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| OF-CONFIG 1.2 (DRAFT) |
| OpenFlow Management and Configuration Protocol |
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# Introduction

This document describes the motivation, scope, requirements, and specification of the standard configuration and management protocol of an operational context which is capable of containing an OpenFlow 1.3 (or previous versions) switch as described in Figure 1. This configuration and management protocol is referred to as OF-CONFIG and is a companion protocol to OpenFlow. This document specifies version 1.1.1 of OF-CONFIG.



Figure : An OpenFlow Configuration Point communicates with an operational context which is capable of supporting an OpenFlow Switch using the OpenFlow Configuration and Management Protocol (OF-CONFIG)

The reader of this document is assumed to be familiar with the OpenFlow protocol and OpenFlow related concepts. Reading the OpenFlow whitepaper (2) and the OpenFlow Specification (1) is recommended prior to reading this document.

It is strongly recommended that switches which implement OF-CONFIG make changes to the OpenFlow logical switch described in this document via OF-CONFIG and limit changes to the OpenFlow logical switch via other methods (e.g. command line interfaces and other legacy management protocols). Future versions may better support other methods of change with detailed notification to the OpenFlow Configuration Point via OF-CONFIG.

# Motivation

The OpenFlow protocol assumes that an OpenFlow datapath (e.g. an Ethernet switch which supports the OpenFlow protocol) has been configured with various artifacts such as the IP addresses of OpenFlow controllers. The motivation for the OpenFlow Configuration Protocol (OF-CONFIG) is to enable the remote configuration of OpenFlow datapaths. While the OpenFlow protocol generally operates on a time-scale of a flow (i.e. as flows are added and deleted), OF-CONFIG operates on a slower time-scale. An example is building forwarding tables and deciding forwarding actions which are done via Openflow protocol while enabling/disabling a port generally does not need to be done at the timescale of a flow and, hence, is done via OF-Config protocol.

OF-CONFIG frames an OpenFlow datapath as an abstraction called an OpenFlow Logical Switch. The OF-CONFIG protocol enables configuration of essential artifacts of an OpenFlow Logical Switch so that an OpenFlow controller can communicate and control the OpenFlow Logical switch via the OpenFlow protocol.

OF-CONFIG introduces an operating context called an OpenFlow Capable Switch for one or more OpenFlow datapaths. An OpenFlow Capable Switch is intended to be equivalent to an actual physical or virtual network element (e.g. an Ethernet switch) which is hosting one or more OpenFlow datapaths by partitioning a set of OpenFlow related resources such as ports and queues among the hosted OpenFlow datapaths. The OF-CONFIG protocol enables dynamic association of the OpenFlow related resources of an OpenFlow Capable Switch with specific OpenFlow Logical Switches which are being hosted on the OpenFlow Capable Switch. OF-CONFIG does not specify or report how the partitioning of resources on an OpenFlow Capable Switch is achieved. OF-CONFIG assumes that resources such as ports and queues are partitioned between multiple OpenFlow Logical Switches such that each OpenFlow Logical Switch can assume full control over the resources that is assigned to it.

OF-CONFIG 1.2 makes simplifying assumptions about the architecture of OpenFlow switches. The specification is deliberately decoupled from whether the switch supports flowvisor or other virtualization models, for example.

The service which sends OF-CONFIG messages to an OpenFlow Capable Switch is called an OpenFlow Configuration Point. No assumptions are made about the nature of the OpenFlow Configuration Point. For example, it may be provided by software acting as an OpenFlow controller or it may by a service provided by a traditional network management framework. Interactions between the OpenFlow Configuration Points and OpenFlow controllers is outside the scope of OF-CONFIG 1.2, but is expected to be addressed in future versions of the specification.

Figure 2 shows the basic abstractions detailed in OF-CONFIG 1.2 and the lines indicate that the OpenFlow Configuration Points and OpenFlow Capable Switches communicate via OF-CONFIG. The configuration settings then take effect on targeted logical switch(es). OpenFlow Controllers and OpenFlow Logical Switches (i.e. datapaths) communicate via OpenFlow.



Figure : Relationship between components defined in this specification, the OF-CONFIG protocol and the OpenFlow protocol

A guiding principle in the development of this specification is to keep the protocol and schema simple and leverage existing protocols and schema models where possible. This helped in quick development of this specification and hopefully will also enable easier adoption, the motivation being to supplement the OpenFlow specification in a meaningful way to further drive the adoption of the software defined networking vision.

## OF-CONFIG and OF-SWITCH

Although OF-CONFIG is considered a complementary protocol to the main OpenFlow switch specification (OF-SWITCH), it is useful to describe the differences that motivate the need for a separate protocol specification in ONF. The table below summarizes the key differences.

|  |  |  |
| --- | --- | --- |
|  | OpenFlow | OF-CONFIG |
| Primary purpose | Modification of match-action rules effecting flows of network packets across an OpenFlow datapath | Remote configuration of possibly multiple OpenFlow datapaths on a physical or virtual platform |
| Terminology | In the OpenFlow 1.3.1 specification and earlier, the terms OpenFlow datapath and OpenFlow Switch are essentially interchangeable | In the OF-Config 1.1.1 specification and earlier, the term OpenFlow Logical Switch maps to the OpenFlow datapath in the OpenFlow 1.3.1 and earlier specs. The term OpenFlow Capable Switch introduces a new abstraction.  OpenFlow Logical Switch = OpenFlow datapath (as defined in the OpenFlow specification)  OpenFlow Controller = controller (as defined in the OpenFlow specification)  OpenFlow Capable Switch = a new element  OpenFlow Configuration Point = a new element |
| Transport | A bit-level protocol specified in the OpenFlow standard currently supported over TCP, TLS, or SSL | An XML data model and operational behavior specified in the OF-Config standard bound to the NETCONF operations and transport standard for network device configuration and management |
| Protocol endpoints | 1) An OpenFlow datapath, also referred to as OpenFlow Logical Switch (OFLS)  2) An OpenFlow Controller (OFC) | 1) An OpenFlow Capable Switch (OFCS) able to instantiate one or more OpenFlow Logical Switches (i.e. OpenFlow datapaths)  2) An OpenFlow Configuration Point (OFCP) |
| Example usage | An OpenFlow Controller adds a flow modification to an OpenFlow datapath (OFLS) which allows Ethernet frames containing IP packets which originated from 192.168.3.10 and are coming in on the datapath's port 2 to be forwarded out on the datapath's port 14 | An OpenFlow Configuration Point configures a particular OpenFlow Logical Switch (OF datapath) to be associated with a particular OpenFlow Controller |

It should be noted that some properties of the OpenFlow Logical Switch (i.e. OpenFlow datapath) are available and configurable via both OpenFlow and OF-CONFIG. Having multiple channels for some of the same data is considered appropriate since the primary purpose of OpenFlow Configuration Points and OpenFlow Controllers are quite different. The ONF strives for synchronization of the data models and semantics between the OpenFlow and OF-CONFIG standards prior to update of either standard.

# Scope

OF-CONFIG 1.2 is focused on the following functions needed to configure an OpenFlow 1.3 datapath:

* The assignment of one or more OpenFlow controllers to openflow data planes
* The configuration of queues and ports
* The ability to remotely change some aspects of ports (e.g. up/down)
* Configuration of ceritificates for secure communication between the OpenFlow Logical Switches and OpenFlow Controllers
* Discovery of capabilities of an OpenFlow Logical Switch
* Configuration of a set of specific tunnel types such as IP-in-GRE, NV-GRE, VxLAN

New functionality introduced in OF-CONFIG 1.2 includes:

* Instantiation of openflow data planes (called openflow logical switches)
* Assignment of resources of an OpenFlow Capable Switch to one or more OpenFlow Logical Switches
* Support for the emerging Negotiable Datapath Model (NDM) being developed in the ONF
* Versioning Support

Other functions and/or the description of their use have been improved.

While limited in scope, OF-CONFIG 1.2 lays the foundation on top of which various automated and more advanced configurations will be possible in future revisions. The ONF Configuration and Management working group will publish additional specifications for network operations, administration, and management (OAM), including, topology discovery, event management, and bootstrap of the OpenFlow capable network.

Note that even though this specification refers to OpenFlow 1.3, OF-CONFIG 1.2 supports previous OpenFlow versions, specifically, OpenFlow 1.0, 1.1 and 1.2.

# Normative Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 (3).

# Terms

The following section lists several terms and definitions used in this document.

## OpenFlow Capable Switch

An OpenFlow Capable switch is a physical or virtual switching device which can act an as operational context for an OpenFlow Logical Switch. OpenFlow Capable Switches contain and manage OpenFlow Resources which may be associated with an OpenFlow Logical Switch context.

## OpenFlow Configuration Point

An OpenFlow Configuration Point configures one or more OpenFlow Capable Switches via the OpenFlow Configuration and Management Protocol (OF-CONFIG).

## OpenFlow Logical Switch

An OpenFlow Logical Switch is a set of resources (e.g. ports) from an OpenFlow Capable Switch which can be associated with a specific OpenFlow Controller. An OpenFlow Logical switch is an instantiation of an OpenFlow Datapath as specified in (1).

## OpenFlow Resource

An OpenFlow Resource is a resource (e.g. port or queue) which is associated with an OpenFlow Capable Switch and may be associated with an OpenFlow Logical Switch.

### OpenFlow Queue

An OpenFlow Queue is a queuing resource of an OpenFlow Logical Switch as described in the OpenFlow specification as the queue component of an OpenFlow datapath.

### OpenFlow Port

An OpenFlow Port is a forwarding interface of an OpenFlow Logical Switch as described in the OpenFlow specification as the port component of an OpenFlow datapath. An Openflow Port may map to a physical port on a physical switch or a logical port on a physical or virtual switch.

## OpenFlow Controller

An OpenFlow Controller is software which controls OpenFlow Logical Switches via the OpenFlow protocol.

## NDM

A Negotiable Datapath Model (NDM) is an abstract switch model that describes specific switch forwarding behaviors controllable via the OpenFlow-Switch protocol. The NDM describes specific requirements for switch behavior so that implementers can perform optimizations or deliver more complex forwarding behaviors (beyond what can be scalably represented in a single OpenFlow table) than they could otherwise.

# Requirements

This section describes requirements for the design of OF-CONFIG 1.2.

## Requirements from the OpenFlow 1.3 Protocol Specification

The specification of version 1.3 of the OpenFlow protocol (1) includes explicit and implicit requirements for the configuration of OpenFlow switches. In (1) the term ‘configuration’ is used for two different kinds of operations: configuration using the OpenFlow protocol and configuration outside of the OpenFlow protocol. The first kind of configuration is dealt within (1). OF-CONFIG 1.2 enables other configuration of OpenFlow switches. The specification of OF-CONFIG 1.2 is written with extensibility in mind. This includes versioning and backward compatibility.

### Instantiation of one or more Openflow Data Planes on an Openflow Capable Switch and assignment of resources to these data planes

An openflow capable switch is capable of hosting one or more openflow data planes (also refered to as openflow logical switch). Initially, the openflow capable switch owns all the resources of the switch and does not have any data plane instantiated. Using the of-config 1.2 protocol, OFCP can instantiate one or more openflow data planes and can assign resources such as queues and ports to these openflow data planes. Some of the resources like management port may not be assigned to any openflow data plane.

### Connection Setup to a Controller

Section 6.2 (Connection Setup) of (1) requires that an OpenFlow switch always initiate the connection to the OpenFlow controller and discusses the process of setting up a connection between the OpenFlow switch and an OpenFlow controller. The switch initiates the connection applying three parameters that need to be configured in advance:

* the IP address of the controller
* the port number at the controller
* the transport protocol to use, either TLS or TCP

OF-CONFIG 1.2 must provide means for configuring these parameters. Note that in future, alternative mechanisms for discovering the OpenFlow controller may be supported.

### Multiple Controllers

Section 6.3 of (1) discusses how a switch deals with multiple controllers simultaneously. This implicitly requires OF-CONFIG 1.2 to provide means for configuring multiple instances of the parameter set listed in 6.1.1 for specifying the connection setup to multiple controllers.

### OpenFlow Logical Switches

The OpenFlow 1.3 protocol specifies various kinds of OpenFlow resources associated with an OpenFlow Logical Switch. The OF-CONFIG protocol must support the configuration of these OpenFlow resources associated with an OpenFlow Logical Switch. Examples of resources include queues and ports that have been assigned to an OpenFlow Logical Switch. It is assumed that OpenFlow Logical Switches have been instantiated out of band, for example, an administrator may have created them upfront. In addition, partitioning/assignment of OpenFlow resources amongst multiple OpenFlow switches that may exist in an OpenFlow Capable Switch has also been done out of band.

### Connection Interruption

Section 6.4 of (1) discusses the choice of two modes the switch should immediately enter after losing contact with all controllers. The modes are

* fail secure mode
* fail standalone mode

OF-CONFIG protocol must provide means for configuring the mode to enter in such a case.

### Encryption

Section 6.5 of (1) discusses encryption of connections to controllers that use TLS. It explicitly states “Each switch must be user-configurable with one certificate for authenticating the controller (controller certificate) and the other for authenticating to the controller (switch certificate)”. Hence, OF-CONFIG must provide means for configuring a switch certificate and a controller certificate for each controller that is configured to use TLS.

### Queues

Section A.3.6 of (1) describes the configuration of queues. Queue in (1) have three parameters that may be configurable:

* min-rate
* max-rate
* experimenter

OF-CONFIG 1.2 must provide means for configuring these parameters.

### Ports

The OpenFlow protocol already contains methods to configure a limited amount of port parameters of OpenFlow switches. The OpenFlow protocol specification (1) does not explicitly require an external configuration means, and therefore we cannot derive the requirement for configuring ports from (1). However, the configuration of ports is an essential step of configuring a network and thus a requirement for OF-CONFIG 1.2. Section A.3.4.3 of (1) defines the following parameters for port configuration:

* no-recveive
* no-forward
* no-packetin
* admin-state

OF-CONFIG 1.2 must provide means for configuring these parameters.

Also defined in Section A.2.1 of the OpenFlow protocol specification (1) are port features. There are four sets of these features for current, advertised, supported, and peer-advertised features. Feature sets current, supported, and peer-advertised contain state information and cannot to be configured. Only advertised features could potentially be configured with the following parameters:

* speed
* duplex-mode
* copper-medium
* fiber-medium
* auto-negotiation
* pause
* asymmetric-pause

OF-CONFIG 1.2 must provide means for configuring these advertised features and for obtaining current, supported and peer-advertised state information for these features.

Section 4.4 of (1) defines logical ports that are higher level abstratcions and that may include encapsulation. In addition, logical ports support passing of meta data to the controller. These logical ports may be used in for example, datacenter scenarios for setting up virtual networks. OF-CONFIG 1.2 must support the configuration of these logical ports. However, the configuration of logical ports in OF-CONFIG 1.2 is limited to a small number of tunnels (specifically to IPinGRE, VxLAN and NVGRE) that may be used in datacenter scenarios like network virtualization. Future versions of OF-CONFIG will support configuration of additional types of tunnels.

### Capability Discovery

OpenFlow 1.3 describes the various capabilities that an OpenFlow Logical Switch may implement eg there are several actions in OpenFlow 1.3 that are optional. While configuration of these capabilities is outside the scope of OF-CONFIG 1.2, it supports discovery of these capabilities. It is assumed that capabilities have been configured for OpenFlow Logical switches either as part of instantiation of these switches or through some out of band mechanisms.

### Datapath ID

Section A.3.1 of (1) discusses the datapath ID of a switch. It is a 64-bit filed with the lower 48 bit intended for the switch MAC address and the remaining 16 bit left to the switch operator. Although not explicitly requested by (1), OF-CONFIG should provide means for configuring the datapath ID.

## Requirements for NDMs

OF-CONFIG 1.2 includes optional support for Negotiable Datapath Models (NDMs). An NDM is an abstract switch model that describes specific switch forwarding behaviors controllable via the OpenFlow-Switch protocol.

When a capable switch implements the NDM framework (which is an optional enhancement to OpenFlow), an OFCP and a capable switch agree on an NDM to be associated with a logical switch prior to sending control messages, such as flowmods, to the logical switch. This agreement may be implicit (i.e., each side is configured a priori) or negotiated when the control relationship is established.

NDMs are characterized by parameters related to table sizes or optional functionality. The NDM framework allows for implementations to have a range of flexibility in their parameters. Some implementations may have no flexibility; others will allow some adjustment of parameters at the time the OFCP associates the NDM with a logical switch. NDM implementations that support parameter adjustment should (?) also offer an RPC mechanism to allow the OFCP and the capable (?) switch to determine the parameters in a specific situation.

The NDM framework simplifies the job of implementing an OpenFlow controller or OpenFlow agent for a switch. The NDM describes specific requirements for switch behavior so that implementers can perform optimizations or deliver more complex forwarding behaviors (beyond what can be scalably represented in a single OpenFlow table) than they could otherwise.

The optional NDM manageability feature must support the following requirements:

1. The ability to query the capable switch about support for NDMs
2. The ability to query the capable switch for the set of available supported NDMs
3. The ability to associate a logical switch with a parameterized NDM
4. The ability to remove a parameterized NDM from a logical switch

## Operational Requirements

The OF-CONFIG 1.2 must meet support the following scenarios:

1. OF-CONFIG 1.2 must support an OpenFlow Capable Switch being configured by multiple OpenFlow Configuration Points.
2. OF-CONFIG 1.2 must support an OpenFlow Configuration Point managing multiple OpenFlow Capable Switches.
3. OF-CONFIG 1.2 must support an OpenFlow Logical Switch being controlled by multiple OpenFlow Controllers.
4. OF-CONFIG 1.2 must support configuring ports and queues of an OpenFlow Capable Switch that have been assigned to an OpenFlow Logical Switch.
5. OF-CONFIG 1.2 must support discovery of capabilities of an OpenFlow Logical Switch.
6. OF-CONFIG 1.2 must support configuration of tunnels such as IP-in-GRE, NVGRE and VxLan that are represented as logical ports of an OpenFlow Logical Switch.

## Requirements for the Switch Management Protocol

OF-CONFIG 1.2 defines a communication standard between an OpenFlow switch and an OpenFlow Configuration Point. It consists of a network management protocol specified in Section 7 and a data model defined in Section 8. This subsection specifies requirements for the network management protocol. Note that these requirements are a superset of the requirements that may be needed for the limited scope of configuration specified in this specifications. The intent for the below requirements is to future proof the protocol choice so that we are able to address the future scenarios without having to modify the protocol choice itself. The protocol must comply with the following requirements:

1. The protocol must be secure providing integrity, privacy, and authentication. Authentication of both ends, switch and configuration point, must be supported.
2. The protocol must support reliable transport of configuration requests and replies.
3. The protocol must support connection setup by the configuration point.
4. The protocol should support connection setup by the switch.
5. The protocol must be able to carry partial switch configurations.
6. The protocol must be able to carry bulk switch configurations.
7. The protocol must support the configuration point setting configuration data at the switch
8. The protocol must support the configuration point retrieving configuration data from the switch.
9. The protocol should support the configuration point retrieving status information from the switch.
10. The protocol must support creation, modification and deletion of configuration information at the switch.
11. The protocol must support reporting on the result of a successful configuration request.
12. The protocol must support reporting error codes for partially or completely failed configuration requests.
13. The protocol should support sending configuration requests independent of the completion of previous requests.
14. The protocol should support transaction capabilities including rollback per operation.
15. The protocol must provide means for asynchronous notifications from the switch to the configuration point. An example may be, even though this scenario is out of scope for OF-CONFIG 1.2, is if an administrator changes a configuration out of band, the switch may need to provide an appropriate notification to the OFCP.
16. The protocol should be extensible.
17. The protocol should support reporting its capabilities.

# NETCONF as the Transport Protocol

The OF-CONFIG1.1.1 protocol provides a standard way to modify basic OpenFlow configuration for the operation of an OpenFlow logical switch within the context of an OpenFlow Capable Switch. At the same time, it provides vendors the ability to extend and innovate by providing new and improved configuration capabilities. To achieve these goals, OF-CONFIG1.1.1 requires that devices supporting OF-CONFIG1.1.1 MUST implement the NETCONF protocol (4) as their transport protocol. This in turn implies as specified by the NETCONF specification that OpenFlow Capable Switches supporting OF-CONFIG1.1.1 must implement SSH as a transport protocol. In addition, the OpenFlow Capable Switches implementing OF-CONFIG1.1.1 protocol may implement additional transports such as Web Services-Management or something else. Future versions of OF-CONFIG may specify binding to these additional transports.

NETCONF is a stable protocol that has been standardized for several years now. It is widely available on various platforms and achieves the needs for OF-CONFIG1.1.1. NETCONF defines a set of operations on top of a messaging layer (RPC). The diagram below shows the various layers of the NETCONF protocol.



Figure 6 NETCONF Layers and Examples

The OpenFlow capable switches MUST support the schema as defined in this specification as the content layer in the above diagram. The schema currently covers basic configuration elements and will be extended in the next versions of this document.

The NETCONF protocol meets the OF-CONFIG 1.2 requirements for communication between an OpenFlow Configuration Point and an OpenFlow switch as listed in Section 6.3. In addition, if future needs of OF-CONFIG are not met by the NETCONF protocol, NETCONF is extensible which will allow OF-CONFIG to extend NETCONF for its purpose.

1. It supports TLS as communication transport protocol (directly or with SOAP or BEEP in between) that can be used for providing integrity, privacy, and mutual authentication.
2. All specified transport mappings for NETCONF use TLS or TCP as underlying transport protocol and thus provide reliable transport.
3. The common way to establish a connection with NETCONF is from the Configuration Point (configuration point) to the managed device (switch).
4. The NETCONF standards support reversed configuration setup only if BEEP is used as transport protocol.
5. It supports partial switch configuration to the most fine-grain level.
6. It supports full switch configuration with a single operation.
7. It supports setting of configuration data.
8. It supports the retrieval of configuration data.
9. It supports the retrieval of (non-configuration) status data.
10. It supports creation, modification and deletion of configuration information.
11. It supports returning success codes after completing a configuration operation.
12. It supports support reporting error codes for partially or completely failed configuration requests.
13. It supports sending configuration requests independent of the completion of previous requests. Requests may be queued or processed concurrently at a switch. Each request has a request ID. Success or failure indications can be sent independently of other requests individually for each request ID.
14. It supports transaction capabilities including rollback per operation.
15. With its extension defined in RFC 5277 it supports asynchronous notifications from the managed device (switch) to the Configuration Point (configuration point).
16. It is extensible. New operations can be added and its support can be checked by capability retrieval.
17. It supports reporting its capabilities.

# Data Model

This section specifies the data model for OF-CONFIG 1.2. Configurations of an OpenFlow Capable Switch or for portions of it are encoded in XML. The data model is structured into classes and attributes of classes. Each class is described in a separate sub-section by

1. a UML diagram giving an overview of the class,
2. a portion of an XML schema extracted from the normative XML schema in 2013, including normative constraints for instances of the class extending the XML schema by semantic specifications,
3. an example for XML code encoding an instance of the class

The full XML schema and the full YANG module are listed in Appendices A and B. Normative for OF-CONFIG 1.2 is the XML schema in 2013 and the normative constraints in the descriptions of the individual elements. The YANG module in Appendix B incorporates the XML schema specifications as well as the normative constraints though is not normative for this specification.

One of the design goals of the model is efficient and clear encoding of switch configurations in XML. Human readability is a strong feature of XML. But since the XML schema will mainly be created and parsed by the protocol entity, the ease of encoding and parsing was preferred over readability. This implies that in case of a trade-off between cleanness and simplicity of the XML-based configuration and simplicity of the XML schema, usually cleanness and simplicity of the XML-based configuration has been preferred.

## YANG Module

In Appendix B you can find a YANG module that conforms to the normative constraints given in XML schema of 2013 and the additional explanations in this section. Most of the constraints that are given in the description of the XML schema are automatically enforced in the YANG module by syntax elements already built into the YANG language. Implementers that already use the NETCONF tools could profit by using the YANG module to reduce implementation time. Nevertheless, they need to ensure that all normative constraints are obeyed – including those that are not expressible by the YANG syntax.

## Core Data Model

The following UML diagram describes the top-level classes of the data model.



Figure : UML Class Diagram for OF-CONFIG Data Model

The core of the model is an OpenFlow Capable Switch that is configured by OpenFlow Configuration Points.

The switch contains a set of resources of different types. For OF-CONFIG 1.2, several types of resources are included in the model: OpenFlow Ports, OpenFlow Queues, External Certificate, Owned Certificate and Flow Table. More resource types may be added in future revisions of OF-CONFIG. OpenFlow resources can be made available for use to OpenFlow Logical Switches.

Instances of OpenFlow logical switches are contained within the OpenFlow Capable Switch. A set of OpenFlow Controllers is assigned to each OpenFlow logical switch.

The data model contains several identifiers, most of them encoded as an XML element <id>. Currently these IDs are defined as strings with required uniqueness in a certain context. Beyond uniqueness requirements, no further guidance is given on how to build these strings. This may be changed in the future. Particularly, the use of Universal Resource Names (URNs) is envisioned. This requires developing a naming scheme for URNs in OF-CONFIG and registering a URN namespace for the ONF. It is expected that recommendations for URN-based identifiers will be introduced by a future version of OF-CONFIG. Since URNs are represented as strings, such recommendations can be made compatible with identifiers in OF-CONFIG 1.2.

## OpenFlow Capable Switch

The OpenFlow Capable Switch serves as the root element for an OpenFlow configuration. It has relationships to

* OpenFlow Configuration Points that manage and particularly configure the OpenFlow Capable Switch,
* OpenFlow logical switches that are contained and instantiated within the OpenFlow Capable Switch,
* OpenFlow Resources contained in the OpenFlow Capable Switch that may be used by OpenFlow Logical Switches.

### UML Diagram



Figure : Data Model Diagram for OpenFlow Capable Switch

### XML Schema

|  |
| --- |
| <xs:element name="capable-switch">  <xs:annotation>  <xs:documentation>  The OpenFlow Capable Switch serves as the root  element for an OpenFlow configuration. It contains OpenFlow logical  switches and resources that can be assigned to logical  switches. It may have relations to OpenFlow Configuration  Points.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="id" type="inet:uri">  <xs:annotation>  <xs:documentation>  A unique but locally arbitrary identifier that  uniquely identifies a Capable Switch within the context of  potential OpenFlow Configuration Points. It MUST be  persistent across reboots of the OpenFlow Capable Switch.  This element MUST be present in the NETCONF data store.  If this element is not present in a NETCONF &lt;edit-config&gt;  operation 'create', 'merge' or 'replace' and the parent  element does not exist, a 'data-missing' error is  returned.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="config-version" minOccurs="0" type="xs:string">  <xs:annotation>  <xs:documentation>  The maximum supported OF-CONFIG version that is  supported by the OpenFlow Capable Switch. For switches  implementing this version of the OF-CONFIG protocol this  MUST always be 1.1.1.  This object can be used to identify the OF-CONFIG version  a capable switch supports beginning with version 1.1.1 of  OF-CONFIG. In addition the supported version can be  determined by the namespace the OpenFlow Capable Switch  returns to configuration request of an element (like  capable-switch) that is present in all OF-CONFIG versions  specified so far. This is the only possiblity to identify  OF-CONFIG versions prior to OF-CONFIG 1.2.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="configuration-points" minOccurs="0">  <xs:complexType>  <xs:sequence>  <xs:element name="configuration-point" minOccurs="0" maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  The list of all Configuration Points known to  the OpenFlow Capable Switch that may manage it using  OF-CONFIG.  The element 'id' of OFConfigurationType MUST be unique  within this list.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFConfigurationPointType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:complexType>  <xs:key name="key\_configuration-points\_capable-switch\_configuration-point">  <xs:selector xpath="of11-config:configuration-point"/>  <xs:field xpath="of11-config:id"/>  </xs:key>  </xs:element>  <xs:element name="resources" minOccurs="0">  <xs:annotation>  <xs:documentation>  A lists containing all resources of the OpenFlow  Capable Switch that can be used by OpenFlow Logical  Switches. Resources are listed here independent of their  actual assignment to OpenFlow Logical Switches. They may  be available to be assigned to an OpenFlow Logical Switch  or already in use by an OpenFlow Logical Switch.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="port" minOccurs="0" maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  The list contains all port resources of the  OpenFlow Capable Switch.  The element 'resource-id' of OFPortType MUST be unique  within this list.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFPortType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="queue" minOccurs="0" maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  The list contains all queue resources of the  OpenFlow Capable Switch.  The element 'resource-id' of OFQueueType MUST be unique  within this list.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFQueueType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="owned-certificate" minOccurs="0" maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  The list contains all owned certificate  resources of the OpenFlow Capable Switch.  The element 'resource-id' of OFOwnedCertificateType MUST  be unique within this list.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFOwnedCertificateType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="external-certificate" minOccurs="0" maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  The list contains all external certificate  resources of the OpenFlow Capable Switch.  The element 'resource-id' of OFExternalCertificateType  MUST be unique within this list.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFExternalCertificateType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="flow-table" minOccurs="0" maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  The list contains all flow table resources of  the OpenFlow Capable Switch.  The element 'resource-id' of OFFlowTableType MUST be  unique within this list.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFFlowTableType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:complexType>  <xs:key name="key\_resources\_capable-switch\_port">  <xs:selector xpath="of11-config:port"/>  <xs:field xpath="of11-config:resource-id"/>  </xs:key>  <xs:key name="key\_resources\_capable-switch\_queue">  <xs:selector xpath="of11-config:queue"/>  <xs:field xpath="of11-config:resource-id"/>  </xs:key>  <xs:key name="key\_resources\_capable-switch\_owned-certificate">  <xs:selector xpath="of11-config:owned-certificate"/>  <xs:field xpath="of11-config:resource-id"/>  </xs:key>  <xs:key name="key\_resources\_capable-switch\_external-certificate">  <xs:selector xpath="of11-config:external-certificate"/>  <xs:field xpath="of11-config:resource-id"/>  </xs:key>  <xs:key name="key\_resources\_capable-switch\_flow-table">  <xs:selector xpath="of11-config:flow-table"/>  <xs:field xpath="of11-config:resource-id"/>  </xs:key>  </xs:element>  <xs:element name="logical-switches" minOccurs="0">  <xs:annotation>  <xs:documentation>  This element contains a list of all OpenFlow  Logical Switches available at the OpenFlow Capable  Switch.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="switch" minOccurs="0" maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  The list of all OpenFlow Logical Switches on  the OpenFlow Capable Switch.  The element 'resource-id' of OFLogicalSwitchType MUST be  unique within this list.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFLogicalSwitchType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:complexType>  <xs:key name="key\_logical-switches\_capable-switch\_switch">  <xs:selector xpath="of11-config:switch"/>  <xs:field xpath="of11-config:id"/>  </xs:key>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element> |

### XML Example

|  |
| --- |
| <capable-switch>  <id>CapableSwitch0</id>  <configuration-points>  ...  </configuration-points>  <resources>  ...  </resources>  <logical-switches>  ...  </logical-switches>  </capable-switch> |

## OpenFlow Configuration Point

The Configuration Point is an entity that manages the switch using the OF-CONFIG protocol. Attributes of an OpenFlow Configuration Point allow the OpenFlow Capable Switches to identify a Configuration Point and specify which protocol is used for communication between Configuration Point and OpenFlow Capable Switch. The OpenFlow Capable Switch stores a list of Configuration Points that manage it or have managed it. An OpenFlow Configuration Point is to an OpenFlow Capable Switch what an OpenFlow Controller is to an OpenFlow Logical switch.

Instances of the Configuration Point class are used by switches to connect to a configuration point. Currently the only transport mapping that supports a connection set-up initiated by the switch to be configured is the mapping to the BEEP protocol (5). Other NETCONF transport mappings (6,7,8) may be extended in the future to also support connection set-up in this direction. Nevertheless SSH is used as a default connection protocol because connection initiation by the switch is optional.

### UML Diagram



Figure : Data Model Diagram for an OpenFlow Configuration Point

### XML Schema

|  |
| --- |
| <xs:group name="OFConfigurationPointType">  <xs:annotation>  <xs:documentation>  Representation of an OpenFlow Configuration Point.  Instances of the Configuration Point class SHOULD be stored  persistently across reboots of the OpenFlow Capable Switch.    When a connection is established between an OpenFlow Capable  Switch and a Configuration Point the switch MUST store the  connection information in an instance of the Configuration  Point class. If such an instance does not exist, the OpenFlow  Capable Switch MUST create an instance where it then stores  the connection information.    An OpenFlow Capable Switch that cannot initiate a connection  to a configuration point does not have to implement the  Configuration Point class. It SHOULD block attempts to write  to instances of the Configuration Point class with NETCONF  &lt;edit-config&gt; operations.  NETCONF &lt;edit-config&gt; operations MUST be implemented as  follows:  \* The 'id' element MUST be present at all &lt;edit-config&gt;  operations to identify the configuration point.  \* If the operation is 'merge' or 'replace', the element is  created if it does not exist, and its value is set to the  value found in the XML RPC data.  \* If the operation is 'create', the element is created if it  does not exist. If the element already exists, a  'data‑exists' error is returned.  \* If the operation is 'delete', the element is deleted if it  exists. If the element does not exist, a 'data‑missing'  error is returned.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:element name="id" type="OFConfigId">  <xs:annotation>  <xs:documentation>  A unique but locally arbitrary identifier that  identifies a Configuration Point within the context of an  OpenFlow Capable Switch.  This element MUST be present to identify the configuration  point.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="uri" type="inet:uri">  <xs:annotation>  <xs:documentation>  A locator of the Configuration Point. It  identifies the location of the Configuration Point as a  service resource and MUST include all information necessary  for the OpenFlow Capable Switch to connect to the  Configuration Point or re-connect to it should it become  disconnected. Such information MAY include, for example,  protocol, fully qualified domain name, IP address, port  number, etc.  This element MUST be present in the NETCONF data store.  If this element is not present in a NETCONF &lt;edit-config&gt;  operation 'create', 'merge' or 'replace' and the parent  element does not exist, a 'data-missing' error is  returned.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="protocol" type="OFConfigurationPointProtocolType">  <xs:annotation>  <xs:documentation>  The transport protocol that the Configuration  Point uses when communicating via NETCONF with the OpenFlow  Capable Switch.  This element is optional. If it is not present its value  defaults to 'ssh'.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:group>  <xs:simpleType name="OFConfigurationPointProtocolType">  <xs:annotation>  <xs:documentation>  Possible protocols to connect ot an OF  Configuration Point  </xs:documentation>  </xs:annotation>  <xs:restriction base="xs:string">  <xs:enumeration value="ssh"/>  <xs:enumeration value="soap"/>  <xs:enumeration value="tls"/>  <xs:enumeration value="beep"/>  </xs:restriction>  </xs:simpleType> |

### XML Example

|  |
| --- |
| <configuration-point>  <id>ConfigurationPoint1</id>  <uri>uri0</uri>  <protocol>ssh</protocol>  <configuration-point> |

## OpenFlow Logical Switch

The OpenFlow Logical Switch represents an instance of a logical switch that is available or can be made available on an OpenFlow Capable Switch. An OpenFlow Logical switch is a logical context which behaves as the datapath as described in the OpenFlow specification. The OpenFlow Logical Switch is connected to one or more OpenFlow Controllers via the OpenFlow protocol. It uses resources of the OpenFlow Capable Switch for realizing the capabilities offered via the OpenFlow protocol. The OpenFlow Logical Switch has relationships to

* OpenFlow Controllers that control the OpenFlow Capable Switch
* OpenFlow Resources that are available from the OpenFlow Capable Switch

### UML Diagram



Figure : Data Model Diagram for an OpenFlow Logical Switch

### XML Schema

|  |
| --- |
| <xs:group name="OFLogicalSwitchType">  <xs:annotation>  <xs:documentation>  This grouping specifies all properties of an  OpenFlow Logical Switch.  Elements of type OFLogicalSwitchType can be created or  deleted with NETCONF &lt;edit-config&gt; operations 'create' or  'delete'. The NETCONF &lt;edit-config&gt; operations MUST be  implemented as follows:  \* The 'id' element MUST be present at all &lt;edit-config&gt;  operations to identify the OpenFlow Logical Switch.  \* If the operation is 'merge' or 'replace', and the element  does not exist, a 'data-missing' error is returned. If the  element exists its value is set to the value found in the  XML RPC data.  \* If the operation is 'create', a 'operation-not-supported'  error with type 'application' is returned.  \* If the operation is 'delete', 'operation-not-supported'  error with type 'application' is returned.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:element name="id" type="OFConfigId">  <xs:annotation>  <xs:documentation>  A unique but locally arbitrary identifier that  identifies a Logical Switch within the context of an  OpenFlow Capable Switch. It MUST be persistent across  reboots of the OpenFlow Capable Switch.  This element MUST be present to identify the OpenFlow  Logical Switch.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="capabilities">  <xs:annotation>  <xs:documentation>  This element contains all capability items that  an OpenFlow Logical Switch MAY implement.  This element and its children can only be retrieved by  NETCONF &lt;get&gt; operation since it contain no configuration  data.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFLogicalSwitchCapabilitiesType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="datapath-id" type="datapath-id-type">  <xs:annotation>  <xs:documentation>  The datapath identifier of the Logical Switch  that uniquely identifies this Logical Switch within the  context of all OpenFlow Controllers associated with the  OpenFlow Logical Switch. The datapath identifier is a  string value that MUST be formatted as a sequence of 8  2-digit hexadecimal numbers that are separated by colons,  for example, '01:23:45:67:89:ab:cd:ef'. When processing a  datapath identifier, the case of the decimal digits MUST be  ignored.  This element MUST be present in the NETCONF data store.  If this element is not present in a NETCONF &lt;edit-config&gt;  operation 'create', 'merge' or 'replace' and the parent  element does not exist, a 'data-missing' error is  returned.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="enabled" type="xs:boolean">  <xs:annotation>  <xs:documentation>  This element indicates the administrative state  of the OpenFlow Logical Switch. A value of 'false' means  the OpenFlow Logical Switch MUST NOT communicate with any  OpenFlow Controllers, MUST NOT conduct any OpenFlow  processing, and SHOULD NOT be utilizing computational or  network resources of the underlying platform.  This element is optional. If this element is not present it  defaults to 'false'.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="check-controller-certificate" type="xs:boolean">  <xs:annotation>  <xs:documentation>  This element indicates the behavior of the  OpenFlow Logical Switch when connecting to an OpenFlow  Controller.    If set to value 'false', the logical switch will connect to  a controller without checking any controller certificate.    If set to value 'true', then the logical switch will  connect to a controller with element &lt;protocol&gt; set to  'TLS', only if the controller provides a certificate that  can be verified with one of the certificates stored in the  list called external-certificates in the OpenFlow Capable  Switch.    If a certificate cannot be validated, the OpenFlow Logical  Switch MUST terminate communication with the corresponding  OpenFlow Controller, MUST NOT conduct any OpenFlow  processing on requests of this OpenFlow controller, and  SHOULD NOT further utilize any computational or network  resources of for dealing with this connection.    If set to value 'true', the OpenFlow Logical Switch MUST  NOT connect to any OpenFlow Controller that does not  provide a certificate. This implies that it cannot connect  to an OpenFlow controller that has the value of element  protocol set to 'TCP'. Only connections with protocol 'TLS'  are possible in this case.  This element is optional. If this element is not present it  defaults to 'false'.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="lost-connection-behavior">  <xs:annotation>  <xs:documentation>  This element indicates the the behavior of the  OpenFlow Logical Switch in case it loses contact with all  OpenFlow Controllers. There are two alternative modes in  such a case: fails secure mode and fail standalone mode as  defined by the OpenFlow protocol specification version 1.2,  section 6.4. These are the only allowed values for this  element. Default is the fail secure mode.  This element is optional. If this element is not present it  defaults to 'failSecureMode'.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:enumeration value="failSecureMode"/>  <xs:enumeration value="failStandaloneMode"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  <xs:element name="controllers">  <xs:annotation>  <xs:documentation>  The list of controllers for this Logical switch.  The element 'id' of OFControllerType MUST be unique within  this list.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="controller" minOccurs="0" maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  The list of OpenFlow Controllers that are  assigned to the OpenFlow Logical Switch. The switch MUST  NOT connect to any OpenFlow Controller that is not  contained in this list.  NETCONF &lt;edit-config&gt; operations MUST be implemented as  follows:  \* The 'id' element MUST be present at all &lt;edit-config&gt;  operations to identify the controller.  \* If the operation is 'merge' or 'replace', the element  is created if it does not exist, and its value is set  to the value found in the XML RPC data.  \* If the operation is 'create', the element is created if  it does not exist. If the element already exists, a  'data‑exists' error is returned.  \* If the operation is 'delete', the element is deleted if  it exists. If the element does not exist, a  'data‑missing' error is returned.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFControllerType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:complexType>  <xs:key name="key\_controllers\_controller">  <xs:selector xpath="of11-config:controller"/>  <xs:field xpath="of11-config:id"/>  </xs:key>  </xs:element>  <xs:element name="resources">  <xs:annotation>  <xs:documentation>  The list of identifiers of all resources of the  OpenFlow Capable Switch that the OpenFlow Logical Switch  has exclusive or non-exclusive access to. A resource is  identified by the value of its resource-identifier element.  For each resource identifier value in this list, there MUST  be an element with a matching resource identifier value in  the resources list of the OpenFlow Capable Switch.    Identifiers of this list are contained in elements  indicating the type of resource: 'port', 'queue',  'certificate', or 'flow-table'. Depending on the type,  different constraints apply. These are specified in  separate descriptions per type.  The elements in this lists can be created, deleted or modified by NETCONF &lt;create&gt;, &lt;delete&gt; and &lt;edit-config&gt; operations. They can be retrieved by NETCONF &lt;get&gt; or &lt;get-config&gt;  operations.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="port" minOccurs="0" maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  A resource identifier of a port of the  OpenFlow Capable Switch that the OpenFlow Logical Switch  has exclusive access to.  The elements in this list MUST refer to elements at the  following path:  /capable-switch/resources/port/resource-id  Elements in this list MUST be unique. This means each  port element can only be referenced once.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="inet:uri">  </xs:restriction>  </xs:simpleType>  </xs:element>  <xs:element name="queue" minOccurs="0" maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  A resource identifier of a queue of the  OpenFlow Capable Switch that the OpenFlow Logical Switch  has exclusive access to.  The elements in this list MUST refer to elements at the  following path:  /capable-switch/resources/queue/resource-id  Elements in this list MUST be unique. This means each  queue element can only be referenced once.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="inet:uri">  </xs:restriction>  </xs:simpleType>  </xs:element>  <xs:element name="certificate" minOccurs="0">  <xs:annotation>  <xs:documentation>  The resource identifier of the owned  certificate in the OpenFlow Capable Switch that the  OpenFlow Logical Switch uses to identify itself. This  element MUST NOT occur more than once in an OpenFlow  Logical Switch's resource list.    If no such element is in an OpenFlow Logical Switch's  resource list, then the OpenFlow Logical Switch does not  authenticate itself towards an OpenFloe Controller with a  certificate. If this element is present, then the  OpenFlow Logical Switch MUST provide this certificate for  authentication to an OpenFlow Controller when setting up  a TLS connection.    For TCP connections this element is irrelevant.  The element MUST refer to an element at the following  path:  /capable-switch/resources/owned-certificate/resource-id  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="inet:uri">  </xs:restriction>  </xs:simpleType>  </xs:element>  <xs:element name="flow-table" minOccurs="0" maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  A resource identifier of a flow table of the  OpenFlow Capable Switch that the OpenFlow Logical Switch  has exclusive access to.  The elements in this list MUST refer to elements at the  following path:  /capable-switch/resources/flow-table/resource-id  Elements in this list MUST be unique. This means each  flow-table element can only be referenced once.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="inet:uri">  </xs:restriction>  </xs:simpleType>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:group>  <xs:simpleType name="datapath-id-type">  <xs:annotation>  <xs:documentation>  The datapath-id type represents an OpenFlow  datapath identifier.  </xs:documentation>  </xs:annotation>  <xs:restriction base="xs:string">  <xs:pattern value="[0-9a-fA-F]{2}(:[0-9a-fA-F]{2}){7}"/>  </xs:restriction>  </xs:simpleType> |

### XML Example

|  |
| --- |
| <logical-switch>  <id>LogicalSwitch5</id>  <capabilities>  ...  <capabilities>  <datapath-id>datapath-id0</datapath-id>  <enabled>true</enabled>  <check-controller-certificate>false</check-controller-certificate>  <lost-connection-behavior>failSecureMode</lost-connection-behavior>  <controllers>  ...  </controllers>  <resources>  <port>port2</port>  <port>port3</port>  <queue>queue0</queue>  <queue>queue1</queue>  <certificate>ownedCertificate4</certificate>  <flow-table>1</flow-table>  <flow-table>2</flow-table>  …  <flow-table>255</flow-table>  </resources>  </logical-switch> |

## Logical Switch Capabilities

### UML Diagram



Figure 7: Data Model Diagram for an OpenFlow Logical Switch Capabilities

### XML Schema

|  |
| --- |
| <xs:group name="OFLogicalSwitchCapabilitiesType">  <xs:annotation>  <xs:documentation>  This grouping specifies all properties of an  OpenFlow logical switch's capabilities.  Elements in the type OFLogicalSwitchCapabilitiesType are not  configurable and can only be retrieved by NETCONF &lt;get&gt;  operations. Attemps to modify this element and its children  with a NETCONF &lt;edit-config&gt; operation MUST result in an  'operation-not-supported' error with type 'application'.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:element name="max-buffered-packets" type="xs:unsignedInt">  <xs:annotation>  <xs:documentation>  The maximum number of packets the logical switch  can buffer when sending packets to the controller using  packet-in messages.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="max-tables" type="xs:unsignedByte">  <xs:annotation>  <xs:documentation>  The number of flow tables supported by the  logical switch.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="max-ports" type="xs:unsignedInt">  <xs:annotation>  <xs:documentation>  The number of flow tables supported by the  logical switch.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="flow-statistics" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Specifies if the logical switch supports flow  statistics.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="table-statistics" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Specifies if the logical switch supports table  statistics.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="port-statistics" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Specifies if the logical switch supports port  statistics.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="group-statistics" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Specifies if the logical switch supports group  statistics.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="queue-statistics" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Specifies if the logical switch supports queue  statistics.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="reassemble-ip-fragments" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Specifies if the logical switch supports  reassemble IP fragments.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="block-looping-ports" type="xs:boolean">  <xs:annotation>  <xs:documentation>  'true' indicates that a switch protocol outside  of OpenFlow, such as 802.1D Spanning Tree, will detect  topology loops and block ports to prevent packet loops.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="reserved-port-types">  <xs:annotation>  <xs:documentation>  Specify generic forwarding actions such as  sending to the controller, flooding, or forwarding using  non-OpenFlow methods, such as 'normal' switch processing.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="type" minOccurs="0" maxOccurs="unbounded">  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:enumeration value="all"/>  <xs:enumeration value="controller"/>  <xs:enumeration value="table"/>  <xs:enumeration value="inport"/>  <xs:enumeration value="any"/>  <xs:enumeration value="normal"/>  <xs:enumeration value="flood"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="group-types">  <xs:annotation>  <xs:documentation>  Specify the group types supported by the logical  switch.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="type" minOccurs="0" maxOccurs="unbounded">  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:enumeration value="all"/>  <xs:enumeration value="select"/>  <xs:enumeration value="indirect"/>  <xs:enumeration value="fast-failover"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="group-capabilities">  <xs:annotation>  <xs:documentation>  Specify the group capabilities supported by the  logical switch.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="capability" minOccurs="0" maxOccurs="unbounded">  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:enumeration value="select-weight"/>  <xs:enumeration value="select-liveness"/>  <xs:enumeration value="chaining"/>  <xs:enumeration value="chaining-check"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="action-types">  <xs:annotation>  <xs:documentation>  Specify the action types supported by the  logical switch.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="type" minOccurs="0" maxOccurs="unbounded" type="OFActionType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="instruction-types">  <xs:annotation>  <xs:documentation>  Specify the instruction types supported by the  logical switch.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="type" minOccurs="0" maxOccurs="unbounded" type="OFInstructionType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:group>  <xs:simpleType name="OFActionType">  <xs:annotation>  <xs:documentation>  The types of actions defined in OpenFlow Switch  Specification versions 1.2, 1.3, and 1.3.1  </xs:documentation>  </xs:annotation>  <xs:restriction base="xs:string">  <xs:enumeration value="output"/>  <xs:enumeration value="copy-ttl-out"/>  <xs:enumeration value="copy-ttl-in"/>  <xs:enumeration value="set-mpls-ttl"/>  <xs:enumeration value="dec-mpls-ttl"/>  <xs:enumeration value="push-vlan"/>  <xs:enumeration value="pop-vlan"/>  <xs:enumeration value="push-mpls"/>  <xs:enumeration value="pop-mpls"/>  <xs:enumeration value="set-queue"/>  <xs:enumeration value="group"/>  <xs:enumeration value="set-nw-ttl"/>  <xs:enumeration value="dec-nw-ttl"/>  <xs:enumeration value="set-field"/>  </xs:restriction>  </xs:simpleType>  <xs:simpleType name="OFInstructionType">  <xs:annotation>  <xs:documentation>  The types of instructions defined in OpenFlow  Switch Specification versions 1.2, 1.3, and 1.3.1.  </xs:documentation>  </xs:annotation>  <xs:restriction base="xs:string">  <xs:enumeration value="apply-actions"/>  <xs:enumeration value="clear-actions"/>  <xs:enumeration value="write-actions"/>  <xs:enumeration value="write-metadata"/>  <xs:enumeration value="goto-table"/>  </xs:restriction>  </xs:simpleType> |

### XML Example

|  |
| --- |
| <capabilities>  <max-buffered-packets>512</max-buffered-packets>  <max-tables>1024</max-tables>  <max-ports>2048</max-ports>  <flow-statistics>true</flow-statistics>  <table-statistics>false</table-statistics>  <port-statistics>true</port-statistics>  <group-statistics>false</group-statistics>  <queue-statistics>true</queue-statistics>  <reassemble-ip-fragments>false</reassemble-ip-fragments>  <block-looping-ports>false</block-looping-ports>  <reserved-port-types>  <type>all</type>  </reserved-port-types>  <group-types>  <type>all</type>  </group-types>  <group-capabilities>  <capability>select-weight</capability>  </group-capabilities>  <action-types>  <type>output</type>  </action-types>  <instruction-types>  <type>apply-actions</type>  <type>write-actions</type>  </instruction-types>  </capabilities> |

## OpenFlow Controller

The OpenFlow Controller class represents an entity that acts as OpenFlow Controller of an OpenFlow Logical Switch. Attributes of the class indicate the role of the controller and parameters of the OpenFlow connection to the controller.

### UML Diagram



Figure 8: Data Model Diagram for an OpenFlow Controller

### XML Schema

|  |
| --- |
| <xs:group name="OFControllerType">  <xs:annotation>  <xs:documentation>  This grouping specifies all properties of an  OpenFlow Logical Switch Controller.  NETCONF &lt;edit-config&gt; operations MUST be implemented as  follows:  \* The 'id' element MUST be present at all &lt;edit-config&gt;  operations to identify the controller.  \* If the operation is 'merge' or 'replace', the element is  created if it does not exist, and its value is set to the  value found in the XML RPC data.  \* If the operation is 'create', the element is created if it  does not exist. If the element already exists, a  'data‑exists' error is returned.  \* If the operation is 'delete', the element is deleted if it  exists. If the element does not exist, a 'data‑missing'  error is returned.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:element name="id" type="OFConfigId">  <xs:annotation>  <xs:documentation>  A unique but locally arbitrary identifier that  uniquely identifies an OpenFlow Controller within the  context of an OpenFlow Capable Switch. It MUST be  persistent across reboots of the OpenFlow Capable Switch.  This element MUST be present to identify the OpenFlow  controller.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="role">  <xs:annotation>  <xs:documentation>  This element indicates the role of the OpenFlow  Controller. Semantics of these roles are specified in the  OpenFlow specifications 1.0 - 1.3.1. It is RECOMMENDED  that the roles of controllers are not configured by  OF-CONFIG 1.2 but determined using the OpenFlow protocol.  OpenFlow Controllers configured by OF-CONFIG 1.2 have the  default role 'equal'. A role other than 'equal' MAY be  assigned to a controller. Roles 'slave' and 'equal' MAY be  assigned to multiple controllers. Role 'master' MUST NOT  be assigned to more than one controller.  This element is optional. If this element is not present it  defaults to 'equal'.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:enumeration value="master"/>  <xs:enumeration value="slave"/>  <xs:enumeration value="equal"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  <xs:element name="ip-address" type="inet:ip-address">  <xs:annotation>  <xs:documentation>  The IP address of the OpenFlow Controller. This  IP address is used by the OpenFlow Logical Switch when  connecting to the OpenFlow Controller.  This element MUST be present in the NETCONF data store.  If this element is not present in a NETCONF &lt;edit-config&gt;  operation 'create', 'merge' or 'replace' and the parent  element does not exist, a 'data-missing' error is  returned.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="port" type="inet:port-number">  <xs:annotation>  <xs:documentation>  The TCP port number at the OpenFlow Controller.  This port number is used by the OpenFlow Logical Switch  when connecting to the OpenFlow Controller using TCP or  TLS. The default value is 6633.  This element is optional. If this element is not present it  defaults to 6633.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="local-ip-address" type="inet:ip-address">  <xs:annotation>  <xs:documentation>  The local IP address of the OpenFlow Logical  Switch when connecting to this OpenFlow Controller. It is  the source IP address of packets sent to this OpenFlow  Controller. If present, this element overrides any default  IP address.      This element is optional. Attempts to set this element to  an IP address that cannot be used by the OpenFlow Logical  Switch MUST result in an 'bad-element' error with type  'application'. The &lt;error-info&gt; element MUST contain the  name of this element in the &lt;bad-element&gt; element.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="local-port" type="inet:port-number">  <xs:annotation>  <xs:documentation>  The local TCP port number of the OpenFlow  Logical Switch when connecting to this OpenFlow Controller.  It is the source TCP port number of packets sent to this  OpenFlow Controller. If this element is not present, then  the port number is chosen arbitrarily by the OpenFlow  Logical Switch.    This element is optional. Attempts to set this element to a  port number that cannot be used by the OpenFlow Logical  Switch MUST result in an 'bad-element' error with type  'application'. The &lt;error-info&gt; element MUST contain the  name of this element in the &lt;bad-element&gt; element.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="protocol">  <xs:annotation>  <xs:documentation>  The default protocol tha the OpenFlow Logical  Switch uses to connect to this OpenFlow Controller. 'tls'  is the default value.  This element is optional. If this element is not present it  defaults to 'tls'.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:enumeration value="tcp"/>  <xs:enumeration value="tls"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  <xs:element name="state">  <xs:annotation>  <xs:documentation>  This container holds connection state  information that indicate the connection state of the  OpenFlow Logical Switch and the OpenFlow protocol version  used for the connection.  Children of this element are not configurable and can only  be retrieved by NETCONF &lt;get&gt; operations. Attemps to modify  this element and its children with a NETCONF &lt;edit-config&gt;  operation MUST result in an 'operation-not-supported' error  with type 'application'.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="connection-state" minOccurs="0" type="OFUpDownStateType">  <xs:annotation>  <xs:documentation>  This object indicates the connections state of  the OpenFlow Logical Switch to this controller.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="current-version" minOccurs="0" type="OFOpenFlowVersionType">  <xs:annotation>  <xs:documentation>  This object indicates the version of the  OpenFlow protocol used between the OpenFlow Logical  Switch and this Controller. If element connection-state  has value 'up', then this element indicates the actual  version in use. If element connection-state has value  'down', then this element indicates the version number of  the last established connection with this OpenFlow  Controller. The value of this element MAY be persistent  across reboots of the OpenFlow Logical Switch in such a  case. If element connection-state has value 'down'and  there is no information about previous connections to  this OpenFlow controller, then this element is not  present or has the value '0'.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="supported-versions" minOccurs="0" maxOccurs="unbounded" type="OFOpenFlowVersionType">  <xs:annotation>  <xs:documentation>  This list of elements includes one entry for  each OpenFlow protocol version that this OpenFlow  controller supports. It SHOULD contain all  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="local-ip-address-in-use" minOccurs="0" type="inet:ip-address">  <xs:annotation>  <xs:documentation>  The local IP address of the OpenFlow Logical  Switch when connecting to this OpenFlow Controller. It  is the source IP address of packets sent to this OpenFlow  Controller. If present, this element overrides any  default IP address.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="local-port-in-use" minOccurs="0" type="inet:port-number">  <xs:annotation>  <xs:documentation>  The local TCP port number of the OpenFlow  Logical Switch. If element connection-state has value  'up', then this element indicates the actual port number  in use. If element connection-state has value 'down',  then this element indicates the port number used for the  last attempt to establish a connection with this OpenFlow  Controller.???  When connecting to this OpenFlow Controller, it is the  source TCP port number of packets sent to this OpenFlow  Controller. If this element has its defaqult value 0,  then port number is chosen arbitrarily by the OpenFlow  Logical Switch.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:group>  <xs:simpleType name="OFConfigId">  <xs:annotation>  <xs:documentation>  Generic type of an identifier in OF-CONFIG  </xs:documentation>  </xs:annotation>  <xs:restriction base="inet:uri">  </xs:restriction>  </xs:simpleType>  <xs:simpleType name="OFOpenFlowVersionType">  <xs:annotation>  <xs:documentation>  This enumeration contains the all OpenFlow  versions released so far.  </xs:documentation>  </xs:annotation>  <xs:restriction base="xs:string">  <xs:enumeration value="not-applicable"/>  <xs:enumeration value="1.0"/>  <xs:enumeration value="1.0.1"/>  <xs:enumeration value="1.1"/>  <xs:enumeration value="1.2"/>  <xs:enumeration value="1.3"/>  <xs:enumeration value="1.3.1"/>  </xs:restriction>  </xs:simpleType>  <xs:simpleType name="OFUpDownStateType">  <xs:annotation>  <xs:documentation>  Type to specify state information for a port or a  connection.  </xs:documentation>  </xs:annotation>  <xs:restriction base="xs:string">  <xs:enumeration value="up"/>  <xs:enumeration value="down"/>  </xs:restriction>  </xs:simpleType> |

### XML Example

|  |
| --- |
| <controller>  <id>Controller3</id>  <role>master</role>  <ip-address>192.168.2.1/26</ip-address>  <port>6633</port>  <local-ip-address>192.168.2.129</local-ip-address>  <local-port>32768</local-port>  <protocol>tcp</protocol>  <state>  <connection-state>up</connection-state>  <current-version>1.2</current-version>  <supported-versions>  <version>1.2</version>  <version>1.1</version>  </supported-versions>  </state>  </controller> |

## OpenFlow Resource

OpenFlow Resource is a superclass of OpenFlow Port, OpenFlow Queue, Owned Certificate and External Certificate. The superclass contains the identifier attribute that is inherited by all subclasses in addition to their individual identifiers.

### UML Diagram



Figure 9: Data Model Diagram for an OpenFlow Resource

### XML Schema

|  |
| --- |
| <xs:group name="OFResourceType">  <xs:annotation>  <xs:documentation>  This element specifies a generic OpenFlow resource  that is used as a basis for specific resources. Even though  this element is not used on its own the following rules for  NETCONF operations MUST be obeyed also by elemnts using this  element.  NETCONF &lt;edit-config&gt; operations MUST be implemented as  follows:  \* The 'id' element MUST be present at all &lt;edit-config&gt;  operations to identify the resource.  \* If the operation is 'merge' or 'replace', the element is  created if it does not exist, and its value is set to the  value found in the XML RPC data.  \* If the operation is 'create', the element is created if it  does not exist. If the element already exists, a  'data‑exists' error is returned.  \* If the operation is 'delete', the element is deleted if it  exists. If the element does not exist, a 'data‑missing'  error is returned.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:element name="resource-id" type="inet:uri">  <xs:annotation>  <xs:documentation>  A unique but locally arbitrary identifier that  uniquely identifies an OpenFlow Port within the context  of an OpenFlow Logical Switch. It MUST be persistent  across reboots of the OpenFlow Capable Switch.  This element MUST be present to identify the OpenFlow  resource.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:group> |

### XML Example

The superclass is not instantiated.

## OpenFlow Port

The OpenFlow Port is an instance of an OpenFlow resource. It may represent a physical port or a logical port. A logical port represents a tunel endpoint as described in the OpenFlow protocol specification.

An OpenFlow Port contains a port configuration object and a port state object. A physical port contains a list of port feature objects. While there can’t be more than one instance of the Port Configuration and the Port State, there may be multiple Port Features. In the case where a port represents a tunnel endpoint, then the port does not contain Port Feature objects, but a Port tunnel object.

### UML Diagram



Figure 10: Data Model Diagram for an OpenFlow Port

### XML Schema

|  |
| --- |
| <xs:group name="OFPortType">  <xs:annotation>  <xs:documentation>  This element specifies all properties of an  OpenFlow resource of type OpenFlow Port. It represent a  physical port or a logical port of the OpenFlow Capable  Switch and can be assigned for exclusive use to an OpenFlow  Logical Switch. A logical port represents a tunnel endpoint  as described in the OpenFlow protocol specification versions  1.3 - 1.3.1.  NETCONF &lt;edit-config&gt; operations MUST be implemented as  follows:  \* The 'resource-id' element of OFResoureType MUST be present  at all &lt;edit-config&gt; operations to identify the port.  \* If the operation is 'merge' or 'replace', the element is  created if it does not exist, and its value is set to the  value found in the XML RPC data.  \* If the operation is 'create', the element is created if it  does not exist. If the element already exists, a  'data‑exists' error is returned.  \* If the operation is 'delete', the element is deleted if it  exists. If the element does not exist, a 'data‑missing'  error is returned.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:group ref="OFResourceType"/>  <xs:element name="number" type="xs:unsignedLong">  <xs:annotation>  <xs:documentation>  This number identifies the OpenFlow Port to  OpenFlow Controllers. It is assigned to an OpenFlow Port  latest when the OpenFlow Port is associated with and  OpenFlow Logical Switch. If the OpenFlow Port is  associated with an OpenFlow Logical Switch, this element  MUST be unique within the context of the OpenFlow Logical  Switch.    OpenFlow Capable Switch implementations may choose to  assign values to OpenFlow Ports that are unique within the  context of the OpenFlow Logical Switch. These numbers can  be used independent of assignments to OpenFlow Logical  Switches.    Other implementations may assign values to this element  only if the OpenFlow Port is assigned to an OpenFlow  Logical Switch. If no value is currently assigned to this  element then this element MUST NOT be included in replies  to NETCONF &lt;get&gt; requests. Since this element is not  configurable with the NETCONF protocol it MUST NOT be  included in replies to NETCONF &lt;get-config&gt; requests.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="name">  <xs:annotation>  <xs:documentation>  This element assists OpenFlow Controllers in  identifying OpenFlow Ports.    This element is not to be set by the OP-CONFIG protocol,  but it is set by the switch implementation. It may be set  at start-up time of an OpenFlow Capable Switch or when the  OpenFlow Port is assigned to an OpenFlow Logical Switch.  It MAY also be not set at all. If this element is set to a  value other than the empty string when being assigned to an  OpenFlow Logical Switch, then the value of this element  MUST be unique within the context of the OpenFlow Logical  Switch.    If no value or the empty string is currently assigned to  this element then this element MUST not be included in  replies to NETCONF &lt;get&gt; requests. Since this element is  not configurable with the NETCONF protocol it MUST NOT be  included in replies to NETCONF &lt;get-config&gt; requests.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:minLength value="1"/>  <xs:maxLength value="16"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  <xs:element name="current-rate" type="xs:unsignedInt">  <xs:annotation>  <xs:documentation>  This element indicates the current bit rate of  the port. Its values is to be provided in units of kilobit  per second (kbps). This element is only valid if the  element called 'rate' in the current Port Features has a  value of 'other'.  Since this element is not configurable with the NETCONF  protocol it MUST NOT be included in replies to NETCONF  &lt;get-config&gt; requests.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="max-rate" type="xs:unsignedInt">  <xs:annotation>  <xs:documentation>  This element indicates the maximum bit rate of  the port. Its values is to be provided in units of kilobit  per second (kbps). This element is only valid if the  element called 'rate' in the current Port Features has a  value of 'other'.  Since this element is not configurable with the NETCONF  protocol it MUST NOT be included in replies to NETCONF  &lt;get-config&gt; requests.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="configuration">  <xs:annotation>  <xs:documentation>  This element represents the general  adminitrative configuration of the OpenFlow Port.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="admin-state" minOccurs="0" type="OFUpDownStateType">  <xs:annotation>  <xs:documentation>  The administrative state of the port. If  true, the port has been administratively brought down and  SHOULD not be used by OpenFlow.  This element is optional. If this element is not present  it defaults to 'up'.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="no-receive" minOccurs="0" type="xs:boolean">  <xs:annotation>  <xs:documentation>  If true, packets received at this OpenFlow  port SHOULD be dropped.  This element is optional. If this element is not present  it defaults to 'false'.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="no-forward" minOccurs="0" type="xs:boolean">  <xs:annotation>  <xs:documentation>  If true, packets forwarded to this OpenFlow  port SHOULD be dropped.  This element is optional. If this element is not present  it defaults to 'false'.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="no-packet-in" minOccurs="0" type="xs:boolean">  <xs:annotation>  <xs:documentation>  If true, packets received on that port that  generate a table miss should never trigger a packet-in  message to the OpenFlow Controller.  This element is optional. If this element is not present  it defaults to 'false'.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="state">  <xs:annotation>  <xs:documentation>  This element represents the general operational  state of the OpenFlow Port.  Children of this element are not configurable and can only be  retrieved by NETCONF &lt;get&gt; operations. Attemps to modify this  element and its children with a NETCONF &lt;edit-config&gt;  operation MUST result in an 'operation-not-supported' error  with type 'application'.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="oper-state" minOccurs="0" type="OFUpDownStateType">  <xs:annotation>  <xs:documentation>  If the value of this element is 'down', it  indicates that there is no physical link present.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="blocked" minOccurs="0" type="xs:boolean">  <xs:annotation>  <xs:documentation>  If the value of this element is 'true', it  indicates that a switch protocol outside of OpenFlow,  such as 802.1D Spanning Tree, is preventing the use of  this OpenFlow port for OpenFlow flooding.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="live" minOccurs="0" type="xs:boolean">  <xs:annotation>  <xs:documentation>  If the value of this element is 'true', it  indicates that this OpenFlow Port is live and can be used  for fast failover.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="features">  <xs:complexType>  <xs:sequence>  <xs:element name="current" minOccurs="0">  <xs:annotation>  <xs:documentation>  The features (rates, duplex, etc.) of the  port, that are currently in use.  Children of this element are not configurable and can  only be retrieved by NETCONF &lt;get&gt; operations. Attemps to  modify this element and its children with a NETCONF  &lt;edit-config&gt; operation MUST result in an  'operation-not-supported' error with type  'application'.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFPortCurrentFeatureListType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="advertised" minOccurs="0">  <xs:annotation>  <xs:documentation>  The features (rates, duplex, etc.) of the  port, that are advertised to the peer port.  NETCONF &lt;edit-config&gt; operations MUST be implemented as  follows:  \* The 'resource-id' element of OFResoureType MUST be  present in the path or in the filter at all  &lt;edit-config&gt; operations to identify the port.  \* If the operation is 'merge' or 'replace', the element  is created if it does not exist, and its value is set  to the value found in the XML RPC data.  \* If the operation is 'create', the element is created if  it does not exist. If the element already exists, a  'data‑exists' error is returned.  \* If the operation is 'delete', the element is deleted if  it exists. If the element does not exist, a  'data‑missing' error is returned.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFPortOtherFeatureListType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="supported" minOccurs="0">  <xs:annotation>  <xs:documentation>  The features (rates, duplex, etc.) of the  port, that are supported on the port.  Children of this element are not configurable and can  only be retrieved by NETCONF &lt;get&gt; operations. Attemps to  modify this element and its children with a NETCONF  &lt;edit-config&gt; operation MUST result in an  'operation-not-supported' error with type  'application'.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFPortOtherFeatureListType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="advertised-peer" minOccurs="0">  <xs:annotation>  <xs:documentation>  The features (rates, duplex, etc.) that are  currently advertised by the peer port.  Children of this element are not configurable and can  only be retrieved by NETCONF &lt;get&gt; operations. Attemps to  modify this element and its children with a NETCONF  &lt;edit-config&gt; operation MUST result in an  'operation-not-supported' error with type  'application'.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFPortOtherFeatureListType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:choice>  <xs:annotation>  <xs:documentation>  Tunnels are modeled as logical ports.  Elements in this choice are not configurable and can only  be retrieved by NETCONF &lt;get&gt; operations. Attemps to modify  this element and its children with a NETCONF &lt;edit-config&gt;  operation MUST result in an 'operation-not-supported' error  with type 'application'.  Only elements from one choice must exist at a time.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:element name="tunnel">  <xs:annotation>  <xs:documentation>  Properties of a basic IP-in-GRE tunnel.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFPortBaseTunnelType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  <xs:sequence>  <xs:element name="ipgre-tunnel">  <xs:annotation>  <xs:documentation>  Properties of a IP-in-GRE tunnel.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFPortIPGRETunnelType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  <xs:sequence>  <xs:element name="vxlan-tunnel">  <xs:annotation>  <xs:documentation>  Properties of a VxLAN tunnel.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFPortVXLANTunnelType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  <xs:sequence>  <xs:element name="nvgre-tunnel">  <xs:annotation>  <xs:documentation>  Properties of a NVGRE tunnel.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="OFPortNVGRETunnelType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:choice>  </xs:sequence>  </xs:group>  <xs:group name="OFPortBaseTunnelType">  <xs:annotation>  <xs:documentation>  A group of common elements that are included  in every supported tunnel type. Tunnels are modeled as  logical ports.  One pair of local/remote endpoints must exist for a tunnel  configuration.  Only elements from one choice must exist at a time.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:choice>  <xs:sequence>  <xs:element name="local-endpoint-ipv4-adress" type="inet:ipv4-address">  <xs:annotation>  <xs:documentation>  The IPv4 address of the local tunnel  endpoint.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="remote-endpoint-ipv4-adress" type="inet:ipv4-address">  <xs:annotation>  <xs:documentation>  The IPv4 address of the remote tunnel  endpoint.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  <xs:sequence>  <xs:element name="local-endpoint-ipv6-adress" type="inet:ipv6-address">  <xs:annotation>  <xs:documentation>  The IPv6 address of the local tunnel  endpoint.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="remote-endpoint-ipv6-adress" type="inet:ipv6-address">  <xs:annotation>  <xs:documentation>  The IPv6 address of the remote tunnel  endpoint.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  <xs:sequence>  <xs:element name="local-endpoint-mac-adress" type="yang:mac-address">  <xs:annotation>  <xs:documentation>  The MAC address of the local tunnel  endpoint.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="remote-endpoint-mac-adress" type="yang:mac-address">  <xs:annotation>  <xs:documentation>  The MAC address of the remote tunnel  endpoint.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:choice>  </xs:sequence>  </xs:group>  <xs:group name="OFPortIPGRETunnelType">  <xs:annotation>  <xs:documentation>  Properties of a IP-in-GRE tunnel with key,  checksum, and sequence number information.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:group ref="OFPortBaseTunnelType"/>  <xs:element name="checksum-present" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Indicates presence of the GRE checksum.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="key-present" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Indicates presence of the GRE key.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="key" type="xs:unsignedInt">  <xs:annotation>  <xs:documentation>  The (optional) key of the GRE tunnel. It MAY  be used to set the OXM\_OF\_TUNNEL\_ID match field metadata  in the OpenFlow protocol  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="sequence-number-present" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Indicates presence of the GRE sequence  number.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:group>  <xs:group name="OFPortVXLANTunnelType">  <xs:annotation>  <xs:documentation>  Properties of a VxLAN tunnel.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:group ref="OFPortBaseTunnelType"/>  <xs:element name="vni-valid" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Indicates how the corresponding flag should be  set in packets sent on the tunnel.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="vni" type="xs:unsignedInt">  <xs:annotation>  <xs:documentation>  Virtual network identifier assigned to all  packets sent on the tunnel. A VxLAN implementation MAY  use the this element to set the OXM\_OF\_TUNNEL\_ID match  field metadata in the OpenFlow protocol.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="vni-multicast-group" type="inet:ip-address">  <xs:annotation>  <xs:documentation>  If IP multicast is used to support broadcast  on the tunnel this specifies the corresponding multicast  IP address  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="udp-source-port" type="inet:port-number">  <xs:annotation>  <xs:documentation>  Specifies the outer UDP source port number.  If this element is absent, the port number MAY be chosen  dynamically.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="udp-dest-port" type="inet:port-number">  <xs:annotation>  <xs:documentation>  Specifies the outer UDP destination port  number. It is intended to reserve a port number for  VxLAN at IANA. As soon as this has been reserved, the  reserved number SHOULD become the default value for this  element.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="udp-checksum" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Boolean flag to indicate whether or not the  outer UDP checksum should be set  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:group>  <xs:group name="OFPortNVGRETunnelType">  <xs:annotation>  <xs:documentation>  Properties of a NVGRE tunnel.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:group ref="OFPortBaseTunnelType"/>  <xs:element name="tni" type="xs:unsignedInt">  <xs:annotation>  <xs:documentation>  Specifies the tenant network identifier  assigned to all packets sent on the tunnel  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="tni-resv" type="xs:unsignedInt">  <xs:annotation>  <xs:documentation>  Used to set the reserved user-defined bits of  the GRE key field  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="tni-multicast-group" type="inet:ip-address">  <xs:annotation>  <xs:documentation>  If IP multicast is used to support broadcast  on the tunnel this element specifies the corresponding  multicast IP address  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:group> |

### XML Examples

|  |
| --- |
| <!-- Example for a physical port -->  <port>  <resource-id>Port214748364</resource-id>  <number>214748364</number>  <name>name0</name>  <current-rate>10000</current-rate>  <max-rate>10000</max-rate>  <configuration>  <admin-state>up</admin-state>  <no-receive>false</no-receive>  <no-forward>false</no-forward>  <no-packet-in>false</no-packet-in>  </configuration>  <state>  <oper-state>up</oper-state>  <blocked>false</blocked>  <live>false</live>  </state>  <features>  <current>  ...  </current>  <advertised>  ...  </advertised>  <supported>  ...  </supported>  <advertised-peer>  ...  </advertised-peer>  </features>  </port>  <!-- Example for a logical port representing a VxLAN tunnel -->  <port>  <resource-id>LogicalPort14</resource-id>  <number>14</number>  <name>logicalPort14VxLAN</name>  <max-rate>10000</max-rate>  <configuration>  <admin-state>up</admin-state>  <no-receive>false</no-receive>  <no-forward>false</no-forward>  <no-packet-in>false</no-packet-in>  </configuration>  <state>  <oper-state>up</oper-state>  <blocked>false</blocked>  <live>true</live>  </state>  <vxlan-tunnel>  <local-endpoint-ipv4-address>  192.0.2.9  </local-endpoint-ipv4-address>  <remote-endpoint-ipv4-address>  192.0.2.112  </remote-endpoint-ipv4-address>  <vni-valid>true</vni-valid>  <vni>15581985</vni>  <udp-source-port>3804</udp-source-port>  <udp-dest-port>4789</udp-dest-port>  <udp-checksum>false</udp-checksum>  </vxlan-tunnel>  </port>  <!-- Example for a logical port representing a NVGRE tunnel -->  <port>  <resource-id>LogicalPort17</resource-id>  <number>17</number>  <name>logicalPort17NVGRE</name>  <max-rate>1000</max-rate>  <configuration>  <admin-state>up</admin-state>  <no-receive>false</no-receive>  <no-forward>false</no-forward>  <no-packet-in>false</no-packet-in>  </configuration>  <state>  <oper-state>up</oper-state>  <blocked>false</blocked>  <live>true</live>  </state>  <nvgre-tunnel>  <local-endpoint-ipv4-address>  192.0.2.7  </local-endpoint-ipv4-address>  <remote-endpoint-ipv4-address>  192.0.2.97  </remote-endpoint-ipv4-address>  <tni>15581985</tni>  <tni-resv>173</tni-resv>  </nvgre-tunnel>  </port> |

## OpenFlow Port Feature

OpenFlow Port Features includePort Rate, Port Medium, Port Pause, and Port Auto-Negotiate.The normative semantics of these features are described in the OpenFlow protocol specification.

### UML Diagram



Figure 1: Data Model Diagram for an OpenFlow Port Feature

### XML Schema

|  |
| --- |
| <xs:group name="OFPortCurrentFeatureListType">  <xs:annotation>  <xs:documentation>  The current features of a port.  Elements in the type OFPortCurrentFeatureListType are not  configurable and can only be retrieved by NETCONF &lt;get&gt;  operations. Attemps to modify this element and its children  with a NETCONF &lt;edit-config&gt; operation MUST result in an  'operation-not-supported' error with type 'application'.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:element name="rate" type="OFPortRateType">  <xs:annotation>  <xs:documentation>  The transmission rate that is currently used.  The value MUST indicate a valid forwarding rate.    The current Port Feature set MUST contain this element  exactly once. The other Port Feature sets MAY contain this  element more than once. If this element appears more than  once in a Port Feature set than the value MUST be unique  within the Port Feature set.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="auto-negotiate" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Specifies the administrative state of the  forwarding rate auto-negotiation protocol at this OpenFlow  Port.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="medium">  <xs:annotation>  <xs:documentation>  This element MUST indicate a valid physical  medium used by the OpenFlow Port.    The current Port Feature set MUST contain this element  exactly once. The other Port Feature sets MAY contain this  element more than once. If this element appears more than  once in a Port Feature set than the value MUST be unique  within the Port Feature set.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:enumeration value="copper"/>  <xs:enumeration value="fiber"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  <xs:element name="pause">  <xs:annotation>  <xs:documentation>  Specifies if pausing of transmission is  supported at all and if yes if it is asymmetric or  symmetric.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:enumeration value="unsupported"/>  <xs:enumeration value="symmetric"/>  <xs:enumeration value="asymmetric"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  </xs:sequence>  </xs:group>  <xs:group name="OFPortOtherFeatureListType">  <xs:annotation>  <xs:documentation>  The features of a port that are supported or  advertised.  If the elements in the OFPortOtherFeatureListType ares used  as configurable elements the NETCONF &lt;edit-config&gt; operations  MUST be implemented as follows:  \* The 'resource-id' element MUST be present in the path or in  the filter at all &lt;edit-config&gt; operations to identify the  resource.  \* If the operation is 'merge' or 'replace', the element is  created if it does not exist, and its value is set to the  value found in the XML RPC data.  \* If the operation is 'create', the element is created if it  does not exist. If the element already exists, a  'data‑exists' error is returned.  \* If the operation is 'delete', the element is deleted if it  exists. If the element does not exist, a 'data‑missing'  error is returned.  If elements in the type OFPortOtherFeatureListType are used  in an non-configurable way, they only be retrieved by NETCONF  &lt;get&gt; operations. Attemps to modify this element and its  children with a NETCONF &lt;edit-config&gt; operation MUST result  in an 'operation-not-supported' error with type  'application'.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:element name="rate" type="OFPortRateType">  <xs:annotation>  <xs:documentation>  The transmission rate that is supported or  advertised. Multiple transmissions rates are allowed.  At least one element MUST be present in the NETCONF data  store. If none of this elements is are present in a NETCONF  &lt;edit-config&gt; operation 'create', 'merge' or 'replace' and  the parent element does not exist, a 'data-missing' error  is returned.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="auto-negotiate" type="xs:boolean">  <xs:annotation>  <xs:documentation>  Specifies if auto-negotiation of transmission  parameters is enabled for the port.  This element is optional. If this element is not present it  defaults to 'true'.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="medium">  <xs:annotation>  <xs:documentation>  The transmission medium used by the port.  Multiple media are allowed.  At least one element MUST be present in the NETCONF data  store. If none of this elements is are present in a NETCONF  &lt;edit-config&gt; operation 'create', 'merge' or 'replace' and  the parent element does not exist, a 'data-missing' error  is returned.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:enumeration value="copper"/>  <xs:enumeration value="fiber"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  <xs:element name="pause">  <xs:annotation>  <xs:documentation>  Specifies if pausing of transmission is  supported at all and if yes if it is asymmetric or  symmetric.  This element MUST be present in the NETCONF data store.  If this element is not present in a NETCONF &lt;edit-config&gt;  operation 'create', 'merge' or 'replace' and the parent  element does not exist, a 'data-missing' error is  returned.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:enumeration value="unsupported"/>  <xs:enumeration value="symmetric"/>  <xs:enumeration value="asymmetric"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  </xs:sequence>  </xs:group>  <xs:simpleType name="OFPortRateType">  <xs:annotation>  <xs:documentation>  Type to specify the rate of a port including the  duplex transmission feature. Possible rates are 10Mb, 100Mb,  1Gb, 10Gb, 40Gb, 100Gb, 1Tb or other. Rates of 10Mb, 100Mb  and 1 Gb can support half or full duplex transmission.  </xs:documentation>  </xs:annotation>  <xs:restriction base="xs:string">  <xs:enumeration value="10Mb-HD"/>  <xs:enumeration value="10Mb-FD"/>  <xs:enumeration value="100Mb-HD"/>  <xs:enumeration value="100Mb-FD"/>  <xs:enumeration value="1Gb-HD"/>  <xs:enumeration value="1Gb-FD"/>  <xs:enumeration value="10Gb"/>  <xs:enumeration value="40Gb"/>  <xs:enumeration value="100Gb"/>  <xs:enumeration value="1Tb"/>  <xs:enumeration value="other"/>  </xs:restriction>  </xs:simpleType> |

### XML Example

|  |
| --- |
| <rate>10Mb-FD</rate>  <auto-negotiate>enabled</auto-negotiate>  <medium>copper</medium>  <pause>symmetric</pause> |

## OpenFlow Queue

The OpenFlow Queue is an instance of an OpenFlow resource. It contains list of queue properties. The OpenFlow Queue is a logical context which represents a queue as described in the OpenFlow protocol specification.

### UML Diagram



Figure 12: Data Model Diagram for an OpenFlow Queue

### XML Schema

|  |
| --- |
| <xs:group name="OFQueueType">  <xs:annotation>  <xs:documentation>  This grouping specifies all properties of a queue  resource.  NETCONF &lt;edit-config&gt; operations MUST be implemented as  follows:  \* The 'resource-id' element of OFResoureType MUST be present  at all &lt;edit-config&gt; operations to identify the port.  \* If the operation is 'merge' or 'replace', the element is  created if it does not exist, and its value is set to the  value found in the XML RPC data.  \* If the operation is 'create', the element is created if it  does not exist. If the element already exists, a  'data‑exists' error is returned.  \* If the operation is 'delete', the element is deleted if it  exists. If the element does not exist, a 'data‑missing'  error is returned.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:group ref="OFResourceType"/>  <xs:element name="id" type="xs:unsignedLong">  <xs:annotation>  <xs:documentation>  This id identifies the OpenFlow Queue to  OpenFlow Controllers. It is assigned to an OpenFlow Queue  latest when the OpenFlow Queue is associated with and  OpenFlow Logical Switch. If the OpenFlow Queue is  associated with an OpenFlow Logical Switch, this element  MUST be unique within the context of the OpenFlow Logical  Switch.    OpenFlow Capable Switch implementations may choose to  assign values to OpenFlow Queues that are unique within the  context of the OpenFlow Logical Switch. These id can be  used independent of assignments to OpenFlow Logical  Switches.    Other implementations may assign values to this element  only if the OpenFlow Queue is assigned to an OpenFlow  Logical Switch. If no value is currently assigned to this  element then this element MUST NOT be included in replies  to NETCONF &lt;get&gt; requests. Since this element is not  configurable with the NETCONF protocol it MUST NOT be  included in replies to NETCONF &lt;get-config&gt; requests.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="port">  <xs:annotation>  <xs:documentation>  Reference to port resources in the Capable  Switch.    This element associates an OpenFlow Queue with an OpenFlow  Port. If the OpenFlow Queue is associated with an OpenFlow  Logical Switch S and this element is present, then it MUST  be set to the value of element resource-id of an OpenFlow  Port which is associated with the OpenFlow Logical Switch  S.  The element MUST refer to an element at the following path:  /capable-switch/resources/port/resource-id  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="inet:uri">  </xs:restriction>  </xs:simpleType>  </xs:element>  <xs:element name="properties">  <xs:annotation>  <xs:documentation>  The queue properties currently configured.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="min-rate" minOccurs="0" type="OFTenthOfAPercentType">  <xs:annotation>  <xs:documentation>  The minimal rate that is reserved for this  queue in 1/10 of a percent of the actual rate.  This element is optional. If not present a min-rate is  not set.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="max-rate" minOccurs="0" type="OFTenthOfAPercentType">  <xs:annotation>  <xs:documentation>  The maximum rate that is reserved for this  queue in 1/10 of a percent of the actual rate.  This element is optional. If not present the max-rate is  not set.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="experimenter" minOccurs="0" maxOccurs="unbounded" type="xs:unsignedInt">  <xs:annotation>  <xs:documentation>  A list of experimenter identifiers of queue  properties used.  This element is optional.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:group>  <xs:simpleType name="OFTenthOfAPercentType">  <xs:annotation>  <xs:documentation>  This type defines a value in tenth of a percent.  </xs:documentation>  </xs:annotation>  <xs:restriction base="xs:unsignedShort">  <xs:minInclusive value="0"/>  <xs:maxInclusive value="1000"/>  </xs:restriction>  </xs:simpleType> |

### XML Example

|  |
| --- |
| <queue>  <resource-id>Queue2</resource-id>  <id>2</id>  <port>4</port>  <properties>  <min-rate>10</min-rate>  <max-rate>500</max-rate>  <experimenter>123498</experimenter>  <experimenter>708</experimenter>  </properties>  </queue> |

## External Certificate

Instances of an External Certificate contain a certificate that can be used by an OpenFlow Logical Switch for authenticating a controller when a TLS connection is established.

### UML Diagram



Figure 3: Data Model Diagram for a Certificate

### XML Schema

|  |
| --- |
| <xs:group name="OFExternalCertificateType">  <xs:annotation>  <xs:documentation>  This grouping specifies a certificate that can be  used by an OpenFlow Logical Switch for authenticating a  controller when a TLS connection is established.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:group ref="OFResourceType"/>  <xs:element name="certificate" type="xs:string">  <xs:annotation>  <xs:documentation>  An X.509 certificate in DER format base64  encoded.  This element MUST be present in the NETCONF data store.  If this element is not present in a NETCONF &lt;edit-config&gt;  operation 'create', 'merge' or 'replace' and the parent  element does not exist, a 'data-missing' error is  returned.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:group> |

### XML Example

|  |
| --- |
| <external-certificate>  <resource-id>ownedCertificate3</resource-id>  <certificate>AEF134F56EDB667DFA4320AEF134F56EDB667DFA4320AEF134F  56EDB667DFA4320AEF134F56EDB667DFA4320AEF134F56EDB667DFA4320  ...  AEF134F56EDB667DFA4320AEF134F56EDB667DFA4320AEF134F56EDB667  DFA4320</certificate>  </external-certificate> |

## Owned Certificate

Instances of an Owned Certificate contain a certificate and a private key. It can be used by an OpenFlow Logical Switch for authenticating itself to a controller when a TLS connection is established.

### UML Diagram



Figure 14: Data Model Diagram for Owned Certificate

### XML Schema

|  |
| --- |
| <xs:group name="OFOwnedCertificateType">  <xs:annotation>  <xs:documentation>  This grouping specifies a certificate and a  private key. It can be used by an OpenFlow Logical Switch for  authenticating itself to a controller when a TLS connection  is established.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:group ref="OFResourceType"/>  <xs:element name="certificate" type="xs:string">  <xs:annotation>  <xs:documentation>  An X.509 certificate in DER format base64  encoded.  This element MUST be present in the NETCONF data store.  If this element is not present in a NETCONF &lt;edit-config&gt;  operation 'create', 'merge' or 'replace' and the parent  element does not exist, a 'data-missing' error is  returned.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="private-key">  <xs:annotation>  <xs:documentation>  This element contains the private key  corresponding to the certificate. The private key is  encoded as specified in XML-Signature Syntax and Processing  (http://www.w3.org/TR/2001/PR-xmldsig-core-20010820/).  Currently the specification only support DSA and RSA keys.  This element MUST be present in the NETCONF data store.  If this element is not present in a NETCONF &lt;edit-config&gt;  operation 'create', 'merge' or 'replace' and the parent  element does not exist, a 'data-missing' error is  returned.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:group ref="KeyValueType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:group>  <xs:group name="KeyValueType">  <xs:annotation>  <xs:documentation>  The KeyValue element contains a single public key  that may be useful in validating the signature.  NETCONF &lt;edit-config&gt; operations MUST be implemented as  follows:  \* Exactly one of the elemenst 'DSAKeyValue' or 'RSAKeyValue'  all &lt;edit-config&gt; operations.  \* If the operation is 'merge' or 'replace', the element is  created if it does not exist, and its value is set to the  value found in the XML RPC data.  \* If the operation is 'create', the element is created if it  does not exist. If the element already exists, a  'data‑exists' error is returned.  \* If the operation is 'delete', the element is deleted if it  exists. If the element does not exist, a 'data‑missing'  error is returned.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:choice>  <xs:sequence>  <xs:element name="DSAKeyValue">  <xs:complexType>  <xs:sequence>  <xs:group ref="DSAKeyValueType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  <xs:sequence>  <xs:element name="RSAKeyValue">  <xs:complexType>  <xs:sequence>  <xs:group ref="RSAKeyValueType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:choice>  </xs:sequence>  </xs:group>  <xs:group name="DSAKeyValueType">  <xs:annotation>  <xs:documentation>  DSA keys and the DSA signature algorithm are  specified in 'FIPS PUB 186-2, Digital Signature Standard (DSS),  U.S. Department of Commerce/National Institute of Standards and  Technology,  http://csrc.nist.gov/publications/fips/fips186-2/fips186-2.pdf'.  DSA public key values can have the following fields:  P  a prime modulus meeting the requirements of the standard  above  Q  an integer in the range 2\*\*159 &lt; Q &lt; 2\*\*160 which is a  prime divisor of P-1  G  an integer with certain properties with respect to P and Q  J  (P - 1) / Q  Y  G\*\*X mod P (where X is part of the private key and not made  public)  seed  a DSA prime generation seed  pgenCounter  a DSA prime generation counter  Parameter J is avilable for inclusion solely for efficiency as  it is calculatable from P and Q. Parameters seed and  pgenCounter are used in the DSA prime number generation  algorithm specified in the above standard. As such, they are  optional but MUST either both be present or both be absent.  This prime generation algorithm is designed to provide  assurance that a weak prime is not being used and it yields a P  and Q value. Parameters P, Q, and G can be public and common to  a group of users. They might be known from application context.  As such, they are optional but P and Q MUST either both appear  or both be absent. If all of P, Q, seed, and pgenCounter are  present, implementations are not required to check if they are  consistent and are free to use either P and Q or seed and  pgenCounter. All parameters are encoded as base64 values.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:element name="P" type="xs:base64Binary">  <xs:annotation>  <xs:documentation>  This element is optional. It MUST be present in  the NETCONF data store, if the element 'Q' is present.    If element 'Q' is present in a NETCONF &lt;edit-config&gt;  operation 'create', 'merge' or 'replace' and this element  is missing, a 'data-missing' error is returned.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="Q" type="xs:base64Binary">  <xs:annotation>  <xs:documentation>  This element is optional. It MUST be present in  the NETCONF data store, if the element 'P' is present.    If element 'P' is present in a NETCONF &lt;edit-config&gt;  operation 'create', 'merge' or 'replace' and this element  is missing, a 'data-missing' error is returned.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="J" type="xs:base64Binary">  <xs:annotation>  <xs:documentation>  This element is optional.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="G" type="xs:base64Binary">  <xs:annotation>  <xs:documentation>  This element is optional.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="Y" type="xs:base64Binary">  <xs:annotation>  <xs:documentation>  This element MUST be present in the NETCONF data  store. If this element is not present in a NETCONF  &lt;edit-config&gt; operation 'create', 'merge' or 'replace' and  the parent element does not exist, a 'data-missing' error  is returned.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="Seed" type="xs:base64Binary">  <xs:annotation>  <xs:documentation>  This element is optional. It MUST be present in  the NETCONF data store, if the element 'PgenCounter' is  present.    If element 'PgenCounter' is present in a NETCONF  &lt;edit-config&gt; operation 'create', 'merge' or 'replace' and  this element is missing, a 'data-missing' error is  returned.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="PgenCounter" type="xs:base64Binary">  <xs:annotation>  <xs:documentation>  This element is optional. It MUST be present in  the NETCONF data store, if the element 'Seed' is present.    If element 'Seed' is present in a NETCONF &lt;edit-config&gt;  operation 'create', 'merge' or 'replace' and this element  is missing, a 'data-missing' error is returned.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:group>  <xs:group name="RSAKeyValueType">  <xs:annotation>  <xs:documentation>  RSA key values have two fields: Modulus and  Exponent.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:element name="Modulus" type="xs:base64Binary">  <xs:annotation>  <xs:documentation>  This element MUST be present in the NETCONF data  store. If this element is not present in a NETCONF  &lt;edit-config&gt; operation 'create', 'merge' or 'replace' and  the parent element does not exist, a 'data-missing' error  is returned.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="Exponent" type="xs:base64Binary">  <xs:annotation>  <xs:documentation>  This element MUST be present in the NETCONF data  store. If this element is not present in a NETCONF  &lt;edit-config&gt; operation 'create', 'merge' or 'replace' and  the parent element does not exist, a 'data-missing' error  is returned.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:group> |

### XML Example

|  |
| --- |
| <owned-certificate>  <resource-id>ownedCertificate3</resource-id>  <certificate>AEF134F56EDB667DFA4320AEF134F56EDB667DFA4320AEF134F  56EDB667DFA4320AEF134F56EDB667DFA4320AEF134F56EDB667DFA4320  ...  AEF134F56EDB667DFA4320AEF134F56EDB667DFA4320AEF134F56EDB667  DFA4320</certificate>  <private-key>  <ds:RSAKeyValue>  <ds:Modulus>CE45BAF6730F28CDB53534bC4323A333AAF555444DEED233232  ...  </ds:Modulus>  <ds:Exponent>DFA4320AEF134F56EDB66786230900DFA3C6F4443234901234...  </ds:Exponent>  </private-key>  </owned-certificate> |

## OpenFlow Flow Table

The OpenFlow Flow Table is an instance of an OpenFlow resource. It contains list of flow table properties. The OpenFlow flow table is a logical context which represents a flow table as described in the OpenFlow protocol specification.

### UML Diagram



Figure 15: Data Model Diagram for Flow Table

### XML Schema

|  |
| --- |
| <xs:group name="OFFlowTableType">  <xs:annotation>  <xs:documentation>  Representation of an OpenFlow Flow Table Resource.  Elements in the type OFFlowTableType are not configurable and  can only be retrieved by NETCONF &lt;get&gt; operations. Attemps to  modify this element and its children with a NETCONF  &lt;edit-config&gt; operation MUST result in an  'operation-not-supported' error with type 'application'.  </xs:documentation>  </xs:annotation>  <xs:sequence>  <xs:group ref="OFResourceType"/>  <xs:element name="max-entries" type="xs:unsignedByte">  <xs:annotation>  <xs:documentation>  The maximum number of flow entries supported by  the flow table.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="next-tables">  <xs:annotation>  <xs:documentation>  An array of resource-ids of all flow tables that  can be directly reached from this table using the  'goto-table' instruction.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="table-id" minOccurs="0" maxOccurs="unbounded" type="inet:uri"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="instructions">  <xs:annotation>  <xs:documentation>  The list of all instruction types supported by  the flow table.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="type" minOccurs="0" maxOccurs="unbounded" type="OFInstructionType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="matches">  <xs:annotation>  <xs:documentation>  The list of all match types supported by the  flow table.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="type" minOccurs="0" maxOccurs="unbounded" type="OFMatchFieldType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="write-actions">  <xs:annotation>  <xs:documentation>  The list of all write action types supported by  the flow table.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="type" minOccurs="0" maxOccurs="unbounded" type="OFActionType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="apply-actions">  <xs:annotation>  <xs:documentation>  The list of all apply action types supported by  the flow table.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="type" minOccurs="0" maxOccurs="unbounded" type="OFActionType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="write-setfields">  <xs:annotation>  <xs:documentation>  The list of all 'set-field' action types  supported by the table using write actions.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="type" minOccurs="0" maxOccurs="unbounded" type="OFMatchFieldType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="apply-setfields">  <xs:annotation>  <xs:documentation>  The list of all 'set-field' action types  supported by the table using apply actions.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="type" minOccurs="0" maxOccurs="unbounded" type="OFMatchFieldType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="wildcards">  <xs:annotation>  <xs:documentation>  The list of all fields for which the table  supports wildcarding.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="type" minOccurs="0" maxOccurs="unbounded" type="OFMatchFieldType"/>  </xs:sequence>  </xs:complexType>  </xs:element>  <xs:element name="metadata-match" type="hex-binary">  <xs:annotation>  <xs:documentation>  This element indicates the bits of the metadata  field on which the flow table can match. It is represented  as 64-bit integer in hexadecimal digits([0-9a-fA-F])  format.  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="metadata-write" type="hex-binary">  <xs:annotation>  <xs:documentation>  This element indicates the bits of the metadata  field on which flow table can write using the  'write-metadata' instruction. It is represented as  64-bit integer in hexadecimal digits([0-9a-fA-F]) format.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:group>  <xs:simpleType name="OFMatchFieldType">  <xs:annotation>  <xs:documentation>  The types of match field defined in OpenFlow  Switch Specification versions 1.2, 1.3, and 1.3.1.  </xs:documentation>  </xs:annotation>  <xs:restriction base="xs:string">  <xs:enumeration value="input-port"/>  <xs:enumeration value="physical-input-port"/>  <xs:enumeration value="metadata"/>  <xs:enumeration value="ethernet-dest"/>  <xs:enumeration value="ethernet-src"/>  <xs:enumeration value="ethernet-frame-type"/>  <xs:enumeration value="vlan-id"/>  <xs:enumeration value="vlan-priority"/>  <xs:enumeration value="ip-dscp"/>  <xs:enumeration value="ip-ecn"/>  <xs:enumeration value="ip-protocol"/>  <xs:enumeration value="ipv4-src"/>  <xs:enumeration value="ipv4-dest"/>  <xs:enumeration value="tcp-src"/>  <xs:enumeration value="tcp-dest"/>  <xs:enumeration value="udp-src"/>  <xs:enumeration value="udp-dest"/>  <xs:enumeration value="sctp-src"/>  <xs:enumeration value="sctp-dest"/>  <xs:enumeration value="icmpv4-type"/>  <xs:enumeration value="icmpv4-code"/>  <xs:enumeration value="arp-op"/>  <xs:enumeration value="arp-src-ip-address"/>  <xs:enumeration value="arp-target-ip-address"/>  <xs:enumeration value="arp-src-hardware-address"/>  <xs:enumeration value="arp-target-hardware-address"/>  <xs:enumeration value="ipv6-src"/>  <xs:enumeration value="ipv6-dest"/>  <xs:enumeration value="ipv6-flow-label"/>  <xs:enumeration value="icmpv6-type"/>  <xs:enumeration value="icmpv6-code"/>  <xs:enumeration value="ipv6-nd-target"/>  <xs:enumeration value="ipv6-nd-source-link-layer"/>  <xs:enumeration value="ipv6-nd-target-link-layer"/>  <xs:enumeration value="mpls-label"/>  <xs:enumeration value="mpls-tc"/>  </xs:restriction>  </xs:simpleType>  <xs:simpleType name="hex-binary">  <xs:annotation>  <xs:documentation>  hex binary encoded string  </xs:documentation>  </xs:annotation>  <xs:restriction base="xs:base64Binary">  </xs:restriction>  </xs:simpleType> |

### XML Example

|  |
| --- |
| <flow-table>  <resource-id>flowtable1</resource-id>  <max-entries>255</max-entries>  <next-tables>  <table-id>100</table-id>  <table-id>101</table-id>  </next-tables>  <instructions>  <type>apply-actions</type>  <type>clear-actions</type>  </instructions>  <matches>  <type>input-port</type>  <type>ethernet-dest</type>  </matches>  <write-actions>  <type>output</type>  <type>pop-mpls</type>  </write-actions>  <apply-actions>  <type>output</type>  <type>set-queue</type>  </apply-actions>  <write-setfields>  <type>ethernet-dest</type>  </write-setfields>  <apply-setfields>  <type>ethernet-dest</type>  </apply-setfields>  <wildcards>  <type> udp-dest</type>  </wildcards>  <metadata-match>30</metadata-match>  </flow-table> |

## NDM

A Negotiable Datapath Model (NDM) is an abstract switch model that describes specific switch forwarding behaviors controllable via the OpenFlow-Switch protocol. When using the NDM framework (an optional enhancement to OpenFlow), an OFCP and a capable switch agree on an NDM to be associated with a logical switch prior to sending control messages, such as flowmods, to the logical switch. (need example)

### UML Diagram

### XML Schema

This XML Schema represents the basic placeholder structure for NDMs. Implementations are expected to extend this schema with a set of NDM-specific data definitions (e.g. L2+L3). The details of the specific NDMs are outside the scope of this document. (add reference to NDM paper)

|  |
| --- |
| <xs:group name="a0">  <xs:sequence>  <xs:element name="ndm">  <xs:annotation>  <xs:documentation>  The container for the capable-switch global list of available  NDMs.  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="available-ndms" minOccurs="0"  maxOccurs="unbounded">  <xs:annotation>  <xs:documentation>  The list of all NDMs implemented by the capable-switch  Clients can query this list to learn about supported  NDMs before implementing them on logical-switches  </xs:documentation>  </xs:annotation>  <xs:complexType>  <xs:sequence>  <xs:element name="name" type="xs:string">  <xs:annotation>  <xs:documentation>  A unique name of the NDM.  This name corresponds to the  'ndm-implementation-choice' name per  logical-switch. Clients are expected to:  - Find out about available NDMs by querying this  list;  - and configure specific NDM implementations per  logical-switch using this name  </xs:documentation>  </xs:annotation>  </xs:element>  <xs:element name="type">  <xs:annotation>  <xs:documentation>  The NDM type.  </xs:documentation>  </xs:annotation>  <xs:simpleType>  <xs:restriction base="xs:string">  <xs:enumeration value="ttp"/>  <xs:enumeration value="fpmod"/>  </xs:restriction>  </xs:simpleType>  </xs:element>  <xs:element name="version" type="xs:string">  <xs:annotation>  <xs:documentation>  The version of this named NDM.  </xs:documentation>  </xs:annotation>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:group>  <xs:group name="a1">  <xs:sequence>  <xs:element name="ndm-implementation">  <xs:complexType>  <xs:sequence>  <xs:choice>  <xs:annotation>  <xs:documentation>  This is the choice-construct for configuring specific NDM  implementations on a logical switch.  Specific NDM implementations augment this choice with new  cases with the same name as the corresponding  'available-ndm'  </xs:documentation>  </xs:annotation>  </xs:choice>  </xs:sequence>  </xs:complexType>  </xs:element>  </xs:sequence>  </xs:group> |

### XML Example

This XML Example comes from a specific NDM supporting L2+L3 features as described in [XXX: reference to FAWG document.

|  |
| --- |
| <capable-switch xmlns="urn:onf:of111:config:yang"  xmlns:ndm="urn:opennetworking.org:yang:ndm"  xmlns:l2l3="urn:opennetworking.org:yang:ndm:l2l3">  <logical-switches>  <switch>  <id>LogicalSwitch5</id>  <resources>  <ndm:ndm-implementation>  <l2l3:l2l3>  <l2l3:ingress-vlan-table-size>128</l2l3:ingress-vlan-table-size>  <l2l3:router-mac-table-size>128</l2l3:router-mac-table-size>  <l2l3:l3-table-size>128</l2l3:l3-table-size>  <l2l3:l2-table-size>128</l2l3:l2-table-size>  <l2l3:egress-vlan-table-size>128</l2l3:egress-vlan-table-size>  </l2l3:l2l3>  </ndm:ndm-implementation>  </resources>  </switch>  </logical-switches>  </capable-switch> |

# Binding to NETCONF

Below we specify the requirements and give examples of how the schema specified in section 8 and 2013 is bound to the NETCONF transport protocol.

## Requirements

When implementing the XML schema defined in Section 8 and 2013 the following schemas are required in addition:

* ietf-yang-types.xsd found at <http://www.yang-central.org/modules/xsd/ietf-yang-types.xsd>
* ietf-inet-types.xsd found at <http://www.cablelabs.com/specifications/XSD/ietf-inet-types.xsd>

Those XML schemas define some basic datatypes that are used in the XML schema defined in this document.

A similar set is required when using the YANG model of Appendix B. There you need:

* ietf-yang-types.yang found at <http://www.yang-central.org/modules/yang/ietf-yang-types.yang>
* ietf-inet-types.yang found at <http://www.yang-central.org/modules/yang/ietf-inet-types.yang>

## How the Data Model is Bound to NETCONF

NETCONF uses the XML encoding format for requests and responses. More specifically, it uses RPC-based communication model. It uses the <rpc> and <rpc-reply> elements as frames of NETCONF requests and responses. The content elements inside of <rpc> element must conform to the OpenFlow Configuraton XML schemas defined in this specification.

All NETCONF base protocol operations can be used to retrieve, configure, copy and delete OpenFlow Configuration data stores. These operations are defined in RFC6241. The commonly used operations are:

* edit-config
* get-config
* copy-config
* delete-config

### edit-config

The <edit-config> operation loads all or part of a specified configuration to the specified target configuration. If the target configuration does not exist, it will be created. The “operation” attribute of elements in the <config> subtree specifies the type of operations to be performed on the element. NETCONF supports “create”, “replace”, “merge” and “delete”. The definition of these operations can be found RFC6241.

#### XML Example: Create a Capable-Switch Configuration

This XML example shows an edit-config operation to create a capable-switch configuration.

|  |
| --- |
| <?xmlversion="1.0" encoding="UTF-8"?>  <rpc message-id="1"  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <edit-config xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <target>  <candidate/>  </target>  <default-operation>merge</default-operation>  <test-option>set</test-option>  <config>  <capable-switch  xmlns:nc="urn:ietf:params:xml:ns:netconf:base:1.0"  nc:operation="create"  xmlns="urn:onf:of12:config:yang">  <id>capable-switch-0</id>  <logical-switches>  <switch>  <id>logic-switch-1</id>  <datapath-id>11:11:11:11:11:11:11:11</datapath-id>  <enabled>true</enabled>  <controllers>  <controller>  <id>controller-0</id>  <role>master</role>  <ip-address>192.168.2.1</ip-address>  <port>6633</port>  <protocol>tcp</protocol>  </controller>  </controllers>  </switch>  </logical-switches>  </capable-switch>  </config>  </edit-config>  </rpc>  <rpc-reply message-id="1"  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <ok/>  </rpc-reply> |

#### XML Example: Replace the ip-address Element of Controller

This XML example shows an edit-config operation to replace the ip-address element of controller.

|  |
| --- |
| <?xml version="1.0" encoding="UTF-8"?>  <rpc message-id="1"  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <edit-config xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <target>  <candidate/>  </target>  <default-operation>merge</default-operation>  <config>  <capable-switch xmlns="urn:onf:of12:config:yang">  <logical-switches>  <switch>  <id>logic-switch-1</id>  <controllers>  <controller>  <id>controller-0</id>  <ip-address operation="replace">10.0.0.10</ip-address>  </controller>  </controllers>  </switch>  </logical-switches>  </capable-switch>  </config>  </edit-config>  </rpc>  <rpc-reply message-id="1"  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <ok/>  </rpc-reply> |

RPC request must contain the key leave(s)( id element in this case) to uniquely identify the element being operated in the NETCONF datastore scope.

### get-config

This operation is used to retrieve all or part of a specified configuration. The filter element identifies the portions of the OpenFlow configuration to retrieve. If this element is unspecified, the entire configuration is returned.

When issuing a NETCONF get request all elements in the requested sub-tree must be returned in the result. Those elements that can be modified by a NETCONF edit-config request or retrieved by a NETCONF get-config request are identified in the normative constraints which can be found in the description of each individual element.

#### XML Example: get-config

|  |
| --- |
| <?xml version="1.0" encoding="UTF-8"?>  <rpc message-id="1"  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <get-config xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <source>  <running/>  </source>  <filter type="xpath" select="/capable-switch"/>  </get-config>  </rpc>  <rpc-reply message-id="1"  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <data>  <capable-switch xmlns="urn:onf:of12:config:yang">  <id>capable-switch-0</id>  <logical-switches>  <switch>  <id>logic-switch-1</id>  <datapath-id>11:11:11:11:11:11:11:11</datapath-id>  <enabled>true</enabled>  <controllers>  <controller>  <id>controller-0</id>  <role>master</role>  <ip-address>192.168.2.1</ip-address>  <port>6633</port>  <protocol>tcp</protocol>  </controller>  </controllers>  </switch>  </logical-switches>  </capable-switch>  </data>  </rpc-reply> |

### copy-config

This operation creates or replaces an entire configuration datastore with the contents of another complete configuration datastore. If the target datastore exists, it is overwritten. Otherwise, a new one is created, if allowed.

#### XML Example: copy-config

|  |
| --- |
| <?xml version="1.0" encoding="UTF-8"?>  <rpc message-id="1"  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <copy-config>  <target>  <running/>  </target>  <source>  <url>https://mydomain.com/of-config/new-config.xml</url>  </source>  </copy-config>  </rpc>  <rpc-reply message-id="1"  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <ok/>  </rpc-reply> |

### delete-config

This operation deletes a configuration datastore. The <running>configuration datastore cannot be deleted.

#### XML Example: delete-config

|  |
| --- |
| <?xml version="1.0" encoding="UTF-8"?>  <rpc message-id="101"  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <delete-config>  <target>  <startup/>  </target>  </delete-config>  </rpc>  <rpc-reply message-id="1"  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0">  <ok/>  </rpc-reply> |

## RPC error

OpenFlow Configuration uses NETCONF <rpc-error> element(s) defined in RFC6241 to report operation failures. The <rpc-error> element(s) are sent in <rpc-reply> messages if an error occurs during the processing of an <rpc> request. The <rpc-reply> MAY contain multiple <rpc-error> elements. The <rpc-error>element includes the following information:

* error-type: Defines the conceptual layer of the error occurred.
* error-tag: contains a string to identifying the error condition.
* error-severity: contains a string to identifying the error severity.
* error-app-tag: contains a string to identifying the data-model-specific or implementation-specific error condition.
* error-path: contains the absolute XPath expression identifying the element path associated to the specific error being reported.
* error-message: contains error description suitable for human display
* error-info: contains data-model-specific error content

Detailed <rpc-error> definitions can be found in RFC 6241. Specific implementation may define implementation-specific error information and messages inside of error-info as sub-elements.

An example of <rpc-error> element in <rpc-reply> message:

|  |
| --- |
| <?xml version="1.0" encoding="UTF-8"?>  <rpc-reply message-id="101"  xmlns="urn:ietf:params:xml:ns:netconf:base:1.0"  <rpc-error>  <error-type>application</error-type>  <error-tag> missing-element</error-tag>  <error-severity>error</error-severity>  <error-message xml:lang="en">  expected key leaf in list  </error-message>  <error-info>  <bad-element>id</bad-element>  <error-number>383</error-number>  </error-info>  </rpc-error>  </rpc-reply> |

1. Bibliography

1. *OpenFlow Specification 1.3.* **Open Networking Foundation.** 2011.

2. *OpenFlow: enabling innovation in campus networks.* **McKeown, Nick, et al., et al.** 2008, ACM SIGCOMM Computer Communication Review, pp. 69-74.

3. **Bradner, S.** RFC 2119. *IETF.* [Online] March 1997. http://www.ietf.org/rfc/rfc2119.txt.

4. **Enns, et al., et al.** RFC 6241. *IETF.* [Online] June 2011. http://tools.ietf.org/rfc/rfc6241.txt.