Configure IP-in-IP tunnels

This chapter provides conceptual and configuration information for IP-in-IP tunnels.

Table 1: Feature History

Release 7.0.11	This feature was introduced.
Release 7.0.14	Support for the following feature was introduced in Configure Tunnels: • Extended ACL must match on the outer header for IP-in-IP Decapsulation.

Tunneling provides a mechanism to transport packets of one protocol within another protocol. IP-in-IP tunneling refers to the encapsulation and decapsulation of an IP packet as a payload in another IP packet. Cisco 8000 Series Routers support IP-in-IP decapsulation with all possible combinations of IPv4 and IPv6 that include

- IPv4 over IPv4
- IPv6 over IPv4
- IPv4 over IPv6, and
- IPv6 over IPv6

For example, an IPv4 over IPv6 refers to an IPv4 packet as a payload encapsulated within an IPv6 packet and routed across an IPv6 network to reach the destination IPv4 network, where it is decapsulated.

Table 2: Feature History Table

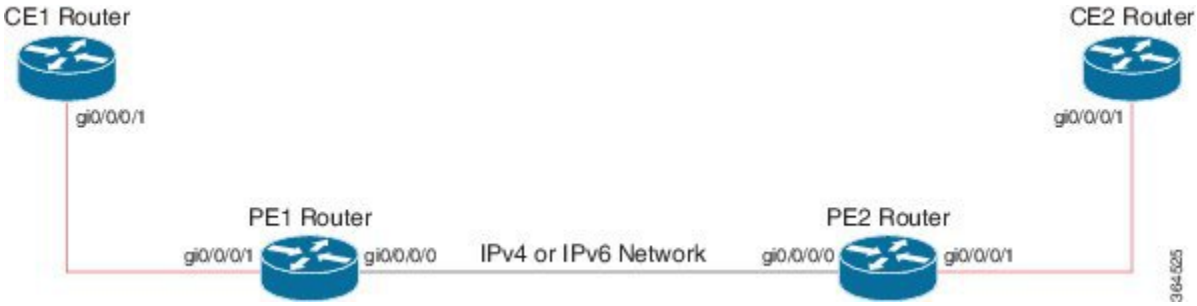
Feature Name	Release Information	Feature Description
Increased IP-in-IP tunnel scale for gRIBI-based nexthops	Release 25.4.1	Introduced in this release on: Fixed Systems (8200 [ASIC: Q200]); Centralized Systems (8600 [ASIC:Q200]) ; Modular Systems (8800 [LC ASIC: Q200]) This feature enables the router to efficiently load balance and manage high traffic volumes by increasing the scale for encapsulation and decapsulation nexthops programmed using gRPC Routing Information Base Interface (gRIBI) to 12K IP-in-IP tunnels. This feature introduces these changes: CLI: The **hw-module profile cef iptunnel scale** command is modified.
Increase in IP-in-IP decapsulation tunnels support	Release 25.3.1	Introduced in this release on: Fixed Systems (8200 [ASIC: Q200]; Centralized Systems (8600 [ASIC:Q200]); Modular Systems (8800 [LC ASIC: Q200]) With this release, we have revised the maximum number of IPv4 and IPv6 IP-in-IP decapsulation tunnels from 64 to 200 on Cisco Silicon One Q200 ASIC-based systems. An increased number enhances the router's ability to support larger and more complex IP-in-IP tunneling scenarios improving scalability, efficiency, and flexibility in network design.
IPv4 packets with IPv6 outer header	Release 25.4.1	Introduced in this release on: Fixed Systems (8700 [ASIC: K100])(select variants only*) *This feature is now supported on Cisco 8711-48Z-M routers
IPv4 packets with IPv6 outer header	Release 25.1.1	Introduced in this release on: Fixed Systems (8010 [ASIC: A100])(select variants only*) *This feature is supported on Cisco 8011-4G24Y4H-I routers.

Feature Name	Release Information	Feature Description
IPv4 packets with IPv6 outer header	Release 24.4.1	Introduced in this release on: Fixed Systems(8200, 8700)(select variants only*); Modular Systems (8800 [LC ASIC: P100])(select variants only*). This feature that allows decapsulation of IPv4 and IPv6 tunnels with IPv6 headers helps the administrators to benefit from an improved IPv6 routing and security without upgrading their entire network to IPv6. *This feature is now supported on: • 8212-48FH-M • 8711-32FH-M • 8712-MOD-M • 88-LC1-12TH24FH-E • 88-LC1-52Y8H-EM • 88-LC1-36EH
IPv4 packets with IPv6 outer header	Release 7.5.3	With this release, decapsulation of IPv4 and IPv6 tunnels with IPv6 outer headers are supported. This feature helps the administrators to take advantage of the benefits of IPv6, such as improved routing and security, without having to upgrade their entire network to IPv6.

IP-in-IP tunneling can be used to connect remote networks securely or provide virtual private network (VPN) services.

This simplified network topology provides the transport VRF as the default VRF for an IPv4 or IPv6 network.

Figure 1: IP-in-IP tunnel network topology



A maximum of 3500 IP-in-IP tunnels are supported until Cisco IOS XR Release 25.4.1.

Increased IP-in-IP tunnel scale for gRIBI-based nexthops

From Cisco IOS XR Release 25.4.1, you can use the **hw-module profile cef iptunnel scale** command to configure up to 12,000 IP-in-IP tunnels that are shared between the gRIBI-based encapsulation and decapsulation next-hop tunnels. Prior to Cisco IOS XR Release 25.4.1, the router supported up to 3500 IP-in-IP tunnels.

This feature ensures efficient load balancing and high-volume traffic management.

Restrictions for IP-in-IP tunnel configuration

- The feature does not support decapsulation tunnels on subinterfaces.
- Only the default Virtual Routing and Forwarding (VRF) instance is supported.
- IPv6 link local addresses are not supported.
- Regular tunnels cannot use a configured IP address as the tunnel source; only a non-existent IP address can be used.
- Configuring multiple interfaces with the same IP address is not supported.
- Each line card can have different number of Network Processor (NP) slices.
- The maximum IPv4 and IPv6 IP-in-IP decapsulation tunnels supported is 64 per slice.
- From Release 25.3.1 onwards, the maximum IPv4 and IPv6 IP-in-IP decapsulation tunnels supported is 200 per slice.

Configuration example for IPv4 tunnel

This example provides the configuration for IPv4 tunnel.

Table 3: PE1 and PE2 Router configuration

PE1 Router configuration	PE2 Router configuration
interface GigabitEthernet0/0/0/0 !! Link between PE1-PE2 ipv4 address 100.1.1.1/24 ! interface GigabitEthernet0/0/0/1 !! Link between CE1-PE1 ipv4 address 20.1.1.1/24 ipv6 address 20::1/64 ! interface tunnel-ip 1 ipv4 address 10.1.1.1/24 ipv6 address 10::1/64 tunnel mode ipv4 tunnel source GigabitEthernet0/0/0/0 tunnel destination 100.1.1.2 ! router static address-family ipv4 unicast 30.1.1.0/24 tunnel-ip1 address-family ipv6 unicast 30::0/64 tunnel-ip1 ! ! !	interface GigabitEthernet0/0/0/0 !! Link between PE1-PE2 ipv4 address 100.1.1.2/24 ! interface GigabitEthernet0/0/0/1 !! Link between PE2-CE2 ipv4 address 30.1.1.1/24 ipv6 address 30::1/64 ! interface tunnel-ip 1 ipv4 address 10.1.1.2/24 ipv6 address 10::2/64 tunnel mode ipv4 tunnel source GigabitEthernet0/0/0/0 tunnel destination 100.1.1.1 ! router static address-family ipv4 unicast 20.1.1.0/24 tunnel-ip1 address-family ipv6 unicast 20::0/64 tunnel-ip1 ! ! !

Table 4: CE1 and CE2 Router configuration

CE1 Router configuration	CE2 Router configuration
interface GigabitEthernet0/0/0/1 !! Link between CE1-PE1 ipv4 address 20.1.1.2 255.255.255.0 ipv6 address 20::2/64 ! router static address-family ipv4 unicast 30.1.1.0/24 20.1.1.1 address-family ipv6 unicast 30::0/64 20::1 ! !	interface GigabitEthernet0/0/0/1 !! Link between CE2-PE2 ipv4 address 30.1.1.2 255.255.255.0 ipv6 address 30::2/64 ! router static address-family ipv4 unicast 20.1.1.0/24 30.1.1.1 address-family ipv6 unicast 20::0/64 30::1 ! !

Configuration example for IPv6 tunnel

This example provides the configuration for IPv6 tunnel.

Table 5: PE1 and PE2 Router configuration

PE1 Router configuration	PE2 Router configuration
interface GigabitEthernet0/0/0/0 !! Link between PE1-PE2 ipv6 address 100::1/64 ! interface GigabitEthernet0/0/0/1 !! Link between CE1-PE1 vrf RED ipv4 address 20.1.1.1/24 ipv6 address 20::1/64 ! interface tunnel-ip 1 vrf RED ipv4 address 10.1.1.1/24 ipv6 address 10::1/64 tunnel mode ipv6 tunnel source GigabitEthernet0/0/0/0 tunnel destination 100::2 ! vrf RED address-family ipv6 unicast import route-target 2:1 ! export route-target 2:1 ! address-family ipv4 unicast import route-target 2:1 ! export route-target 2:1 ! router static vrf RED address-family ipv4 unicast 30.1.1.0/24 tunnel-ip1 address-family ipv6 unicast 30::0/64 tunnel-ip1 ! ! !	interface GigabitEthernet0/0/0/0 !! Link between PE1-PE2 ipv6 address 100::2/64 ! interface GigabitEthernet0/0/0/1 !! Link between PE2-CE2 vrf RED ipv4 address 30.1.1.1/24 ipv6 address 30::1/64 ! interface tunnel-ip 1 vrf RED ipv4 address 10.1.1.2/24 ipv6 address 10::2/64 tunnel mode ipv6 tunnel source GigabitEthernet0/0/0/0 tunnel destination 100::1 ! vrf RED address-family ipv6 unicast import route-target 2:1 ! export route-target 2:1 ! address-family ipv4 unicast import route-target 2:1 ! export route-target 2:1 ! router static vrf RED address-family ipv4 unicast 20.1.1.0/24 tunnel-ip1 address-family ipv6 unicast 20::0/64 tunnel-ip1 ! ! !

Table 6: CE1 and CE2 Router configuration

CE1 Router configuration	CE2 Router configuration

interface GigabitEthernet0/0/0/1
!! Link between CE1-PE1
 ipv4 address 20.1.1.2 255.255.255.0
 ipv6 address 20::2/64
!
router static
 address-family ipv4 unicast
  30.1.1.0/24 20.1.1.1
 address-family ipv6 unicast
  30::0/64 20::1
 !
!
	interface GigabitEthernet0/0/0/1
	!! Link between CE2-PE2
	 ipv4 address 30.1.1.2 255.255.255.0
	 ipv6 address 30::2/64
	!
	router static
	 address-family ipv4 unicast
	  20.1.1.0/24 30.1.1.1
	address-family ipv6 unicast
	  20::0/64 30::1
	 !
	!

Configure improved scale for IP-in-IP tunnels

Procedure

Step 1 Enter the **hw-module profile cef iptunnel scale** command to configure the maximum IP-in-IP tunnel scale to 12K for gRIBI-based encapsulation and decapsulation nexthops.

Example:

```
Router# configure
Router(config)# hw-module profile cef iptunnel scale
Router(config)# commit
Router(config)# exit
```

Step 2 Reload the line cards with the **reload location all** command to enable increased IP-in-IP scale limit.

```
Router# reload location all
```

Step 3 Execute the **show hw-module profile cef** command to view the configuration status of CEF hardware-modules.

```
Router# show hw-module profile cef

Fri Aug 22 13:23:17.796 UTC
-----------------------------------------------------------------
Knob                          Status          Applied   Action
-----------------------------------------------------------------
CBF Enable                    Unconfigured    N/A       None
CBF forward-class-list        Unconfigured    N/A       None
BGPLU                         Unconfigured    N/A       None
LPTS ACL                      Unconfigured    N/A       None
Dark Bandwidth                Unconfigured    N/A       None
SR-OPT                        Unconfigured    N/A       None
IP Redirect Punt              Unconfigured    N/A       None
IPv6 Hop-limit Punt           Unconfigured    N/A       None
MPLS Per Path Stats           Unconfigured    N/A       None
SRv6 Per Path Stats           Unconfigured    N/A       None
Tunnel TTL Decrement          Unconfigured    N/A       None
High-Scale No-LDP-Over-TE     Unconfigured    N/A       None
Label over TE counters        Unconfigured    N/A       None
```

```
Highscale LDPoTE No SRoTE     Unconfigured    N/A       None
LPTS Pifib Entry Counters     Unconfigured    N/A       None
Unipath surpf                 Unconfigured    N/A       None
Source-based rtbh             Unconfigured    N/A       None
Vxlan ipv6 tunnel scale       Unconfigured    N/A       None
Encap Exact                   Unconfigured    N/A       None
Iptunnel scale                Configured      Yes       None
BGPLU over RSVPTE Enable      Unconfigured    N/A       None
MPLS Decap Stats              Unconfigured    N/A       None
```

Controlling the TTL Value of Inner Payload Header

Cisco 8000 Routers allow you to control the TTL value of inner payload header of IP-in-IP tunnel packets before it gets forwarded to the next-hop router. This feature enables a router to forward custom formed IP-in-IP stacked packets even if the inner packet TTL is 1. Therefore, this feature enables you to measure the link-state and path reachability from end to end in a network.

Note After you enable or disable the decrement of the TTL value of the inner payload header of a packet, you do not need to reload the line card.

Configuration

To disable the decrement of the TTL value of inner payload header of an IP-in-IP packet, use the following steps:

1. Enter the global configuration mode.
2. Disable the decrement of TTL value of inner payload header of an IP-in-IP packet.

Configuration Example

```
/* Enter the Global Configuration mode. */
Router# configure

/* Disable the decrement of TTL value of inner payload header of an IP-in-IP packet. */
Router(config)# hw-module profile cef ttl tunnel-ip decrement disable
Router(config)# commit
```

Note Starting from Release 7.3.3, Cisco IOS XR 8000 router supports a maximum of 16 IP-in-IP decap tunnels with unique source addresses. If 15 unique tunnel sources are configured that is rounded to 95% of the tunnel hardware resource OOR threshold level. As a result, the OOR State displays *Red* in **show controllers npu resources sipidxtbl location all** command output.

Associated Commands

- hw-module profile cef ttl tunnel-ip decrement disable

Time-to-Live uniform mode

Time-to-Live (TTL) uniform mode is a mechanism that:

- ensures consistent TTL management by synchronizing the TTL values between inner and outer packet headers during encapsulation and decapsulation, allowing the receiving device to accurately interpret the packet's remaining lifespan
- allows you to copy the TTL values from inner headers to outer headers during encapsulation (ENCAP) and from outer headers to inner headers during decapsulation (DECAP), and
- ensures consistent TTL management across various network scenarios.

For more information on the various network scenarios, see Use cases for TTL uniform mode on a router, on page 10.

Table 7: Feature History Table

Feature Name	Release Information	Feature Description
Copy TTL value to IP headers	Release 25.1.1	Introduced in this release on: Fixed Systems (8200 [ASIC: Q200]; Centralized Systems (8600 [ASIC:Q200]); Modular Systems (8800 [LC ASIC: Q200]) We've introduced support for Time-to-Live (TTL) uniform mode, which ensures consistent TTL management by synchronizing the TTL values between inner and outer packet headers during encapsulation and decapsulation, allowing the receiving device to accurately interpret the packet's remaining lifespan. TTL uniform mode is enabled only for the **pbr vrf-redirect** mode in IP-in-IP tunnels.

Benefits of TTL uniform mode

Enabling TTL uniform mode offers these advantages:

- **Enhanced packet integrity and lifespan accuracy**: The TTL uniform mode ensures consistent TTL management by allowing the copying of TTL values between inner and outer headers during encapsulation and decapsulation. This consistency helps in accurately interpreting the packet's remaining lifespan at the receiving device.
- **Network diagnostics and troubleshooting**: By controlling and monitoring the TTL values, you can better diagnose and troubleshoot network paths and performance issues.

Configuration guidelines for TTL uniform mode

These configuration guidelines apply to the TTL uniform mode:

- **Hardware and feature prerequisites**: TTL uniform mode is only enabled on the Cisco Silicon One Q200 ASIC-based systems when the **pbr vrf-redirect** mode in the **hw-module profile** command is enabled.
- **Post-configuration requirements**: You must reload the router by using the **reload location all** command for the configuration changes to take effect.

Use cases for TTL uniform mode on a router

This table details the various scenarios of encapsulation and decapsulation, and their corresponding TTL action that the router performs.

Table 8: Use cases for TTL uniform mode on a router

Use case if the TTL uniform mode is..	Then..	Example
encapsulation-only	The router decrements the TTL value and copies the value from the inner header to outer header.	Consider this example for the encapsulation-only use case for a packet: • **Initial state**: TTL value of the packet is 100 • **Decrement**: The router decrements the inner header TTL value by one, making it 99. • **Copy**: The router then copies the inner header TTL value to the outer header TTL value. The outer header TTL value becomes 99. • **Result**: The inner and outer header TTL becomes 99, making it uniform.

Use case if the TTL uniform mode is..	Then..	Example
decapsulation-only	The router decrements the TTL value and copies the value from the outer header to inner header.	Consider this example for the decapsulation-only use case for a packet: • **Initial state**: The outer header TTL value is 77 and the inner header TTL value is 99 • **Decrement**: The router decreases the outer header TTL value by 1, making it 76. • **Copy**: The router then copies the outer header TTL value to the inner header TTL value. • **Removal**: The router removes the outer header TTL value. • **Result**: The final packet TTL value becomes 76.

Use case if the TTL uniform mode is..	Then..	Example
decapsulation and encapsulation	The router copies the TTL value from the outer header and applies it to the new outer header. Decrements the TTL value by 1 and forwards the packet.	Consider this example for the encapsulation and decapsulation use case. Such scenarios apple when packet travels through IP tunnels: • Encapsulation • **Initial state**: TTL value of the packet is 100 • **Decrement**: The router decrements the inner header TTL value by one, making it 99. • **Copy**: The router then copies the inner header TTL value to the outer header TTL value. The outer header TTL value becomes 99. • **Result**: The inner and outer header TTL becomes 99, making it uniform. • Decapsulation • **Initial state**: The outer header TTL value is 77 and the inner header TTL value is 99 • **Decrement**: The router decreases the outer header TTL value by 1, making it 76. • **Copy**: The router then copies the outer header TTL value to the inner header TTL value. • **Removal**: The router removes the outer header TTL value. • **Result**: The final packet TTL value becomes 76.

Use case if the TTL uniform mode is..	Then..	Example
decapsulation and lookup	The router copies the TTL value from the outer header to the inner header. Decrements the TTL value by 1 and forwards the packet.	Consider this example for the decapsulation and lookup use case for a packet: • **Initial state**: The outer header TTL value is 77 and the inner header TTL value is 99. • **Decrement**: The router decreases the outer header TTL value by 1, making it 76. • **Copy**: The router copies the outer header TTL value to the inner header TTL value. • **Removal**: The router removes the outer header TTL value. • **Lookup**: The router then forwards the packet to the next hop.
repair	The router keeps the inner header TTL value unchanged and forwards the packet as usual. The repair use case occurs after the encapsulation-only and decapsulation-encapsulation use cases.	Consider this example for the repair use case for a packet: • **Initial state**: The primary path for a packet on a tunnel is unavailable. • **Initiate recycle**: The router begins the recycling of the packet by re-entering the packet into the ingress pipeline from the egress pipeline. • **Header update**: The router updates the packet by replacing the old outer header with a new outer header.

IP-in-IP Decapsulation

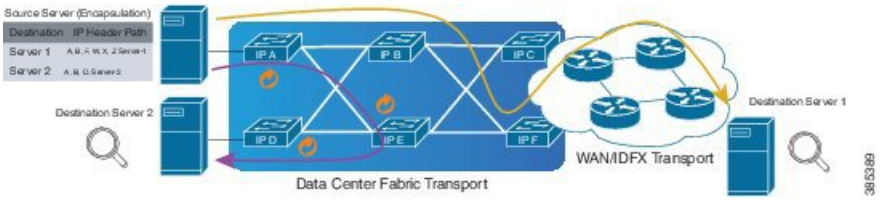
IP-in-IP encapsulation involves the insertion of an outer IP header over the existing IP header. The source and destination address in the outer IP header point to the endpoints of the IP-in-IP tunnel. The stack of IP headers is used to direct the packet over a predetermined path to the destination, provided the network administrator knows the loopback addresses of the routers transporting the packet. This tunneling mechanism can be used for determining availability and latency for most network architectures. It is to be noted that the entire path from source to the destination does not have to be included in the headers, but a segment of the network can be chosen for directing the packets.

In IP-in-IP encapsulation and decapsulation has two types of packets. The original IP packets that are encapsulated are called Inner packets and the IP header stack added while encasulation are called the Outer packets.

Note The router only supports decapsulation and no encapsulation. Encapsulation is done by remote routers.

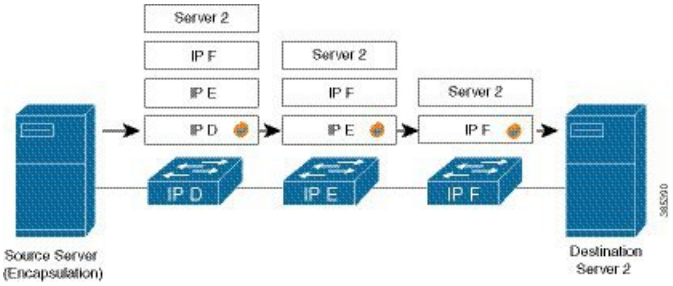
The following topology describes a use case where IP-in-IP encapsulation and decapsulation are used for different segments of the network from source to destination. The IP-in-IP tunnel consists of multiple routers that are used to decapsulate and direct the packet through the data center fabric network.

Figure 2: IP-in-IP Decapsulation Through a Data Center Network



The following illustration shows how the stacked IPv4 headers are decapsulated as they traverse through the decapsulating routers.

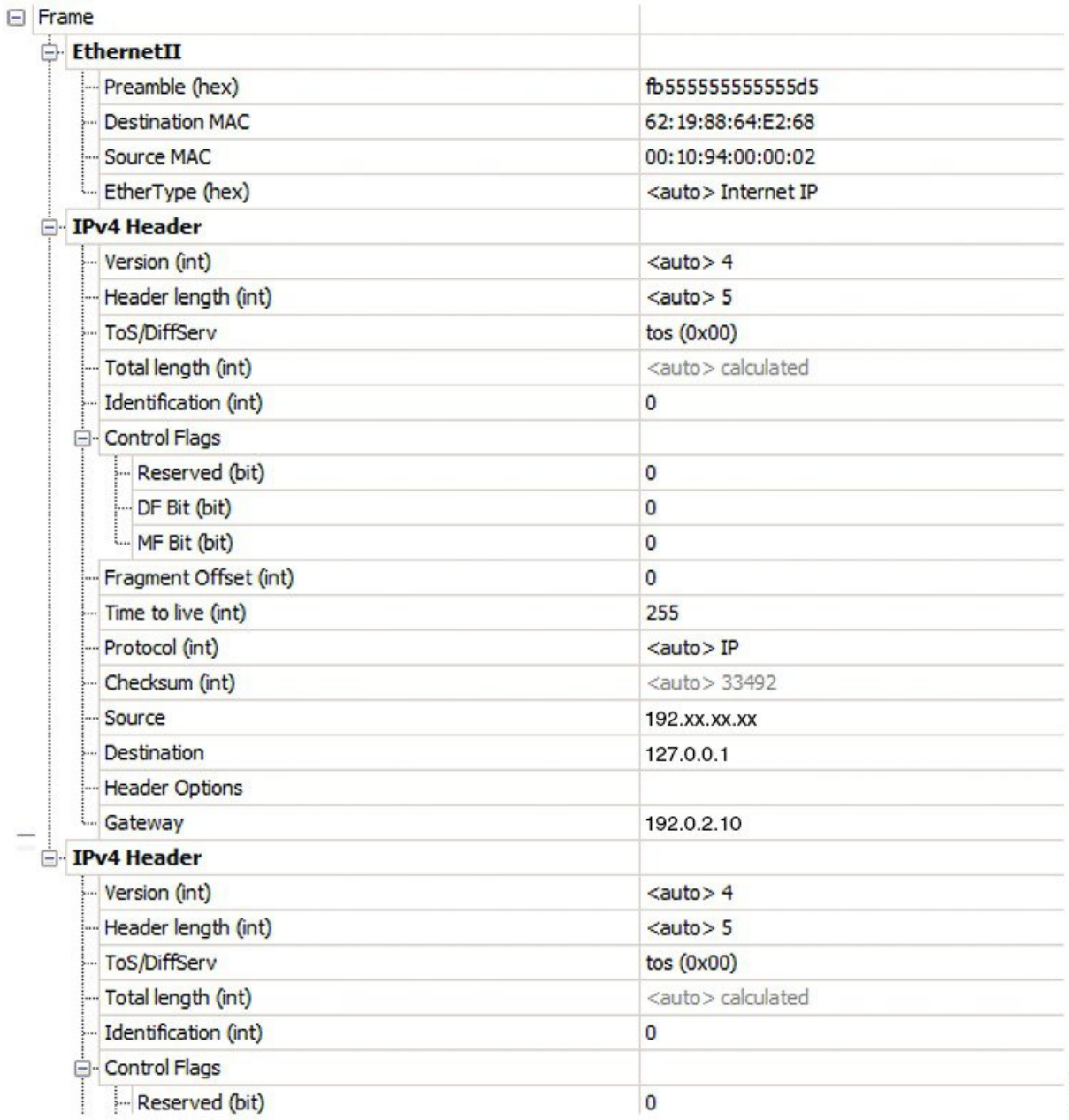
Figure 3: IP Header Decapsulation



Stacked IP Header in an Encapsulated Packet

The encapsulated packet has an outer IPv4 header that is stacked over the original IPv4 header, as shown in the following illustration.

Figure 4: Encapsulated Packet



Configuration

You can use the following sample configuration in the routers to decapsulate the packet as it traverses the IP-in-IP tunnel:

```
Router(config)# interface loopback 0
Router(config-if)# ipv4 address 127.0.0.1/32
Router(config-if)# no shutdown
Router(config-if)# interface tunnel-ip 10
```

```
Router(config-if)# ipv4 unnumbered loopback 1
Router(config-if)# tunnel mode ipv4 decap
Router(config-if)# tunnel source loopback 0
```

- **tunnel-ip**: configures an IP-in-IP tunnel interface.
- **ipv4 unnumbered loopback address**: enables ipv4 packet processing without an explicit address, except for loopback address.
- **tunnel mode ipv4 decap**: enables IP-in-IP decapsulation.
- **tunnel source**: indicates the source address for the IP-in-IP decap tunnel with respect to the router interface.

Note You can configure the tunnel destination only if you want to decapsulate packets from a particular destination. If no tunnel destination is configured, then all the ip-in-ip ingress packets on the configured interface are decapsulated.

Running Configuration

```
Router# show running-config interface tunnel-ip 10
...
interface tunnel-ip 10
ipv4 unnumbered loopback 1
tunnel mode ipv4 decap
```

Extended ACL to Match the Outer Header for IP-in-IP Decapsulation

Starting with Cisco IOS XR Software Release 7.0.14, extended ACL has to match on the outer header for IP-in-IP Decapsulation. Extended ACL support reduces mirrored traffic throughput. This match is based only on the IPv4 protocol, and extended ACL is applied to the received outermost IP header, even if the outer header is locally terminated.

Sample configuration:

```
Router#show running-config interface bundle-Ether 50.5
Tue May 26 12:11:49.017 UTC
interface Bundle-Ether50.5
ipv4 address 101.1.5.1 255.255.255.0
encapsulation dot1q 5
ipv4 access-group ExtACL_IPinIP ingress
ipv4 access-group any_dscpegg egress
!


Router#show access-lists ipv4 ExtACL_IPinIP hardware ingress location$
Tue May 26 12:11:55.940 UTC
ipv4 access-list ExtACL_IPinIP
10 permit ipv4 192.168.0.0 0.0.255.255 any ttl gt 150
11 deny ipv4 172.16.0.0 0.0.255.255 any fragments
12 permit ipv4 any any
```

Decapsulation using tunnel source direct

Table 9: Feature History Table

Feature Name	Release Information	Feature Description
Decapsulation using tunnel source direct	Release 25.4.1	Introduced in this release on: Fixed Systems (8700 [ASIC: K100])(select variants only*) *This feature is supported on Cisco 8711-48Z-M routers.
Decapsulation using tunnel source direct	Release 25.1.1	Introduced in this release on: Fixed Systems (8010 [ASIC: A100])(select variants only*) *This feature is supported on Cisco 8011-4G24Y4H-I routers.
Decapsulation using tunnel source direct	Release 24.4.1	Introduced in this release on: Fixed Systems (8200 [ASIC: P100], 8700 [ASIC: P100, K100])(select variants only*); Modular Systems (8800 [LC ASIC: P100])(select variants only*) *This feature is now supported on: • 8212-48FH-M • 8711-32FH-M • 8712-MOD-M • 88-LC1-12TH24FH-E • 88-LC1-36EH+A8:B12 • 88-LC1-52Y8H-EM
Decapsulation using tunnel source direct	Release 7.5.3	Tunnel source direct allows you to decapsulate the tunnels on any L3 interface on the router. You can use the **tunnel source direct** configuration command to choose the specific IP Equal-Cost Multipath (ECMP) links for troubleshooting, when there are multiple IP links between two devices.

To debug faults in various large networks, you may have to capture and analyze the network traffic at a packet level. In datacenter networks, administrators face problems with the volume of traffic and diversity of faults. To troubleshoot faults in a timely manner, DCN administrators must identify affected packets inside large

volumes of traffic. They must track them across multiple network components, analyze traffic traces for fault patterns, and test or confirm potential causes.

In some networks, IP-in-IP decapsulation is currently used in network management, to verify ECMP availability and to measure the latency of each path within a datacenter.

The Network Management System (NMS) sends IP-in-IP (IPv4 or IPv6) packets with a stack (multiple) of predefined IPv4 or IPv6 headers (device IP addresses). The destination device at each hop removes the outside header, performs a lookup on the next header, and forwards the packets if a route exists.

Using the **tunnel source direct** command, you can choose the specific IP Equal-Cost Multipath (ECMP) links for troubleshooting, when there are multiple IP links between two devices.

Tip You can programmatically configure and manage the Ethernet interfaces using `openconfig-ethernet-if.yang` and `openconfig-interfaces.yang` OpenConfig data models. To get started with using data models, see the *Programmability Configuration Guide for Cisco 8000 Series Routers*.

Guidelines and Limitations

The following guidelines are applicable to this feature.

- The **tunnel source direct** command is only compatible with 'tunnel mode decap' for IP-in-IP decapsulation.
- The source-direct tunnel is always operationally `up` unless it is administratively shut down. The directly connected interfaces are identified using the **show ip route direct** command.
- All Layer 3 interfaces that are configured on the device are supported.
- Platform can accept and program only certain number of IP addresses. The number of IP addresses depends on the make of the platform linecard (LC). Each LC can have different number of Network Processor (NP) slices and interfaces.
- Only one source-direct tunnel per address-family is supported for configuration.
- Source-direct and regular decap tunnels can't co-exist for a specific address-family. Any configuration that attempts to enable both is automatically rejected, and an error message is displayed to indicate the conflict.
- Inline modification of an existing regular decap tunnel (**tunnel source** *interface | IP address*) to a source-direct tunnel (**tunnel source direct**), or changing a source-direct tunnel to a regular decap tunnel, is not supported. Commit-replace may fail if the same tunnel-id is used as part of the commit-replace operation. You must delete the tunnel and recreate it.

The following functionalities are not supported for the **tunnel source direct** option.

- GRE tunneling mode.
- VRF (only default VRF is supported).
- ACL and QoS on the tunnels.
- Tunnel encapsulation.
- Tunnel NetIO DLL: Decapsulation is not supported if the packet is punted to slow path.

Configure Decapsulation Using Tunnel Source Direct

Configuration

The **tunnel source direct** configures IP-in-IP tunnel decapsulation on any directly connected IP addresses. This option is now supported only when the IP-in-IP decapsulation is used to source route the packets through the network.

This example shows how to configure IP-in-IP tunnel decapsulation on directly connected IP addresses:

```
Router# configure terminal
Router(config)#interface Tunnel4
  Router(config)#tunnel mode ipv4 decap
  Router(config)#tunnel source direct
  Router(config)#no shutdown
```

This example shows how to configure IP-in-IP tunnel decapsulation on IPv6 enabled networks:

```
Router# configure terminal
Router(config)#interface Tunnel6
  Router(config)#tunnel mode ipv6 decap
  Router(config)#tunnel source direct
  Router(config)#no shutdown
```

Verifying the Configuration

The following example shows how to verify IP-in-IP tunnel decapsulation with **tunnel source direct** option:

```
Router#show running-config interface tunnel 1
interface Tunnel1
  tunnel mode ipv6ipv6 decapsulate-any
  tunnel source direct
  no shutdown

Router#show interface tunnel 1
Tunnel1 is up    Admin State: up
MTU 1460 bytes, BW 9 Kbit
Tunnel protocol/transport IPv6/DECAPANY/IPv6
Tunnel source - direct
Tx    0 packets output, 0 bytes    Rx    0 packets input, 0 bytes
```

Configure Tunnel Destination with an Object Group

Table 10: Feature History Table

Feature Name	Release Information	Description
Configure Tunnel Destination with an Object Group	Release 7.5.4	You can now assign an object group as the destination for an IP-in-IP decapsulation tunnel. With this functionality, you could configure an IPv4 or IPv6 object group consisting of multiple IPv4 or IPv6 addresses as the destination for the tunnel instead of a single IPv4 or IPv6 address. Using an object group instead of a singular IP address. This helps reduce the configuration complexity in the router by replacing the multiple tunnels with one destination with a single decapsulation tunnel that supports a diverse range of destinations The feature introduces these changes: • **CLI**: New **tunnel destination** command. • **YANG Data Model**: New **object-group** option supported in Cisco-IOS-XR-um-if-tunnel-cfg.yang Cisco native model (see GitHub).

In IP-in-IP Decapsulation, the router accepts a packet on a tunneled interface only when the tunnel IP address matches the source IP address of the incoming packets. With this implementation, the user needs to configure separate interface tunnels for each IP address that the router needs to receive the traffic packets. This limitation often leads to configuration overload on the router.

You can eliminate the configuration overload on the router by assigning an object group as the tunnel destination for IPv4 and IPv6 traffic types. That is, the router matches the source IP address of the incoming packet against the object group available as the tunnel destination. The decapsulation tunnel accepts the incoming traffic packets when there's a match between the packet source and the object group. Otherwise, the router drops the packets.

Restrictions

The following restrictions are applicable to the tunnel destination with an object group feature:

- GRE tunnels don't support configuring object groups as the tunnel destination.

- The router supports configuring tunnel destination with an object group only when the tunnel source is tunnel source direct.
- You can configure the object group as tunnel destination only on default VRF.
- Configuring object groups as the tunnel destination isn't applicable to tunnel encapsulation.
- Subinterfaces don't support configuring object groups as the tunnel destination.
- Configuring object groups as the tunnel destination feature is mutually exclusive with ACL and QoS features.
- The tunnel destination feature supports only IPv4 and IPv6 object groups.
- The router does not support changing tunnel configuration after its creation. Configure the tunnel source direct and tunnel destination with an object group while creating the tunnel only.

Prerequisites

- Define an object group including the network elements for the tunnel destination.
- Enable the tunnel source direct feature. For more information, see Decapsulation using tunnel source direct, on page 17.

Configuration example

This section provides an example for configuring the tunnel destination with an object group.

IPv4 configuration

```
Router# configure
/* Configure the IPv4 object group */
Router(config)# object-group network ipv4 Test_IPv4
Router(config-object-group-ipv4)# 192.0.2.0/24
Router(config-object-group-ipv4)# 198.51.100.0/24
Router(config-object-group-ipv4)# 203.0.113.0/24
Router(config-object-group-ipv4)# commit
Router(config-object-group-ipv4)# exit

/* Enters the tunnel configuration mode */
Router(config)# interface tunnel-ip 1

/* Configures the tunnel mode */
Router(config-if)# tunnel mode ipv4 decap

/* Configures the tunnel to accept all packets with destination address matching the IP
addresses on the router */
Router(config-if)# tunnel source direct

/* Configures the destination of the tunnel as the defined object-group */
Router(config-if)# tunnel destination object-group ipv4 Test_IPv4

Router(config-if)# no shutdown
Router(config-if)# commit
Router(config-if)# exit
```

IPv6 configuration

```
Router# configure
/* Configure the IPv6 object group */
Router(config)# object-group network ipv6 Test_IPv6
```

```
Router(config-object-group-ipv6)# 2001:DB8::/32
Router(config-object-group-ipv6)# 2001:DB8::/48
Router(config-object-group-ipv6)# commit
Router(config-object-group-ipv6)# exit

/* Enters the tunnel configuration mode */
Router(config)# interface tunnel-ip 2

/* Configures the tunnel mode */
Router(config-if)# tunnel mode ipv6 decap

/* Configures the tunnel to accept all packets with destination address matching the IP
addresses on the router */
Router(config-if)# tunnel source direct

/* Configures the destination of the tunnel as the defined object-group */
Router(config-if)# tunnel destination object-group ipv6 Test_IPv6

Router(config-if)# no shutdown
Router(config-if)# commit
Router(config-if)# exit
```

Running Configuration

```
Router# show running-config object-group
object-group network ipv4 Test_IPv4
 192.0.2.0/24
 198.51.100.0/24
 203.0.113.0/24
!
object-group network ipv6 Test_IPv6
 2001:DB8::/32
 2001:DB8::/48
!

Router#show running-config interface tunnel-ip 1
interface tunnel-ip1
 tunnel mode ipv4 decap
 tunnel source direct
 tunnel destination object-group ipv4 Test_IPv4
!

Router#show running-config interface tunnel-ip 2
Fri Nov 29 11:26:54.716 UTC
interface tunnel-ip2
 tunnel mode ipv6 decap
 tunnel source direct
 tunnel destination object-group ipv6 Test_IPv6
!
```

Verification

```
Router# show tunnel ip ea database

----- node0_0_CPU0 -----
tunnel ifhandle 0x80022cc
tunnel source 161.115.1.2
tunnel destination address group Test_IPv4
tunnel transport vrf table id 0xe0000000
tunnel mode gre ipv4, encap
tunnel bandwidth 100 kbps
tunnel platform id 0x0
tunnel flags 0x40003400
IntfStateUp
BcStateUp
Ipv4Caps
```

```
Encap
tunnel mtu 1500
tunnel tos 0
tunnel ttl 255
tunnel adjacency flags 0x1
tunnel o/p interface handle 0x0
tunnel key 0x0, entropy length 0 (mask 0xffffffff)
tunnel QT next 0x0
tunnel platform data (nil)
Platform:
Handle: (nil)
Decap ID: 0
Decap RIF: 0
Decap Recycle Encap ID: 0x00000000
Encap RIF: 0
Encap Recycle Encap ID: 0x00000000
Encap IPv4 Encap ID: 0x4001381b
Encap IPv6 Encap ID: 0x00000000
Encap MPLS Encap ID: 0x00000000
DecFEC DecRcyLIF DecStatsId EncRcyLIF
```

Hashing for load balancing

Hashing is a technique used by network devices such as routers and switches to distribute traffic flows or packets efficiently across multiple available paths, links, or resources. Hashing technique

- ensures all packets from the same traffic flow (e.g., TCP connection) follow the same path, avoiding out-of-order delivery
- distributes multiple traffic flows across all paths thus preventing overload of any single path, and
- works automatically as paths or links are added or removed.

How hashing works

1. Field extraction:

   The device extracts certain fields from the packet header (e.g., source/destination IP addresses, ports, protocol).

2. Hash function:

   These fields are combined and fed into a mathematical function called a *hash function*. This function produces a fixed-size output known as the *hash value*.

3. Path selection:

   The resulting hash value is used to select one of several possible paths, links, or next hops. For example, if there are 4 links in a bundle, the device might use:

   ```
   path = hash_value % 4
   ```

   Here, `%` indicates the modulus operation.

If multiple routers use the same hash algorithm and field selection, the same flows may be mapped to the same paths on each router, resulting in polarization. This can lead to uneven traffic distribution and underused network capacity.

By increasing the variety of hash profiles using extended entropy profiles, each router hashes differently thus reducing the chance of polarization while improving the overall load balancing. For more information, see Enhanced hashing functions using extended profiles.

Configure hash rotation value

These configurations control the `node-id` (also referred to as HASH_ROTATE), which influences how the hashing algorithms process input fields, effectively reordering them to de-correlate flows. This is a mechanism to combat polarization.

Procedure

Step 1 Configure hash rotation value using one of these options.

- Set a specific `node-id` (hash rotation value) for the entire chassis as this `node-id` determines one of the 216 possible permutations of input fields for the hashing algorithm.

  ```
  Router# config
  Router (config)# cef platform load-balancing algorithm adjust 10
  ```

  A specific value might be chosen to optimize load balancing for a known network topology or to address observed polarization issues.

- Set a specific `node-id` (hash rotation value) for a particular NPU instance on a specific line card, location 0/0/CPU0 and instance 0 to identify the NPU as this `node-id` provides granular control, allowing different NPUs within the same chassis to use distinct hash rotation values.

  ```
  Router# config
  Router (config)# cef platform load-balancing algorithm adjust 20 instance 0 location 0/0/CPU0
  ```

  This configuration can be useful in complex scenarios where traffic characteristics vary significantly across different NPU-handled interfaces.

- Enable the system to automatically determine and set the `node-id` (hash rotation value) globally for the entire chassis as this configuration aims to dynamically select an optimal `node-id` to improve load balancing and minimize polarization without requiring manual intervention.

  ```
  Router# config
  Router (config)# cef platform load-balancing algorithm adjust auto-global
  ```

- Enable the system to automatically determine and set the `node-id` (hash rotation value) for each individual NPU instance across all NPUs in the chassis as it allows each NPU to independently optimize its hash rotation based on its specific traffic load and characteristics.

  ```
  Router# config
  Router (config)# cef platform load-balancing algorithm adjust auto-instance
  ```

Step 2 Execute this command to view the `node-id` (hash rotation value) specified on the location, 0/0/CPU0.

Example:

```
Router(config)# show running-config | incl cef platform load-balancing
Tue Nov 18 07:14:00.722 UTC
cef platform load-balancing algorithm adjust 20 instance 0 location 0/0/CPU0
Router(config)#
```

Hashing functions for load balancing

A hashing function is a network algorithm that

- computes a hash value based on selected user-defined packet header fields such as source IP, destination IP, source port, destination port, and next header or protocol
- enables efficient distribution of traffic flows across network paths, and
- minimizes traffic polarization by supporting varied entropy profiles.

Table 11: Feature History Table

Feature Name	Release Information	Description
Enhanced hashing functions using extended entropy profiles	Release 25.4.1	Introduced in this release on: Fixed Systems (8200 [ASIC: Q200]); Modular Systems (8800 [LC ASIC: Q200]) This enhancement significantly reduces the risk of traffic polarization thus ensuring more even and efficient distribution of traffic across multiple network paths in large-scale networks. Load balancing hashing functions have been improved with extended entropy profiles that generate thousands of unique hash function selections on certain user-defined header fields. This feature introduces these changes: CLI: • A new keyword, **extended-entropy**, has been added to the **cef platform load-balancing** command. • Two new keywords, **ecmp-seed** and **spa-seed**, are added to the **cef platform load-balancing algothirm adjust** command. • Two new keywords, **hash** and **ip-field-duplication**, are added to the **hw-module cef** command.

Addressing traffic polarization with extended entropy profiles

In large-scale networks, optimal load balancing is critical. Routers use hash algorithms to distribute traffic flows across multiple paths. However, if the hashing functions on consecutive routers are too similar, this can cause polarization—many flows get mapped to the same path on multiple routers, reducing network efficiency and resilience.

Starting with Cisco IOS XR version 25.4.1, load balancing hashing functions have been improved with extended entropy profiles. These profiles utilize specific packet header fields, such as IP addresses and port numbers, to generate thousands of unique hash function combinations. This feature introduces a new **extended-entropy** keyword in the **cef platform load-balancing** command to configure the extended entropy.

Configuring ECMP and SPA seed values

You can configure 16-bit *seed values*[1] for ECMP and SPA (System port aggregate), which is an internal load balancing component. To set the seed values for ECMP and SPA, use the **cef platform loading-balancing algorithm adjust ecmp-seed** and **cef platform loading-balancing algorithm adjust spa-seed** commands respectively.

Enabling ASIC property for single IP header traffic

We recommend you to enable the **hw-module profile cef hash ip-field-duplication** command when using **cef platform load-balancing extended-entropy**. This setting activates an ASIC property that enhances load balancing for traffic with a single IP header. Without this configuration, certain devices may not detect all varying bits in IPv4 or IPv6 plain traffic, potentially causing traffic polarization on some nodes.

How enhanced hashing functions for load balancing work

Summary

The key components involved in the process are:

- Algorithm adjustments: Modify the load balancing algorithms to utilize additional entropy from inner header fields during hash calculation.
- Extended entropy profiles: Define two sets of offsets and widths for fields within IPv4 or IPv6 inner headers, increasing the available entropy for hashing.

  The **cef platform load-balancing extended-entropy** configuration leverages the variation or entropy used in the inner header fields and incorporates this information into the outer header's hash calculation. This approach is beneficial when the inner headers have sufficient entropy, but the outer header does not vary.
- ECMP and SPA seed values: Use specific seed values to further diversify the hash results, ensuring unique traffic distribution across routers.

Enhanced hashing functions for load balancing optimize how traffic is distributed across network paths by incorporating greater entropy from packet headers. This process leverages extended entropy profiles, algorithm adjustments, and specific ECMP and SPA seed values to create highly diversified hash results, minimizing the risk of traffic collisions while promoting balanced network utilization.

[1] Seed values introduce an additional element of randomness into the hashing process, further helping to de-correlate flows and prevent polarization

Workflow

These stages describe the enhanced hashing functions for load balancing:

1. Profile selection: The system selects one of 256 available extended-entropy profiles, each specifying which fields within the inner packet header are used for entropy.
2. Hash input extraction: The selected profile identifies two sets of offsets and widths in the IPv4 or IPv6 inner header, and extracts these field values as hash input.
3. Algorithm application: The load balancing algorithm incorporates the extracted entropy, along with ECMP and SPA seed values, into the hash calculation.
4. Hash calculation: The router computes a hash value based on the combined entropy from the inner header and the seed values.
5. Traffic distribution: The computed hash value determines how each packet flow is distributed across available network paths, ensuring varied and balanced load sharing.

Result

The enhanced hashing process produces highly unique hash inputs, enabling routers to split traffic flows more effectively and consistently achieve balanced utilization of all network paths, even when outer packet headers lack sufficient variability.

Benefits of enhanced hashing functions

These are some benefits of the enhanced hashing functions using extended entropy profiles:

- Improves traffic distribution across paths and devices, even with random node-id assignments.
- Suitable for very large, multi-router, multi-path networks.
- Supports a range of configurations and traffic types.

Configuration guidelines for enhanced hashing functions

- Do not configure both **cef platform load-balancing extended-entropy**, and **cef platform load-balancing fields user-data** at the same time. These configurations are mutually exclusive.
- When using **cef load-balancing algorithm adjust auto-instance** on adjacent devices with small and symmetric topologies, use **cef load-balancing algorithm adjust auto-global** to avoid uneven load balancing.
- Do not configure the same seed value on adjacent devices or within the same topology.
- Enable **cef platform load-balancing extended-entropy** before enabling **hw-module profile cef hash ip-field-duplication**.

Restrictions for enhanced hashing functions

Only Cisco Silicon One Q200-based systems support the enhanced hashing functions for load balancing.

Configure ECMP and SPA seed values

Follow this procedure to configure seed values for ECMP and SPA hashing.

By default, the hashing algorithm uses a 16-bit seed from the router ID, providing differentiation across devices.

You can customize ECMP or SPA seeds to introduce randomness into the hash function. To avoid load-balancing issues, configure different seed values on adjacent devices or within the same topology.

Procedure

Step 1 Set a specific hexadecimal ECMP seed value (`0xaa` in this example) for the chassis to ensure that the traffic is distributed consistently and without bias across multiple equal-cost paths, preventing polarization.

Example:

```
Router# config
Router (config)# cef platform load-balancing algorithm adjust ecmp-seed 0xaa
Router (config)# commit
```

Step 2 Set a specific hexadecimal SPA seed value (`0xbb` in this example) for the chassis so that the seed is incorporated into the hashing calculation to add an element of uniqueness, which can help distribute traffic more evenly across multiple paths.

Example:

```
Router# config
Router (config)# cef platform load-balancing algorithm adjust spa-seed 0xbb
Router (config)# commit
```

Step 3 Set a specific hexadecimal ECMP seed value (`0xdd` in this example) on a particular NPU instance to provide NPU-specific control over the ECMP hashing randomness, which can be beneficial in complex network designs.

Example:

```
Router# config
Router (config)# cef platform load-balancing algorithm adjust ecmp-seed 0xdd instance 0 location
0/0/CPU0
Router (config)# commit
```

Step 4 Set a specific hexadecimal SPA seed value (`0xcc` in this example) on a particular NPU instance as this seed allows for fine-grained control, enabling different NPUs to use distinct SPA seed values if their traffic patterns or load-balancing requirements differ.

Example:

```
Router# config
Router (config)# cef platform load-balancing algorithm adjust spa-seed 0xcc instance 0 location
0/0/CPU0
Router (config)# commit
```

Step 5 Verify the ECMP and SPA seed value configurations.

Example:

```
Router# show running-config | include cef platform load-balancing
Tue Nov 18 07:08:56.704 UTC
cef platform load-balancing algorithm adjust spa-seed 0xcc instance 0 location 0/0/CPU0
cef platform load-balancing algorithm adjust ecmp-seed 0xdd instance 0 location 0/0/CPU0
Router#
```

What to do next

Make sure that you have configured the extended entropy profiles and algorithm adjustments for the enhanced hashing functions for loading balancing to work properly.

Configure extended entropy profile

This procedure allows you to configure **cef platform load-balancing extended-entropy**. This configuration increases the number of uncorrelated hash selection algorithms by modifying how input fields are processed.

Before you begin

Make sure that you have configured the ECMP and SPA seed values and algorithm adjustments along with the extended entropy profiles configuration so that the enhanced hashing functions for load balancing work correctly.

Procedure

Step 1 Configure the extended entropy profile using one of these commands:

- Enable the system to automatically select the most suitable extended entropy profile globally for the entire chassis.

  ```
  Router# config
  Router (config)# cef platform load-balancing extended-entropy auto-global
  ```

  This is the recommended option.
- Enables the system to automatically select the most suitable extended entropy profile for each individual NPU instance across all NPUs in the chassis.

  ```
  Router# config
  Router (config)# cef platform load-balancing extended-entropy auto-instance
  ```

  This provides NPU-level optimization, allowing each NPU to dynamically choose a profile that best suits the traffic it is processing, further enhancing load balancing and polarization avoidance.
- Selects a specific extended entropy profile (identified by `profile-index 10` in this example) to be used for hashing across the entire chassis.

  ```
  Router# config
  Router (config)# cef platform load-balancing extended-entropy profile-index 10
  ```

  These profiles define how the hashing functions are applied to various header fields such as inner source or destination IP, TCP or UDP ports, and so on to maximize entropy and de-correlation. This allows an administrator to explicitly choose a profile optimized for a particular traffic mix or to address specific polarization issues.

Step 2 (Optional) Enable the ASIC property using the **hw-module profile cef hash ip-field-duplication** command.

Example:

```
Router# config
Router (config)# hw-module profile cef hash ip-field-duplication
Router (config)# commit
Router (config)# exit
Router# reload location all
```

Enabling the ASIC property improves load balancing for traffic with a single IP header. Without this configuration, some devices may not capture the varying bits in IPv4 or IPv6 plain traffic, which results in polarization on certain nodes.

Step 3 Execute this command to view the running configuration.

Example:

```
Router# show running-config | incl cef platform load-balancing
Mon Nov 17 08:16:06.749 UTC
```

```
cef platform load-balancing extended-entropy auto-global
Router(config)#
```

ECMP Hashing Support for Load Balancing

The system inherently supports the n-tuple hash algorithm. The first inner header in the n-tuple hashing includes the source port and the destination port of UDP / TCP protocol headers.

The load balancing performs these functions:

- Incoming data traffic is distributed over multiple equal-cost connections.
- Incoming data traffic is distributed over multiple equal-cost connections member links within a bundle interface.
- Layer 2 bundle and Layer 3 (network layer) load-balancing decisions are taken on IPv4, and IPv6. If it is an IPv4 or an IPv6 payload, then an n-tuple hashing is done.
- An n-tuple hash algorithm provides more granular load balancing and used for load balancing over multiple equal-cost Layer 3 (network layer) paths. The Layer 3 (network layer) path is on a physical interface or on a bundle interface.
- The n-tuple load-balance hash calculation contains:
  - Source IP address
  - Destination IP address
  - IP Protocol type
  - Router ID
  - Source port
  - Destination port
  - Input interface
  - Flow-label (for IPv6 only)

User-defined fields for ECMP hashing

Table 12: Feature History Table

Feature Name	Release Information	Description
User-defined fields for ECMP hashing	Release 25.4.1	Introduced in this release on: Fixed Systems (8700 [ASIC: K100])(select variants only*) *This feature is supported on Cisco 8711-48Z-M routers.

Feature Name	Release Information	Description
User-defined fields for ECMP hashing	Release 25.1.1	Introduced in this release on: Fixed Systems (8010 [ASIC: A100])(select variants only*) *This feature is supported on Cisco 8011-4G24Y4H-I routers.
User-defined fields for ECMP hashing	Release 24.4.1	Introduced in this release on: Fixed Systems (8200 [ASIC: P100], 8700 [ASIC: P100, K100])(select variants only*); Modular Systems (8800 [LC ASIC: P100])(select variants only*) *This feature is now supported on: • 8212-48FH-M • 8711-32FH-M • 8712-MOD-M • 88-LC1-12TH24FH-E • 88-LC1-36EH • 88-LC1-52Y8H-EM

Feature Name	Release Information	Description
User-defined fields for ECMP hashing	Release 24.2.11	We ensure that in cases where multiple paths are used to carry packets from source to destination, each path is utilized for this purpose and no path is over-utilized or congested. This is made possible because we now provide customized ECMP hashing fields that are used for path computation. Previously, the router relied on fixed packet header fields for hashing, which were not user configurable. With additional user-defined bytes considered for hashing, the granularity at which the traffic can be analyzed for ECMP load balancing increases, resulting in better load balancing and path utilization. The feature introduces these changes: **CLI:** • **cef load-balancing fields user-data** • The **show cef exact-route** command is modified with a new **user-data** keyword. • The **show cef ipv4 exact-route** command is modified with a new **user-data** keyword. • The **show cef ipv6 exact-route** command is modified with a new **user-data** keyword. **YANG:** • New Xpath for `Cisco-IOS-XR-8000-fib-platform-cfg.yang` (see Github, YANG Data Models Navigator).

ECMP hashing is used to distribute traffic across multiple equal-cost paths. See ECMP Hashing Support for Load Balancing, on page 30 for the default static hashing algorithm details.

You can now add user-defined packet header fields for ECMP path calculation for ipv4 and ipv6 flows using the **cef platform load-balancing fields user-data** command. Ensure you specify these user-defined fields based on the type of traffic flow that requires load balancing. You can include the following parameters:

- **Hash header:** The hash header specifies which packet header is being considered for load balancing. You can enable any or all of the available six profiles.
  - IPv4: tcp, udp, non-tcp-udp
  - IPv6: tcp, udp, non-tcp-udp

  If any hash header profile is defined for load balancing, along with the fixed fields considered for hashing, additional bytes in the payload are also used for path computation.
- **Hashing offset:** The hashing offset specifies the byte location from the end of the configured header.
- **Hash size:** The hash size specifies the number of bytes that is considered from the start of the hash offset by the ECMP hashing algorithm. Range is 1 to 4 bytes.
- **Location:** This specifies the location of the ingress line card that receives the incoming traffic. The user-defined hashing configuration is applied on the specified line card.

The addition of the user-defined packer header fields increases the granularity at which the traffic is analyzed for ECMP load balancing. When multiple paths with equal cost are available for routing a specific type of packet from a source to a destination, this granularity ensures that the intended type of traffic is evenly distributed across these paths. This ensures all available paths are used efficiently and prevents congestion or over-utilization of a single path.

You can also retrieve the exact-route information based on the configured user-data using the **show cef exact-route** command with **user-data** keyword.

Note

- When the user-defined hashing configuration is active, any additional options or optional keywords are disregarded during the parsing of incoming packets for retrieving the user-defined bytes.
- The hashing results based on user-defined hash feature is applicable to BGP/IGP ECMP and LAG hashing.
- The use of the user-defined hashing configuration changes the load balancing behavior of GRE and IPinIP traffic. This includes all traffic that begins with ipv4, ipv6, ipv4+udp, ipv6+udp, ipv4+tcp, and ipv6+tcp, regardless of the payload.

Configure User-Defined Fields for ECMP Hashing

The command **cef load-balancing fields user-data** configures the additional user-defined fields that are to be considered for the hashing algorithm.

This example shows how to configure the additional IPv4 header fields for TCP packets:

```
Router# configure terminal
Router(config)#cef load-balancing fields user-data ipv4 tcp offset 5 size 3 location 0/0/CPU0
Router(config)#commit
```

- offset 5: The payload considered for hashing starts from byte 6 from the end of TCP header.
- size 3: Three bytes of payload are considered.

- location 0/0/CPU0: Specifies the line card on which the configuration is applied.

In the above example, the sixth, seventh, and eighth bytes of the payload are considered additionally for the hashing.

This example shows how to configure the additional IPv6 header fields for UDP packets:

```
Router# configure terminal
Router(config)#cef load-balancing fields user-data ipv6 udp offset 0 size 2 location 0/0/CPU0
Router(config)#commit
```

- offset 0: The payload considered for hashing starts from the end of UDP header.
- size 2: Two bytes of payload are considered.
- location 0/0/CPU0: Specifies the line card on which the configuration is applied.

In the above example, the first two bytes of payload of a UDP packet are considered additionally for the hashing.

Running Configuration

The following example shows the running configuration:

```
Router#show running-config | include cef
Fri Jul 28 12:02:01.002 UTC
cef load-balancing fields user-data ipv4 tcp offset 5 size 3 location 0/0/CPU0
cef load-balancing fields user-data ipv6 udp offset 0 size 2 location 0/0/CPU0
Router#
```

Verification

The following example shows the difference in load balancing before and after applying user-defined hashing, for a flow with data that exhibits good hashing behavior.

Before applying user-defined hashing

```
Router#show interfaces accounting | i IPV6_U
  Protocol              Pkts In         Chars In     Pkts Out        Chars Out
  IPV6_UNICAST                1               72            0                0
  IPV6_UNICAST                1               72            0                0
  IPV6_UNICAST                1               72            0                0
  IPV6_UNICAST                1               72            0                0
  IPV6_UNICAST                2              144            0                0
  IPV6_UNICAST                1               72            0                0
  IPV6_UNICAST                0                0      3979416       1981749168
  IPV6_UNICAST          4191438       2087336124            0                0
  IPV6_UNICAST                1               72            0                0
  IPV6_UNICAST                1               72            0                0
  IPV6_UNICAST                1               72            0                0
Router#
```

After applying user-defined hashing

```
Router#show interfaces accounting | i IPV6_U
  Protocol              Pkts In         Chars In     Pkts Out        Chars Out
  IPV6_UNICAST                0                0        39119         19481262
  IPV6_UNICAST                0                0        39801         19820898
  IPV6_UNICAST                0                0        40483         20160534
  IPV6_UNICAST                0                0        40524         20180952
  IPV6_UNICAST                0                0        40573         20205354
  IPV6_UNICAST                0                0        40614         20225772
  IPV6_UNICAST                0                0        39368         19605264
```

```
  IPV6_UNICAST               0               0        40734         20285532
  IPV6_UNICAST               0               0        40777         20306946
  IPV6_UNICAST               0               0        40171         20005158
  IPV6_UNICAST               0               0        40858         20347284
  IPV6_UNICAST               0               0        40269         20053962
  IPV6_UNICAST               0               0        41603         20718294
  IPV6_UNICAST               0               0        40363         20100774
  IPV6_UNICAST               0               0        40407         20122686
  IPV6_UNICAST               0               0        41098         20466804
  IPV6_UNICAST          850393       423495714            0               0
```

To view the exact route information allocated to the packets, use **show cef exact-route** command with **user-data** keyword.

The packet contains value 0x2 in the packet position for the ipv6 packet, for which the user-defined configuration has been added for a non-tcp-udp ipv6 flow.

```
Router#show cef ipv6 exact-route 100::10 60::1 flow-label 0 protocol 59 source-port 0
destination-port 0 user-data 0x2 ingress-interface HundredGigE0/0/0/2 location 0/0/cpu0
Unsupported protocol value 59
60::/16, version 1293, internal 0x1000001 0x20 (ptr 0x8b78ef00) [1], 0x400 (0x8e9cfc48),
0x0 (0x0)
 Updated Aug 14 07:50:20.022
 local adjacency to Bundle-Ether3.30

 Prefix Len 16, traffic index 0, precedence n/a, priority 2
   via Bundle-Ether3.30
   via fe80::72b3:17ff:feae:d703/128, Bundle-Ether3.30, 7 dependencies, weight 0, class 0
[flags 0x0]
    path-idx 7 NHID 0x0 [0x8db8bed8 0x0]
    next hop fe80::72b3:17ff:feae:d703/128
    local adjacency
```