



OpenFlow

This module describes how to enable and configure OpenFlow on a device.

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Prerequisites for OpenFlow

The device must be booted up in OpenFlow mode.

OpenFlow mode is enabled, when you configure the **boot mode openflow** command on a switch. All ports will be in this mode, and the switch will not support any regular Cisco IOS XE features.

Restrictions for OpenFlow

- When enabling OpenFlow mode on a device, erase all prior configurations, and delete the `vlan.dat` and `stby-vlan.dat` files from the flash filesystem.

When the device is in Openflow mode, do not enable other control plane protocols (protocols such as Border Gateway Protocol [BGP], Spanning Tree Protocol [STP], Port Channels, StackWise and so on) that work when the device is in normal mode.

Information About OpenFlow

OpenFlow Overview

OpenFlow is a specification from the Open Networking Foundation (ONF) that defines a flow-based forwarding infrastructure and a standardized application-programmatic interface. OpenFlow allows a controller to direct the forwarding functions of a device through a secure channel.

OpenFlow is the protocol between the controller (control plane) and the Ethernet switch (data plane). The switch/device has flow tables arranged into a pipeline. Flows are rules to examine packets that reach these tables.

An OpenFlow agent on the switch communicates with the controller using the OpenFlow protocol. The agent supports both OpenFlow 1.0 (wire protocol 0x1) and OpenFlow 1.3 (wire protocol 0x4). It can have up to 8 controller connections. These connections are not preserved across switchover, and the controller will have to reconnect to the agent.

The OpenFlow implementation on Cisco Catalyst 9400 Series Switches is stateless; and non-stop forwarding (NSF) is not supported. The standby supervisor does not sync to the flow database.

OpenFlow Controller

The OpenFlow controller is an entity that interacts with the OpenFlow switch using the OpenFlow protocol. In most cases, the controller is a software that manages many OpenFlow logical switches. Controllers offer a centralized view of the network, and enable administrators to dictate to the underlying systems (switches and routers) on how to handle the network traffic. A controller typically runs on a Linux server, and must have IP connectivity to OpenFlow-capable switches.

The controller manages the switch, and inserts and deletes flows on the switch. These flows support a subset of OpenFlow 1.3 and 1.0 *match* and *action* criteria.

The switch connects to the controller using the management port. The management port is in the management virtual routing and forwarding (VRF) instance, and hence provides a secure connection to the controller. To connect a controller to the switch, configure the IP address and port number on which the controller can be reached.

Flow Management

A flow entry is an element in a flow table that is used to match and process packets. It contains a priority for matching precedence, a set of match fields for matching packets, a set of instructions to apply, and packet and byte counters. A timeout is also associated with each flow (a hard timeout or an inactivity timeout), which is used to automatically remove flows.

Cisco Catalyst 9000 Series Switches support a maximum of 9 flow tables.

Each flow provides the following information:

- **Priority:** High priority flows are matched first. Any flow update requires all flows to be prioritized based on the configured priority.
- **Match fields:** A part of a flow entry against which a packet is matched. Match fields can match the various packet header fields. If no match information is provided for a field; a wildcard is used.

- Action: An operation that acts on a packet.

OpenFlow Pipeline

An OpenFlow pipeline is a set of linked flow tables that provide matching, forwarding, and packet modification in an OpenFlow switch. A port is where packets enter and exits the pipeline.

Packets are received on an ingress port and processed by the OpenFlow pipeline that forwards it to output ports. The packet ingress port is owned by the packet throughout the pipeline, and represents the port on which the packet was received into the switch. The ingress port can also be used as a match field in a flow.

Flow actions allow packets to be sent to subsequent tables in the pipeline for further processing, and allow information to be communicated between tables. Pipeline processing stops when the action associated with a matching flow entry does not specify the next table. At this point, the packet is usually modified and forwarded. The packet can also be dropped.

Flow tables of an OpenFlow switch are sequentially numbered, starting from 0. Pipeline processing always starts by matching the packet against flow entries of flow table 0. Other flow tables may be used depending on the outcome of the match and actions in the first table, which could result in matching the packet against flow entries in subsequent tables.

Supported Match Fields and Actions

Match Field is a field against which a packet is matched, including packet headers, and the ingress port. A match field can be a wildcard (match any value) and have a bit mask to match selected bits of the field.

Action is an operation that forwards a packet to a port or subsequent tables, or modifies a packet field. Actions may be specified as part of the instructions associated with a flow entry, or an action bucket associated with a group entry. A group entry is a collection of actions that can be shared by multiple flows.

The action specified in one or more flow entries can direct packets to a base action called a group action. The purpose of the group action is to share a set of actions among multiple flows. A group consist of one or more buckets, and in turn, a bucket can have a set of actions (set, pop, or output). Cisco Catalyst 9000 Series Switches support group types, *all* and *indirect*.

This section lists the supported match fields and actions:

Table 1: Supported Match Fields

Header Fields	Prerequisites	Maskable Entries	Example Value
Ethernet destination MAC address		Yes	01:80:c2:00:00:00/ ff:ff:ff:00:00:00 (with mask) de:f3:50:c7:e2:b2 (without mask)
Ethernet source MAC address		Yes	0e:00:00:00:00:019 (without mask)
Ethernet type			ARP (0x0806), IPv4 (0x0800), IPv6 (0x86dd), and so on

Header Fields	Prerequisites	Maskable Entries	Example Value
VLAN ID			0x13f
ARP target protocol address	Ethernet type should be set to 0x0806	Yes	
IP protocol	Ethernet type should be set to 0x0800 or 0x86dd		ICMP (0x01), TCP (0x06), UDP (0x11), and so on
IPv4 source address	Ethernet type should be set to 0x0800	Yes	10.0.0.0/24 (with mask)
IPv4 destination address	Ethernet type should be set to 0x0800	Yes	10.0.0.254 (without mask)
IPv6 source address	Ethernet type should be set to 0x08dd	Yes	2001:DB8::1 (without mask)
IPv6 destination address	Ethernet type should be set to 0x08dd	Yes	2001:DB8:0:ABCD::1/48 (with mask)
Neighbor Discovery Target	Ethernet type should be set to 0x08dd and IP protocol should be set to 0x01		ND target
ICMPv6 type	Ethernet type should be set to 0x08dd and IP protocol should be set to 0x01		
UDP/TCP source port	Ethernet type should be set to 0x0800 or 0x86dd and protocol should be set to 0x06 or 0x11		
UDP/TCP destination port	Ethernet type should be set to 0x0800 or 0x86dd and protocol should be set to 0x06 or 0x11		
Incoming interface			

Supported Actions

A flow can send a packet to:

- The controller
- Any interface of the switch (including the incoming interface)
- A subsequent flow table (after table 0) for another lookup

- To a group

A flow can also modify the following header fields of a packet:

- Ethernet destination MAC address
- Ethernet source MAC address
- VLAN ID

A flow can add (push) or remove (pop) a VLAN tag. If the packet is an IP packet, the flow can decrement the Time to Live (TTL) header field.

Flow Operations

This section describes the operations that take place when a flow is sent by the controller to be programmed in the OpenFlow device.

The device has flow tables arranged into a pipeline. The pipeline capabilities information specifies the structure of the pipeline, such as the number of tables/stages, what each stage is capable of doing (match/actions), and the size of each table.

When the controller sends a flow request, the OpenFlow agent verifies whether the flow can be handled by the hardware. It compares the flow against the capabilities of the hardware that are defined when the switch is booted up. If the flow is valid, it is then programmed in the appropriate flow table.

If the new pipeline is validated (whether the hardware can support the pipeline), it becomes the new set of capabilities that is used to check if a flow can be installed or not.

Once the pipeline is instantiated and flows are installed, packets are forwarded by the switch. Ingress packets are matched against flows in each flow table, until the highest-priority matching flow entry is found. Packet matching may be exact (match all fields of the table exactly), or partial (match some or all fields, and fields with bit masks may be partially matched). Packets may be modified or forwarded based on the configured actions. Actions can be applied at any time in the pipeline. The action may determine the next flow table to match, the set of egress ports for the packet, and whether the packet should be routed to the controller.

OpenFlow Table Pipeline

OpenFlow table feature request messages allow an OpenFlow controller to query the capabilities of existing flow tables of an OpenFlow-managed device, or configure these tables to match the supplied configuration.

All tables may be configured with any subset of the match and action capabilities. Table sizes can also be modified at runtime. When a new flow table configuration is successfully applied, flow entries from old flow tables are removed without any notification. Dynamically configured flow tables are not persistent across reboot. The default pipeline comes up when the device boots up.

While configuring a new flow table based on a request from the OpenFlow controller, any ongoing traffic flowing via the existing flows are dropped.

How to Configure OpenFlow

Enabling OpenFlow Mode on a Device

If the switch is operating in normal mode, we recommend that you configure the **write erase** command to delete the previous configuration.

SUMMARY STEPS

1. **enable**
2. **configure terminal**
3. **boot mode openflow**
4. **exit**
5. **write erase**
6.
 - **delete flash:vlan.dat**
 - **delete flash:stby-vlan.dat**
7. **reload**
8. **enable**
9. **show boot mode**

DETAILED STEPS

	Command or Action	Purpose
Step 1	enable Example: Device> enable	Enables privileged EXEC mode. • Enter your password if prompted.
Step 2	configure terminal Example: Device# configure terminal	Enters global configuration mode.
Step 3	boot mode openflow Example: Device(config)# boot mode openflow	Enables OpenFlow forwarding mode.
Step 4	exit Example: Device(config)# exit	Exits global configuration mode and enters privileged EXEC mode.
Step 5	write erase Example: Device# write erase	Erases all files in the NVRAM. • This is recommended if the device was operating in normal mode previously.
Step 6	• delete flash:vlan.dat	Deletes the vlan.dat file that stores the VLAN information.

	Command or Action	Purpose
	<ul style="list-style-type: none"> • delete flash:stby-vlan.dat Example: Device# delete flash:vlan.dat Device# delete flash:stby-vlan.dat	<ul style="list-style-type: none"> • Delete the stby-vlan.dat file, if you have a standby device.
Step 7	reload Example: Device# reload	Reloads the switch and enables OpenFlow forwarding mode for the switch.
Step 8	enable Example: Device> enable	Enables privileged EXEC mode. <ul style="list-style-type: none"> • Enter your password if prompted.
Step 9	show boot mode Example: Device# show boot mode	Displays information about the device forwarding mode.

Example

The following sample output from the **show boot mode** command shows that the device is in OpenFlow mode:

```
Device# show boot mode

System initialized in openflow forwarding mode
System configured to boot in openflow forwarding mode
```

What to do next

To go back to normal mode, configure the **no boot mode openflow** command and then reload the device.

Configuring OpenFlow

SUMMARY STEPS

1. **enable**
2. **configure terminal**
3. **feature openflow**
4. **openflow**
5. **switch 1 pipeline 1**
6. **controller ipv4 ip-address port port-number vrf vrf-name security {none | tls}**
7. **datapath-id ID**
8. **tls trustpoint local name remote name**
9. **end**

DETAILED STEPS

	Command or Action	Purpose
Step 1	enable Example: Device> enable	Enables privileged EXEC mode. <ul style="list-style-type: none"> • Enter your password if prompted
Step 2	configure terminal Example: Device# configure terminal	Enters global configuration mode.
Step 3	feature openflow Example: Device(config)# feature openflow	Enables the OpenFlow feature.
Step 4	openflow Example: Device(config)# openflow	Enables OpenFlow configuration and enters OpenFlow configuration mode.
Step 5	switch 1 pipeline 1 Example: Device(config-openflow)# switch 1 pipeline 1	Configures a logical switch and pipeline, and enters OpenFlow switch configuration mode.
Step 6	controller ipv4 ip-address port port-number vrf vrf-name security {none tls} Example: Device(config-openflow-switch)# controller ipv4 10.2.2.2 port 6633 vrf Mgmt-vrf security tls	Connects to a controller. <ul style="list-style-type: none"> • You must configure the tls trustpoint command, if you have configured TLS as the OpenFlow controller connection security option. • You do not need to configure tls trustpoint command, if you have not configured any security option for the OpenFlow controller.
Step 7	datapath-id ID Example: Device(config-openflow-switch)# datapath-id 0x12345678	(Optional) Sets the OpenFlow logical switch ID. <ul style="list-style-type: none"> • The <i>ID</i> argument specifies the Switch ID, which is a hexadecimal value.
Step 8	tls trustpoint local name remote name Example: Device(config-openflow-switch)# tls trustpoint local trustpoint1 remote trustpoint1	(Optional) Configures an OpenFlow switch Transport Layer Security (TLS) trustpoint.
Step 9	end Example: Device(config-openflow-switch)# end	Exits OpenFlow switch configuration mode and returns to privileged EXEC mode.

Configuring Interfaces in OpenFlow Mode

You can either configure a Layer 2 or Layer 3 interface in OpenFlow mode. When using a Layer 3 interface, configure the **no switchport** command in interface configuration mode. Perform the following task when using a Layer 2 interface.

SUMMARY STEPS

1. **enable**
2. **configure terminal**
3. **feature openflow**
4. **interface** *type number*
5. **switchport mode trunk**
6. **switchport nonnegotiate**
7. **no keepalive**
8. **spanning-tree bpduguard enable**
9. **end**

DETAILED STEPS

	Command or Action	Purpose
Step 1	enable Example: Device> enable	Enables privileged EXEC mode. • Enter your password if prompted
Step 2	configure terminal Example: Device# configure terminal	Enters global configuration mode.
Step 3	feature openflow Example: Device(config)# feature openflow	Enables the OpenFlow feature.
Step 4	interface <i>type number</i> Example: Device(config)# interface gigabitethernet 1/0/3	Configures an interface and enters interface configuration mode.
Step 5	switchport mode trunk Example: Device(config-if)# switchport mode trunk	Sets the trunking mode of the Layer 2-switched interface to trunk.
Step 6	switchport nonnegotiate Example: Device(config-if)# switchport nonnegotiate	Specifies that the device will not engage in negotiation protocol on this interface.

	Command or Action	Purpose
Step 7	no keepalive Example: Device(config-if)# no keepalive	Disables keepalive packets.
Step 8	spanning-tree bpdudfilter enable Example: Device(config-if)# spanning-tree bpdudfilter enable	Enables bridge protocol data unit (BPDU) filtering on the interface.
Step 9	end Example: Device(config-if)# end	Exits interface configuration mode and returns to privileged EXEC mode.

Configuration Examples for OpenFlow

Example: Enabling OpenFlow on a Device

```
Device> enable
Device# configure terminal
Device(config)# boot mode openflow
Device(config)# exit
Device# write erase
Device# delete flash:vlan.dat
Device# reload
Device> enable
Device# show boot mode
```

Example: Configuring OpenFlow

```
Device# configure terminal
Device(config)# feature openflow
Device(config)# openflow
Device(config-openflow)# switch 1 pipeline 1
Device(config-openflow-switch)# controller ipv4 10.2.2.2 port 6633 vrf Mgmt-vrf security
tls
Device(config-openflow-switch)# datapath-id 0x12345678
Device(config-openflow-switch)# tls trustpoint local trustpoint1 remote trustpoint1
Device(config-openflow-switch)# end
```

Example: Configuring Interfaces in OpenFlow Mode

You can either configure a Layer 2 or Layer 3 interface in OpenFlow mode. When using a Layer 3 interface, configure the **no switchport** command in interface configuration mode. Perform the following task when using a Layer 2 interface.

```
Device> enable
Device# configure terminal
Device(config)# feature openflow
Device(config)# interface gigabitethernet 1/0/3
Device(config-if)# switchport mode trunk
Device(config-if)# switchport nonnegotiate
Device(config-if)# no keepalive
Device(config-if)# spanning-tree bpdufilter enable
Device(config-if)# end
```

Verifying OpenFlow

SUMMARY STEPS

1. **enable**
2. **show openflow hardware capabilities**
3. **show openflow switch 1 controller**
4. **show openflow switch 1 ports**
5. **show openflow switch 1 flows list**

DETAILED STEPS

Step 1 **enable**

Enables privileged EXEC mode.

- Enter your password if prompted.

Example:

```
Device> enable
```

Step 2 **show openflow hardware capabilities**

Displays the hardware capabilities of an OpenFlow device.

Example:

```
Device# show openflow hardware capabilities
```

```
Max Interfaces: 1000
Aggregated Statistics: YES
```

```
Pipeline ID: 1
Pipeline Max Flows: 2322
Max Flow Batch Size: 100
```

```

Statistics Max Polling Rate (flows/sec): 10000
Pipeline Default Statistics Collect Interval: 5

```

```
Flow table ID: 0
```

```

Max Flow Batch Size: 100
Max Flows: 1022
Bind Subintfs: FALSE
Primary Table: TRUE
Table Programmable: TRUE
Miss Programmable: TRUE
Number of goto tables: 1
Goto table id: 1
Number of miss goto tables: 1
Miss Goto table id: 1
Stats collection time for full table (sec): 1

```

```

!
!
!

```

Step 3 show openflow switch 1 controller

Displays information about the controller connected to the switch.

Example:

```
Device# show openflow switch 1 controller
```

```

Logical Switch Id: 1
Total Controllers: 1
Controller: 1
10.10.23.200:6633
Protocol: tcp
VRF: Mgmt-vrf
Connected: Yes
Role: Equal
Negotiated Protocol Version: OpenFlow 1.3
Last Alive Ping: 2018-06-04 17:59:20 PDT
state: ACTIVE
sec_since_connect: 50

```

Step 4 show openflow switch 1 ports

Displays information about the ports on an OpenFlow switch.

Example:

```
Device# show openflow switch 1 ports
```

```

Logical Switch Id: 1

```

Port	Interface Name	Config-State	Link-State	Features
1	Gi1/0/1	PORT_UP	LINK_UP	1GB-FD
2	Gi1/0/2	PORT_UP	LINK_UP	1GB-FD
3	Gi1/0/3	PORT_UP	LINK_UP	1GB-FD
4	Gi1/0/4	PORT_UP	LINK_UP	1GB-FD
5	Gi1/0/5	PORT_UP	LINK_DOWN	1GB-HD
6	Gi1/0/6	PORT_UP	LINK_DOWN	1GB-HD
7	Gi1/0/7	PORT_UP	LINK_DOWN	1GB-HD
8	Gi1/0/8	PORT_UP	LINK_DOWN	1GB-HD
9	Gi1/0/9	PORT_UP	LINK_UP	1GB-FD
10	Gi1/0/10	PORT_UP	LINK_UP	1GB-FD
11	Gi1/0/11	PORT_UP	LINK_UP	1GB-FD
12	Gi1/0/12	PORT_UP	LINK_UP	1GB-FD
13	Gi1/0/13	PORT_UP	LINK_DOWN	1GB-HD

14	Gi1/0/14	PORT_UP	LINK_DOWN	1GB-HD
15	Gi1/0/15	PORT_UP	LINK_DOWN	1GB-HD
16	Gi1/0/16	PORT_UP	LINK_DOWN	1GB-HD
17	Gi1/0/17	PORT_UP	LINK_DOWN	1GB-HD
18	Gi1/0/18	PORT_UP	LINK_DOWN	1GB-HD
19	Gi1/0/19	PORT_UP	LINK_UP	1GB-FD
20	Gi1/0/20	PORT_UP	LINK_UP	1GB-FD
21	Gi1/0/21	PORT_UP	LINK_UP	1GB-FD
22	Gi1/0/22	PORT_UP	LINK_UP	1GB-FD
23	Gi1/0/23	PORT_UP	LINK_DOWN	1GB-HD
24	Gi1/0/24	PORT_UP	LINK_DOWN	1GB-HD
25	Gi1/1/1	PORT_UP	LINK_DOWN	1GB-HD
26	Gi1/1/2	PORT_UP	LINK_DOWN	1GB-HD
27	Gi1/1/3	PORT_UP	LINK_DOWN	1GB-HD
28	Gi1/1/4	PORT_UP	LINK_DOWN	1GB-HD
29	Te1/1/1	PORT_UP	LINK_DOWN	10GB-FD
30	Te1/1/2	PORT_UP	LINK_DOWN	10GB-FD
31	Te1/1/3	PORT_UP	LINK_DOWN	10GB-FD
32	Te1/1/4	PORT_UP	LINK_DOWN	10GB-FD
33	Te1/1/5	PORT_UP	LINK_DOWN	10GB-FD
34	Te1/1/6	PORT_UP	LINK_DOWN	10GB-FD
35	Te1/1/7	PORT_UP	LINK_DOWN	10GB-FD
36	Te1/1/8	PORT_UP	LINK_DOWN	10GB-FD
37	Fo1/1/1	PORT_UP	LINK_DOWN	40GB-FD
38	Fo1/1/2	PORT_UP	LINK_DOWN	40GB-FD
39	Twe1/1/1	PORT_UP	LINK_DOWN	10GB-FD
40	Twe1/1/2	PORT_UP	LINK_DOWN	10GB-FD

Step 5 show openflow switch 1 flows list

Displays OpenFlow entries.

The following sample output displays a flow that is installed in table 0, where *match any* goes to Table 1. (Match any means that all packets go to Table 1.) In table 1, the destination MAC address 00:00:01:00:00:01 is matched, and the output port is set to 36.

Example:

```
Device# show openflow switch 1 flows list
```

```
Logical Switch Id: 1
Total flows: 8
```

```
Flow: 1 Match: any Actions: goto_table:1, Priority: 9000, Table: 0, Cookie: 0x1,
Duration: 2382.117s, Packets: 34443, Bytes: 3359315
```

```
Flow: 2 Match: any Actions: drop, Priority: 0, Table: 0, Cookie: 0x0,
Duration: 2382.118s, Packets: 294137, Bytes: 28806211
```

```
Flow: 3 Match: any Actions: drop, Priority: 0, Table: 1, Cookie: 0x0,
Duration: 2382.118s, Packets: 34443, Bytes: 3359315
```

```
Flow: 4 Match: dl_dst=00:00:01:00:00:01 Actions: output:36, Priority: 9000,
Table: 1, Cookie: 0x1, Duration: 2382.116s, Packets: 0, Bytes: 0
```

Additional References for OpenFlow

Related Documents

Related Topic	Document Title
OpenFlow commands	<i>Programmability Command Reference</i>
Open Network Foundation	https://www.opennetworking.org/
Faucet OpenFlow controller	<ul style="list-style-type: none"> • https://faucet.nz/ • https://docs.faucet.nz/en/latest/

MIBs

MIB	MIBs Link
	<p>To locate and download MIBs for selected platforms, Cisco IOS releases, and feature sets, use Cisco MIB Locator found at the following URL:</p> <p>http://www.cisco.com/go/mibs</p>

Technical Assistance

Description	Link
<p>The Cisco Support website provides extensive online resources, including documentation and tools for troubleshooting and resolving technical issues with Cisco products and technologies.</p> <p>To receive security and technical information about your products, you can subscribe to various services, such as the Product Alert Tool (accessed from Field Notices), the Cisco Technical Services Newsletter, and Really Simple Syndication (RSS) Feeds.</p> <p>Access to most tools on the Cisco Support website requires a Cisco.com user ID and password.</p>	http://www.cisco.com/support

Feature Information for OpenFlow

The following table provides release information about the feature or features described in this module. This table lists only the software release that introduced support for a given feature in a given software release train. Unless noted otherwise, subsequent releases of that software release train also support that feature.

Use Cisco Feature Navigator to find information about platform support and Cisco software image support. To access Cisco Feature Navigator, go to www.cisco.com/go/cfn. An account on Cisco.com is not required.

Table 2: Feature Information for OpenFlow

Feature Name	Release	Feature Information
OpenFlow	Cisco IOS XE Fuji 16.9.1	<p>OpenFlow is a Software-Defined Network (SDN) standard. It defines a communication protocol in SDN environments that enables an SDN controller to directly interact with the forwarding plane of network devices such as switches and routers.</p> <p>This feature was implemented on the following platforms:</p> <ul style="list-style-type: none"> • Catalyst 9300 Series Switches • Catalyst 9400 Series Switches • Catalyst 9500 Series Switches • Catalyst 9500 Series High Performance Switches
	Cisco IOS XE Gibraltar 16.10.1	Table feature message support on Catalyst 9500 Series High Performance Switches was introduced.
OpenFlow Power over Ethernet	Cisco IOS XE Gibraltar 16.12.1	<p>PoE is supported on OpenFlow ports.</p> <p>This feature was implemented on the following platforms:</p> <ul style="list-style-type: none"> • Catalyst 9300 Series Switches • Catalyst 9400 Series Switches

