386    2/1  default up     2      no/yes/no   No/No  0:00:47:59   0:11:11:43  N    5
 Default
```

These two commands display information about the control connections established by the affinity configuration. To see, for each interface, which controller groups are configured and which Cisco SD-WAN Controller the interface is connected to, use the **show sdwan control affinity config** command:

```
Edge1# show sdwan control affinity config

EFFECTIVE CONTROLLER LIST FORMAT - G(C),...     - Where G is the Controller Group ID
                                                        C is the Required vSmart Count

CURRENT CONTROLLER LIST FORMAT   - G(c)s,...    - Where G is the Controller Group ID
                                                        c is the current vSmart count
                                                        s Status Y when matches, N when
does not match


                      EFFECTIVE
                      REQUIRED
       LAST-RESORT
INDEX INTERFACE       VS COUNT  EFFECTIVE CONTROLLER LIST  CURRENT CONTROLLER LIST
EQUILIBRIUM  INTERFACE
-------------------------------------------------------------------------------------------------------------

0     GigabitEthernet1  2         2(1),3(1)                2(1)Y,3(1)Y              Yes
        No
```

The command output above shows that affinity is configured on interface GigabitEthernet1:

Table 2:

Field	Description
Effective Required VS Count	Shows that the interface is configured to create two control connections, and two control connections have been established.
Effective Controller List	Shows that affinity on the interface is configured to use one Cisco SD-WAN Controller from Controller Group 1, shown as 1(1), and one Cisco SD-WAN Controller from Controller Group 2, shown as 2(1). You configure the affinity controller identifiers with the **controller-group-list** command (at the **system** level) and, for the tunnel interface, the **exclude-controller-group-list** command.
Current Controller List	Lists the actual affinity configuration for the interface. The output here shows that the interface has two control connections with Cisco SD-WAN Controller in group 1 and another control connection. The “Y” indicates that the current and effective controller lists match each other.

Field	Description
Equilibrium	Indicates that the current controller lists match what is expected from the affinity configuration for that tunnel interface.

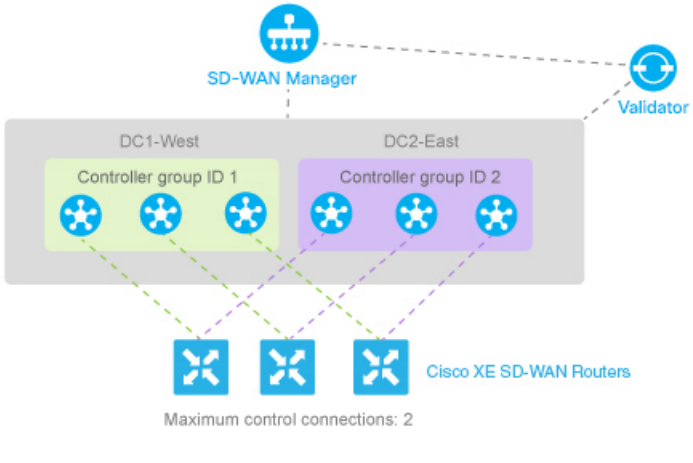
To determine the exact Cisco Catalyst SD-WAN Controllers with which the tunnel interface has established control connections, use the **show control affinity status** command:

```
Edge1# show sdwan control affinity status

ASSIGNED CONNECTED CONTROLLERS   - System IP( G),..  - System IP of the assigned vSmart
                                                     G is the group ID to which the vSmart
 belongs to
UNASSIGNED CONNECTED CONTROLLERS - System IP( G),..  - System IP of the unassigned vSmart
                                                     G is the group ID to which the vSmart
 belongs to


INDEX INTERFACE     ASSIGNED CONNECTED CONTROLLERS        UNASSIGNED CONNECTED CONTROLLERS

-------------------------------------------------------------------------------------------------

0     GigabitEthernet1     172.16.255.20(2),172.16.255.27(3)
```

The command output above shows that interface **GigabitEthernet1** has control connections to two Cisco SD-WAN Controllers, 172.16.255.20, which is in group 1, and 172.16.255.27, which is in group 2. These Cisco SD-WAN Controllers are assigned for this device as indicated by the **Assigned Connected Controller** column. If the interface were connected to a Cisco SD-WAN Controller other than these two, it would be listed in the **Unassigned Connected Controllers** column and the tunnel interface would not be in equilibrium.

Configure Affinity for Cisco Catalyst SD-WAN Controllers on Two Data Centers

You can use affinity to enable redundancy among data centers, for a network design in which multiple Cisco SD-WAN Controllers are spread across two or more data centers. Then, if the link between a Cisco IOS XE Catalyst SD-WAN device and one of the data centers goes down, the Cisco SD-WAN Controllers in the second data center are available to continue servicing the overlay network. The figure below illustrates this scenario, showing three Cisco SD-WAN Controllers in each of two data centers. Each of the three Cisco IOS XE Catalyst SD-WAN devices establishes a control connection to one controller in the West data center and one in the East data center.



You configure the three Cisco SD-WAN Controllers in DC1-West with controller group identifier 1:

```
vSmart-DC1(config)# system controller-group-id 1
```

The three Cisco SD-WAN Controllers in DC2-East are in controller group 2:

```
vSmart-DC2(config)# system controller-group-id 2
```

We want all the Cisco IOS XE Catalyst SD-WAN devices to have a maximum of two OMP sessions, and we want each tunnel interface to have a maximum of two control connections and to not exclude any controller groups. So the only configuration that needs to be done on the routers is to set the controller group list. We want Cisco IOS XE Catalyst SD-WAN devices in the west to prefer Cisco Catalyst SD-WAN Controllers in DC1-West over DC2-East:

```
ISR4331-West(config)#  system controller-group-list 1 2
```

Similarly, we want Cisco IOS XE Catalyst SD-WAN devices in the East to prefer DC2-East:

```
ISR4331-East(config)# system controller-group-list 2 1
```

The software evaluates the controller group list in order, so with this configuration, the Cisco IOS XE Catalyst SD-WAN devices-West prefer Cisco SD-WAN Controller group 1 (which is the West data center), and the Cisco IOS XE Catalyst SD-WAN devices - East prefer Cisco SD-WAN Controller group 2.

When a Cisco IOS XE Catalyst SD-WAN devices-West router needs to connect to only one Cisco SD-WAN Controller (based on configuration), it connects only to the West data center. If the router needs to connect to two Cisco SD-WAN Controllers, it connects to one Cisco SD-WAN Controller from the West data center and another Cisco SD-WAN Controller from the East data center.

You can fine-tune the controller group preference in other ways:

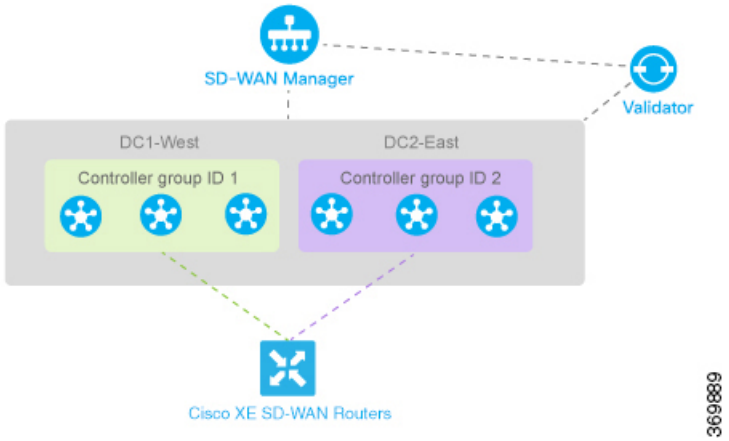
- Set the maximum number of OMP sessions allowed on the router to 1 (**system max-omp-sessions 1**). To illustrate how this works, let's look at a Cisco IOS XE Catalyst SD-WAN devices - West. The router has only one tunnel interface, and that interface creates one control connection to Cisco SD-WAN Controller list 1. If all the Cisco SD-WAN Controllers in this group become unavailable, or if the connection between the router that the DC1-West data center goes down, the tunnel interface establishes one control connection to Cisco SD-WAN Controller list 2, because this group is listed in the **system controller-group-list** command.
- Set the maximum number of control connections that the tunnel interface can establish to 1 (**sdwan interface** *interface-name* **tunnel-interface max-control-connections 1**). Because the software evaluates the controller group list in order, for a Cisco IOS XE Catalyst SD-WAN devices - West, this configuration

forces the tunnel interface to establish a control connection to Cisco SD-WAN Controller group 1. Again, if this controller group or data center becomes unreachable, the tunnel establishes a control connection with controller group 2, because this group is configured in the **system controller-group-list** command.

- Exclude the non-preferred Cisco SD-WAN Controller group for a particular tunnel. For example, for a Cisco IOS XE Catalyst SD-WAN devices -West to prefer controller group 1, you configure **sdwan interface** *interface-name* **tunnel-interface exclude-controller-group-list 2**. As with the above configurations, if this controller group or West data center becomes unreachable, the tunnel establishes a control connection with controller group 2, because this group is configured in the **system controller-group-list** command.

Configure Redundant Control Connections on Single Device

When a Cisco IOS XE Catalyst SD-WAN device has two tunnel connections and the network has two (or more) data centers, you can configure redundant control connections from the Cisco IOS XE Catalyst SD-WAN device to Cisco SD-WAN Controllers in two of the data centers. It is recommended that do this using the minimum number of OMP sessions—in this case, two. To do this, you configure one of the tunnel interfaces to go only to one of the data centers and the other to go only to the second. This configuration provides Cisco SD-WAN Controller redundancy with the minimum number of OMP sessions.



On the Cisco IOS XE Catalyst SD-WAN device router, define the controller group list and configure the maximum number of OMP sessions to be 2:

```
ISR4331(config)# system controller-group-list 1 2
ISR4331(config)#  system max-omp-sessions 2
```

For one of the tunnels, you can use the default affinity configuration (that is, there is nothing to configure) to have this tunnel prefer a Cisco Catalyst SD-WAN Controller in group 1. You can also explicitly force this tunnel to prefer Cisco Catalyst SD-WAN Controller group 1:

```
ISR4331(config-tunnel-interface-1)# max-control-connections 1
```

You do not need to configure **exclude-controller-group-list 2** , because the software evaluates the controller group list in order, starting with group 1. However, you could choose to explicitly exclude Cisco SD-WAN Controller group 2.

Then, on the second tunnel, configure it to prefer a Cisco SD-WAN Controller in group 2. As with the other tunnel, you limit the maximum number of control connections to 1. In addition, you have to exclude controller group 1 for this tunnel.

```
ISR4331(config-tunnel-interface-2)# max-control-connections 1
ISR4331(config-tunnel-interface-2)# exclude-controller-group-list 1
```

Configure Control Plane and Data Plane High Availability Parameters

This topic discusses the configurable high availability parameters for the control plane and the data plane.

Control Plane High Availability

A highly available Cisco Catalyst SD-WAN network contains two or more Cisco SD-WAN Controllers in each domain. A Cisco Catalyst SD-WAN domain can have up to 12 Cisco SD-WAN Controllers, and each Cisco IOS XE Catalyst SD-WAN device, by default, connects to two of them. You change this value on a per-tunnel basis:

```
ISR4331(config)# sdwan interface interface-name tunnel-interface max-control-connections
  number
```

Regardless of the number of Cisco SD-WAN Controller in the domain, the Cisco IOS XE Catalyst SD-WAN device connects to the maximum number of controllers based on MCC/MOS configuration (if there are enough controllers). The Cisco IOS XE Catalyst SD-WAN device connects to the same controllers across all TLOCs.

Note To maximize the efficiency of the load-balancing among Cisco SD-WAN Controllers, use sequential numbers when assigning system IP addresses to the Cisco IOS XE Catalyst SD-WAN devices in the domain. One example of a sequential numbering schemes is 172.1.1.1, 172.1.1.2, 172.1.1.3, and so forth. Another is 172.1.1.1, 172.1.2.1, 172.1.3.1, and so forth.

Data Plane High Availability

BFD, which detects link failures as part of the Cisco Catalyst SD-WAN high availability solution, is enabled by default on all Cisco devices. BFD runs automatically on all IPsec data tunnels between Cisco IOS XE Catalyst SD-WAN devices. It does not run on the control plane (DTLS or TLS) tunnels that Cisco SD-WAN Controllers establish with all Cisco devices in the network.

You can modify the BFD Hello packet interval and the number of missed Hello packets (the BFD interval multiplier) before BFD declares that a link has failed.

Change the BFD Hello Packet Interval

BFD sends Hello packets periodically to detect faults on the IPsec data tunnel between two Cisco IOS XE Catalyst SD-WAN devices. By default, BFD sends these packets every 1000 milliseconds (that is, once per second). To change this interval on one or more traffic flow, use the **hello-interval** command:

```
ISR4331(config)#bfd color color hello-interval milliseconds
```

The interval can be a value from 100 to 300000 milliseconds (5 minutes).

Configure the interval for each tunnel connection, which is identified by a color. The color can be **3g**, **biz-internet**, **blue**, **bronze**, **custom1**, **custom2**, **custom3**, **default**, **gold**, **green**, **lte**, **metro-ethernet**, **mpls**, **private1**, **private2**, **public-internet**, **red**, or **silver**.

Change the BFD Packet Interval Multiplier

After BFD has not received a certain number of Hello packets on a link, it declares that the link has failed. This number of packets is a multiplier of the Hello packet interval time. By default, the multiplier is 7 for hardware routers and 20 for Cloud software routers. This means that if BFD has not received a Hello packet after 7 seconds, it considers that the link has failed and implements its redundancy plan.

To change the BFD packet interval multiplier, use the **multiplier** command:

```
ISR4331(config)#bfd color color multiplier integer
```

Multiplier range: 1 to 60 (integer)

You configure the multiplier for each tunnel connection, which is represented by a color.

Control PMTU Discovery

On each transport connection (that is, for each TLOC, or color), the Cisco Catalyst SD-WAN BFD software performs path MTU (PMTU) discovery, which automatically negotiates the MTU size in an effort to minimize or eliminate packet fragmentation on the connection. BFD PMTU discovery is enabled by default, and it is recommended that you use BFD PMTU discovery and not disable it. To explicitly enable it:

```
ISR4331(config)#bfd color color pmtu-discovery
```

With PMTU discovery enabled, the path MTU for the tunnel connection is checked periodically, about once per minute, and it is updated dynamically. With PMTU discovery enabled, 16 bytes might be required by PMTU discovery, so the effective tunnel MTU might be as low as 1452 bytes. From an encapsulation point of view, the default IP MTU for GRE is 1468 bytes, and for IPsec it is 1442 bytes because of the larger overhead. Enabling PMTU discovery adds to the overhead of the BFD packets that are sent between the Cisco IOS XE Catalyst SD-WAN devices, but does not add any overhead to normal data traffic.

If PMTU discovery is disabled, the expected tunnel MTU is 1472 bytes (tunnel MTU of 1500 bytes less 4 bytes for the GRE header, 20 bytes for the outer IP header, and 4 bytes for the MPLS header). However, the effective tunnel MTU might be 1468 bytes, because the software might sometimes erroneously add 4 bytes to the header.

Configure High Availability

CLI commands for configuring and monitoring high availability.

High Availability Configuration Commands

Use the following commands to configure high availability on a Cisco IOS XE Catalyst SD-WAN device:

```
bfd
  app-route
    multiplier number
    poll-interval milliseconds
  color color
    hello-interval milliseconds
    multiplier number
    pmtu-discovery
```

High Availability Monitoring Commands

show sdwan bfd sessions—Display information about the BFD sessions running on the local Cisco IOS XE Catalyst SD-WAN device.

Best Practices for Configuring Affinity

- In the **system controller-group-list** command on the Cisco IOS XE Catalyst SD-WAN device, list all the controller groups that are available in the overlay network. Doing so ensures that all the Cisco SD-WAN Controllers in the overlay network are available for the affinity configuration, and provides additional redundancy if connectivity to the preferred group or groups is lost. You can manipulate the number of control connections and their priority with the maximum number of OMP sessions for the router, the maximum number of control connections for the tunnel, and the controller groups that the tunnel should not use as the preferred group (**exclude-controller-group-list** command).

  Listing all controller groups in the **system controller-group-list** command provides an additional layer of redundancy in situations where the Cisco IOS XE Catalyst SD-WAN device site is experiencing connectivity problems with the Cisco SD-WAN Controllers in the controller group list.

  To illustrate, consider a network with three controller groups (1, 2, and 3), and in which the controller group list on a Cisco IOS XE Catalyst SD-WAN device includes only groups 1 and 2 as preferred groups. In this scenario, if the router learns from the Cisco SD-WAN Validator that the Cisco SD-WAN Controllers in groups 1 and 2 are operational, but the router is unable to establish a connection to either device, it loses connectivity to the overlay network. However, if the controller group list contains all three controller groups and group 3 is set up as a less preferred (excluded) group, the router still normally prefers groups 1 and 2, but would fall back and connect to the controllers in group 3 if it cannot connect to group 1 or group 2.

- The controller groups listed in the **exclude-controller-group-list** command must be a subset of the controller groups configured for the entire router, in the **system controller-group-list** command.

- When a data center has multiple Cisco SD-WAN Controllers that use the same controller group identifier, and when the overlay network has two or more data centers, it is recommended that the number of Cisco SD-WAN Controllers in each of the controller groups be the same. For example, if Data Center 1 has three Cisco SD-WAN Controllers, all with the same group identifier (let's say, 1), Data Center 2 should also have three Cisco SD-WAN Controllers, all with the same group identifier (let's say, 2), and any additional data centers should also have three Cisco SD-WAN Controllers.

- When a data center has Cisco SD-WAN Controllers in the same controller group, the hardware capabilities—specifically, the memory and CPU—on all the Cisco SD-WAN Controllers should be identical. More broadly, all the Cisco SD-WAN Controllers in the overlay network, whether in one data center or in many, should have the same hardware capabilities. Each Cisco SD-WAN Controller should have equal capacity and capability to handle a control connection from any of the Cisco IOS XE Catalyst SD-WAN devices in the network.

- When a router has two tunnel connections and the network has two (or more) data centers, it we recommend that you configure one of the tunnel interfaces to go to one of the data centers and the other to go to the second. This configuration provides Cisco SD-WAN Controller redundancy with the minimum number of OMP sessions.

- Whenever possible in your network design, you should leverage affinity configurations to create fault-isolation domains.

- After affinity reconfiguration, controllers which were previously overloaded may continue to experience persistently high memory utilization that does not decrease. It is recommended to reboot such overloaded controllers, one at a time, to recover from memory overload. The rebalancing requires a reload of the Cisco SD-WAN Controller node.