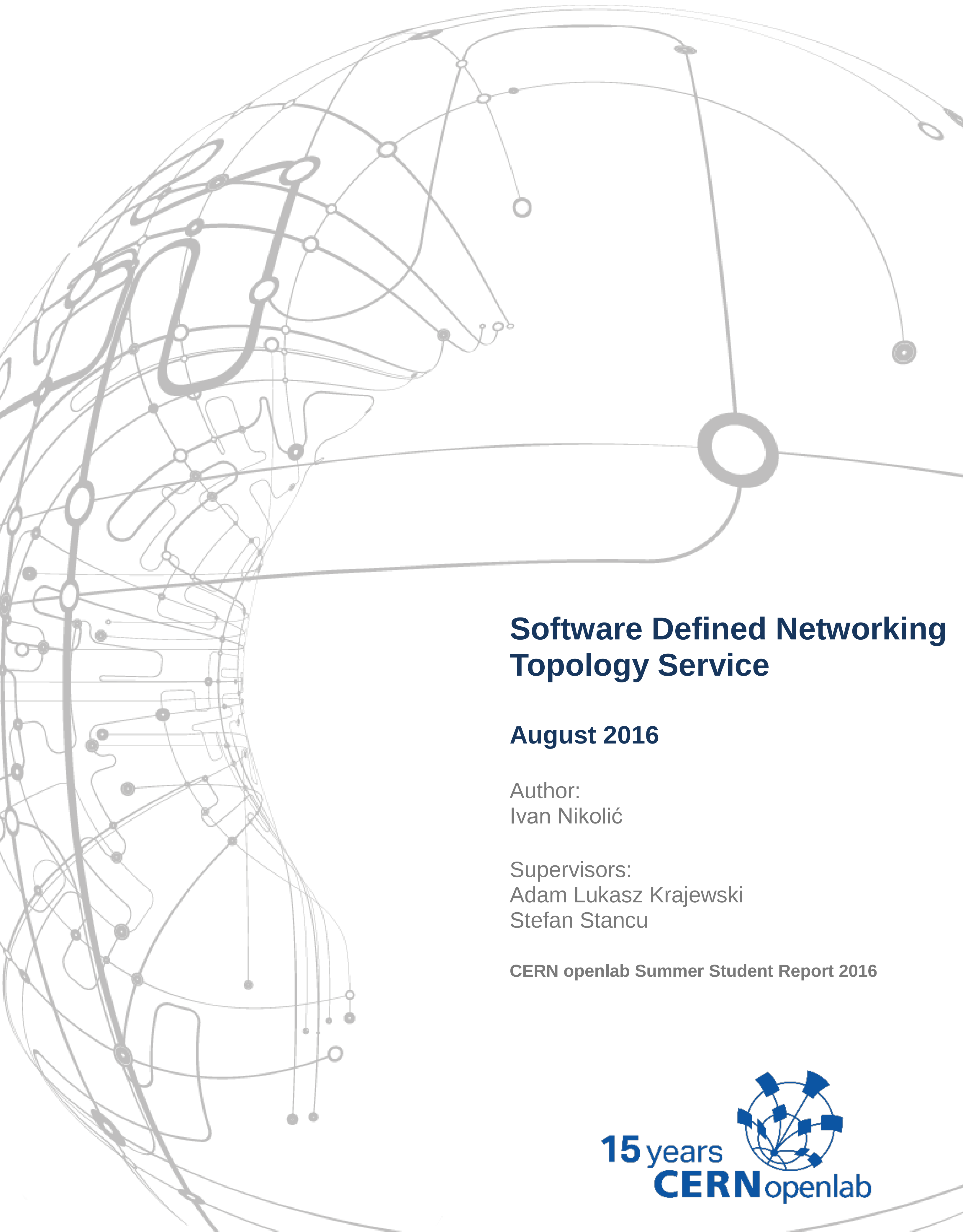

Software Defined Networking Topology Service

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Project Specification

Through the openlab collaboration with Brocade, CERN is investigating the potential of Software Defined Networking (SDN) [1] for improving the programmability and agility of its network services. The underlying network topology (physical and logical) information is a key prerequisite for providing flexible and resilient SDN-enabled network services.

The aim of the project is to investigate the network topology services offered by the OpenDaylight [2] controller and to implement a software module for fetching and tracking network topology information in real-time.

Abstract

Traditional networks, while using stable and proven technology, don’t always provide enough agility for modern computing environments. Software Defined Networking is a new paradigm meant to improve this shortcoming, decoupling the control plane (the logic deciding about where traffic is sent) from the data plane (the network devices that forward traffic to the intended destination).

The openlab collaboration with Brocade gives CERN the opportunity to experiment and investigate the potential of the SDN technology for improving its network services. To take the correct decisions, the control plane logic (also denoted as SDN controller) must be aware of the paths that are available in the network.

The outcome of the project is a good understanding of the topology services offered by the OpenDaylight controller and their reactivity to network changes, complemented by a software module that maintains an up to date network topology graph. This graph can then be used by higher level SDN applications (such as Brocade’s BFO) to make optimal routing decisions.

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1 Introduction

One of the shortcomings of networks today is vertical integration. That means that software and hardware are coupled together. Because of that, today's networks are very complex and very hard to manage. Also they are not flexible for adding new network services. The SDN paradigm breaks vertical integration which means that it separates network control logic from network devices. Separated control logic allows centralized network management and programmability.

The SDN architecture is characterized by the following features:

1) Control and data planes are decoupled.
2) Forwarding decisions are flow-based, instead of destination-based. A flow is a sequence of packets between a given source and destination.
3) The network is programmable through software applications running on top of a controller that interacts with network devices.

These features offer multiple benefits:

- it is much simpler to modify network policies through high level languages compared to performing low level device specific configurations,
- the control program can automatically react to network state changes and lastly,
- the control logic centralization simplifies the development of more sophisticated networking functions and services.

The typical SDN architecture can be divided in 5 parts, as illustrated in Figure 1:

1) **Network devices** - network devices in SDN have a well-defined instruction set used to take actions on the incoming packets (e.g., forward to specific ports, drop, forward to the controller). Instructions are defined by southbound interfaces.
2) **Southbound interface –** the southbound interface defines the communication protocol between forwarding devices and control plane elements. This protocol formalizes the way the control and data plane elements interact.
3) **SDN controller –** platform used to control the network
4) **Northbound interface -** the northbound interface abstracts the low level instruction set used by southbound interfaces to program forwarding devices.
5) **Network applications –** applications written in high level language. Network applications can be used to monitor network traffic, optimize flow paths in the network, etc.

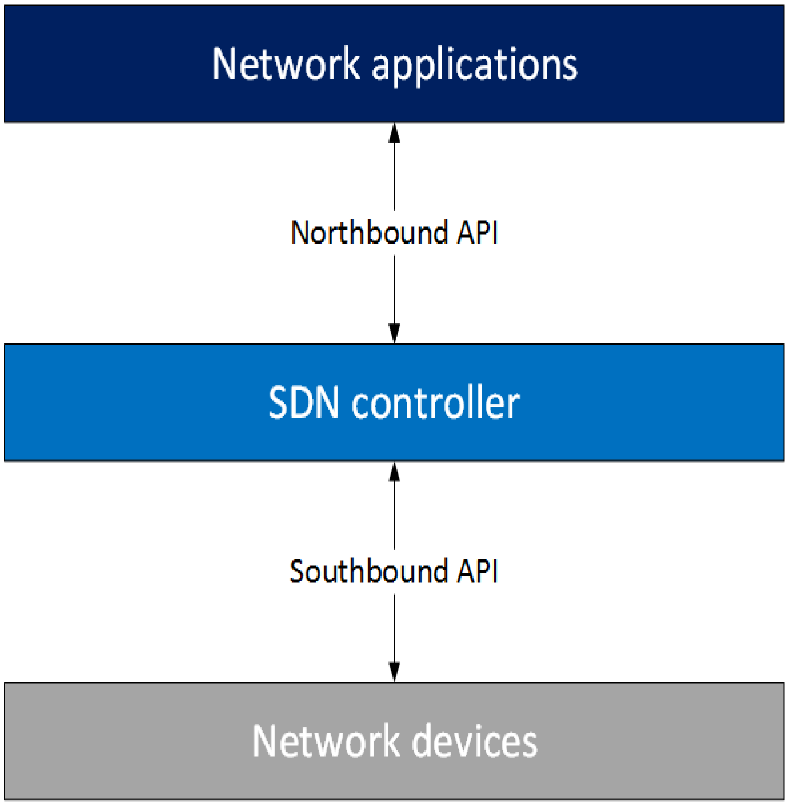


Figure 1 SDN architecture

The strong coupling between control and data plane in traditional networks makes adding new features in the network difficult. If there is a need for change in the network, devices must be reconfigured or their software needs to be upgraded. With the decoupling of control and data plane, SDN brings various advantages. Examples of this advantages are: all applications can benefit of the global network view leading to more effective policy decisions and these applications can take actions from any part of the network.

The difference between traditional networks and SDN is depicted in *Figure 2*.

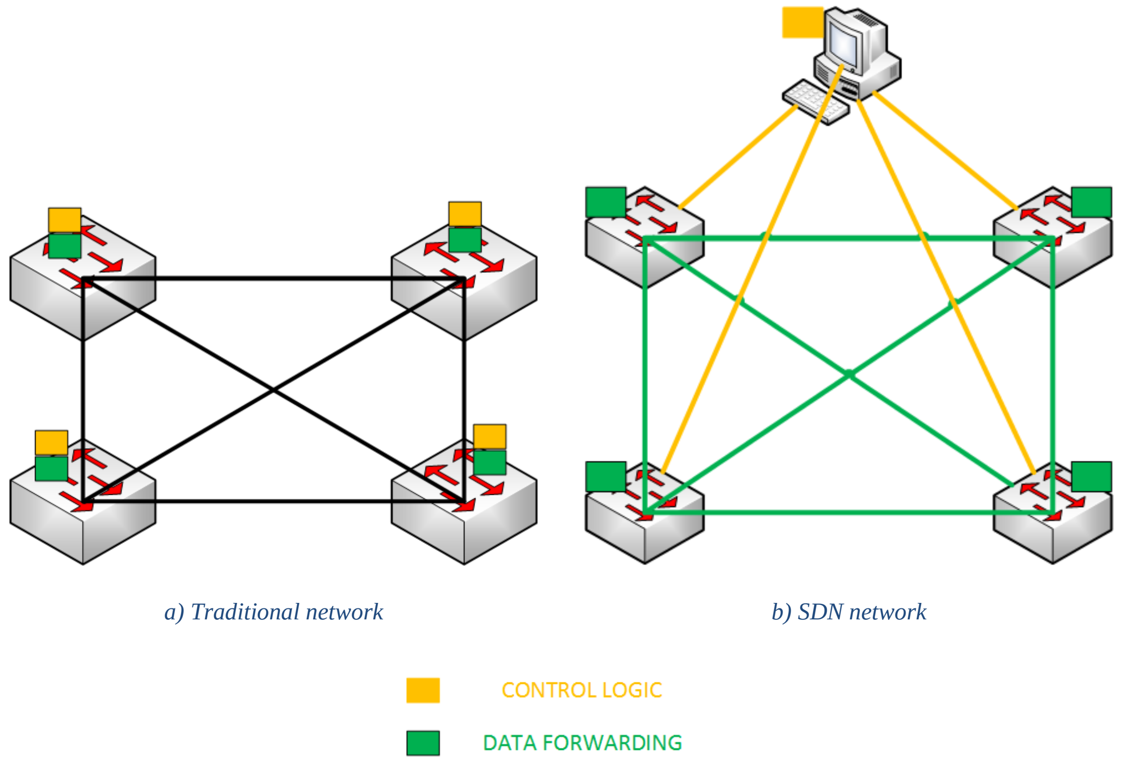


Figure 2 Difference between traditional networks and SDN

The goal of this project was to develop a software module to fetch and track network topology information in real-time. Mapping this onto the SDN architecture (Figure 1), this translates to developing a network application in Java programming language, which will fetch topology via northbound API (in this case REST). Experiments and tests were done with both the Mininet network emulator [3] and real network hardware consisting of Brocade ICX switches. The project design is shown in Figure 3.

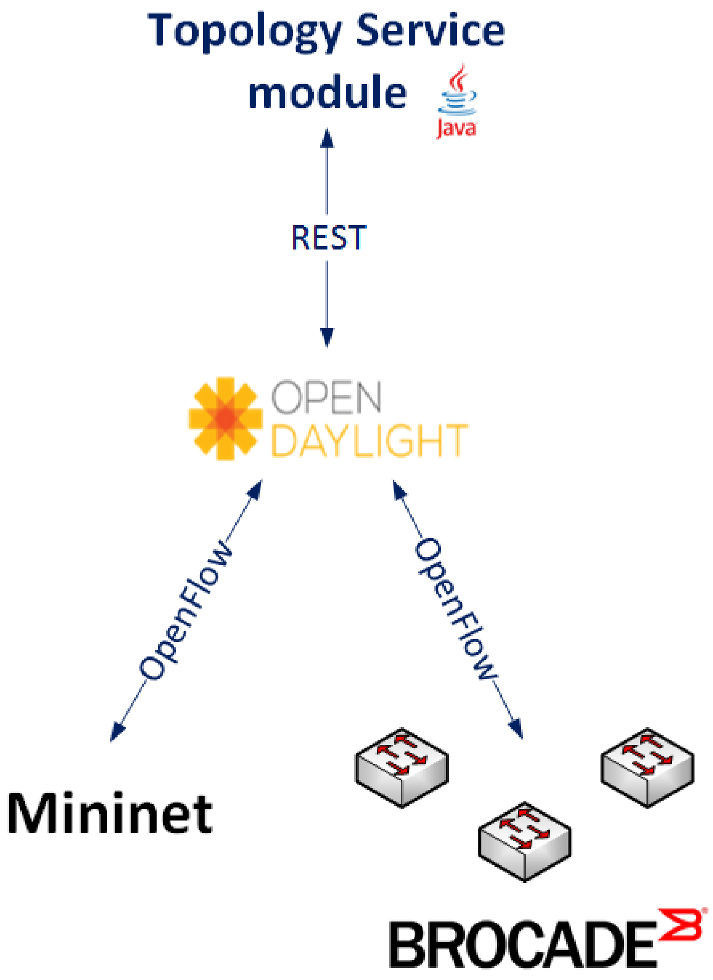


Figure 3 Project design

2 Technologies

The project software module was developed in the Java programming language using Eclipse IDE and Maven project builder. OpenDaylight was used as the SDN network controller. Testing was initially done using the Mininet network emulator and then the functionality was validated on a physical network testbed composed of three Brocade ICX 7450-24 switches. Both OpenDaylight and Mininet are further described in this chapter.

2.1 OpenDaylight

OpenDaylight is an open-source controller written in Java supported by the OpenDaylight foundation. It is currently the most widely used open-source SDN controller. It supports network programmability via multiple southbound protocols and offers a collection of northbound APIs.

OpenDaylight architecture consists of three layers:

1) Southbound plugins and protocols
2) Service adaptations and network functions
3) Northbound APIs and applications

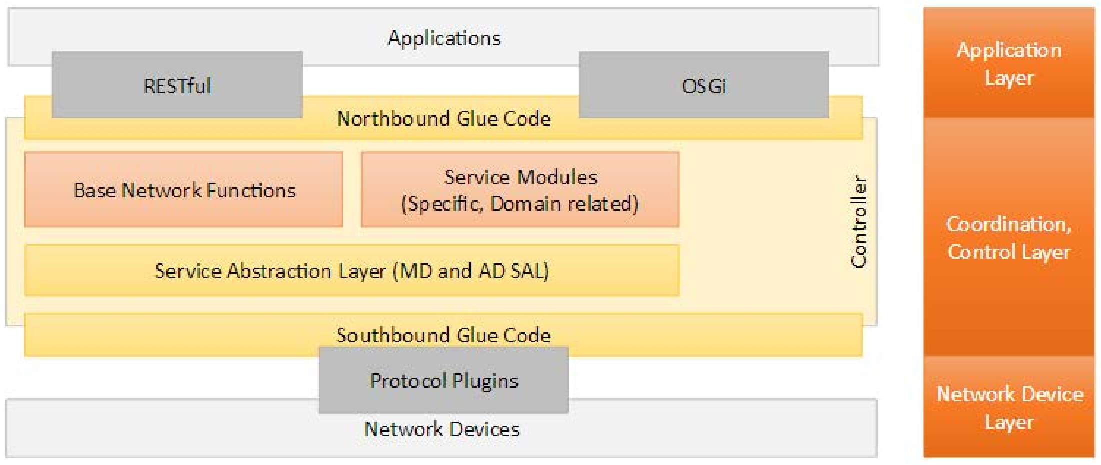


Figure 4 OpenDaylight architecture [4]

The controller allows the applications to be agnostic about the network device specifications, thereby allowing developers to concentrate on the application functionality rather than writing device- specific commands. The architecture of OpenDaylight controller is illustrated in Figure 4.

In this project the OpenDaylight OpenFlow plugin was used for interacting with network devices, be them real or emulated in Mininet. For the northbound API we chose the well documented REST API. The installation process of the OpenDaylight controller and its OpenFlow plugin, as well as the access to API are further described in section 3.

2.2 Mininet

Mininet is a network emulator. It uses lightweight virtualization to make a single system look like a complete network. Mininet's virtual hosts, switches and links behave like real devices, they are just created using software rather than hardware.

Mininet is designed to easily create virtual software-defined networks consisting primarily of multiple OpenFlow-enabled Ethernet switches and hosts connected to those switches.

Managing networks in Mininet is straightforward. The subsequent example shows how to create simple network, connect it to a remote controller and manipulate diverse nodes and links within the network. For using Mininet, super user privileges are required.

```
/* Creates simple network topology (see Figure 5)and connects it to a remote
controller */

$ sudo mn --topo linear,4 --mac –controller=remote,
ip=188.184.19.247, port=6633 –-switch ovs, protocols=OpenFlow13
```

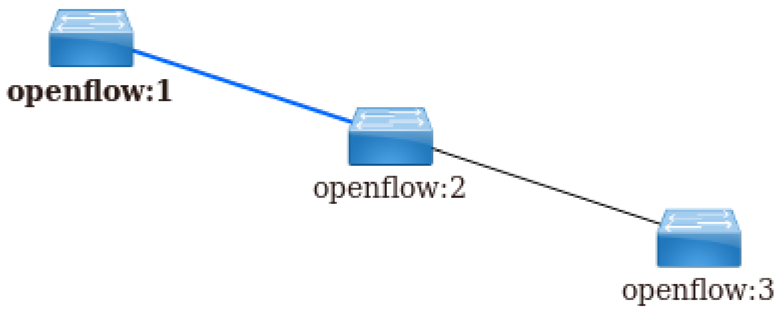


Figure 5 Linear network topology

```
// Stops node
mininet> switch s1 stop

// Starts node
mininet> switch s1 start

// Puts link in state DOWN
mininet> link s1 s2 down

// Puts link in state UP
mininet> link s1 s2 up
```

3 Development process

This chapter describes how to set up the development environment, what were the problems encountered during the development of the software module, and what were the proposed solutions.

3.1 Environment setup

The development environment consisted of two remote VM's: one used for the Mininet network emulator, the other one used for running the OpenDaylight controller. The software module development was done on a local machine using Eclipse IDE and Maven.

OpenDaylight installation

The OpenDaylight controller installation is fairly straightforward. In this project the latest stable version of OpenDaylight was used (Beryllium, downloaded from [5]). After downloading and unzipping the release the next step is to navigate to package directory and run the following command:

```
$ ./bin/karaf
```

After this process, OpenDaylight is up and ready for use. The next step is to install OpenDaylight's OpenFlow plugin by entering the following command:

```
opendaylight-user@root> feature:install odl-openflowplugin-all
```

3.2 Module class design

All the classes in this module are divided into 3 packages. Those three packages are called *primitives*, *clients* and *sdn*. The first package consists of primitive data types which are specific for this module. The *clients* package consists of various clients which are required for fetching data from the controller. The *sdn* package contains the main module class and various classes that can be represented as module services. All packages and related classes are further described below.

3.2.1 Primitives

The class diagram of the *primitives* package is depicted in Figure 6. The package contains the following classes:

- **Link** – used to describe the link data type. Attributes of this class are ID, destination node and source node.
- **Node –** used to describe the node data type. Attributes are ID, IP address and connectors.
- **Connector** – used to describe the connector data type. Connectors are ports on switches. Attributes of this class are ID, MAC address, name and port number.
- **Event** – used to describe event data type. Attributes are timestamp (the time when the event occurred), event message (describes which element of network is affected by this event) and event type (for the time being it can be "created" or "deleted").

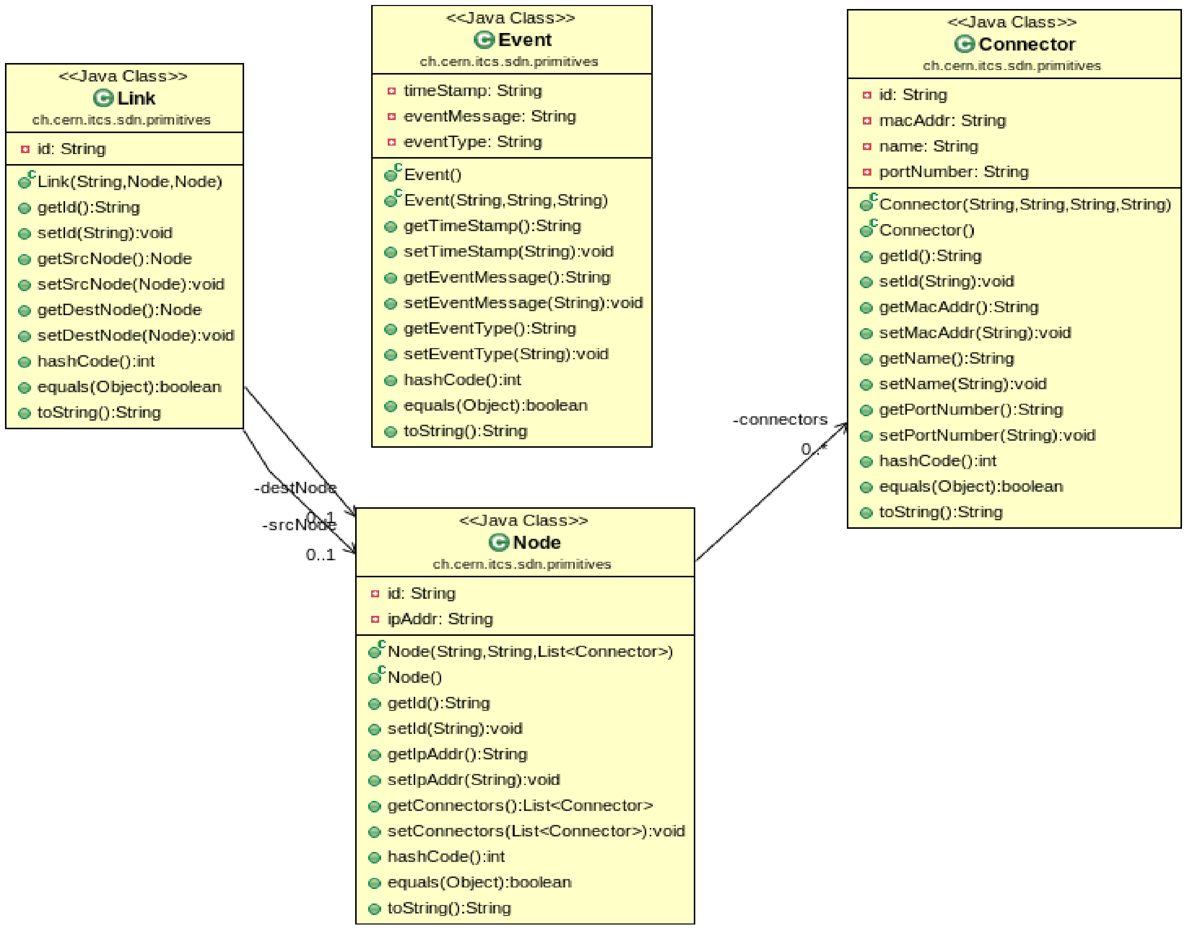


Figure 6 Package primitives - class diagram

3.2.2 Clients

The class diagram of the *clients* package is shown in Figure 7. The package contains the following classes:

- **WebSocketClient** – used to connect to web sockets.
- **WebSocketClientHandler –** used to handle connection with web sockets.
- **OdlClient** – used to communicate with OpenDaylight. Input arguments for constructor are the controller IP address and port number as well as the user name and password. The class is used to query information about nodes and links, to update the connectors of a given node and to receive notifications about network changes. All received responses are in JSON format.

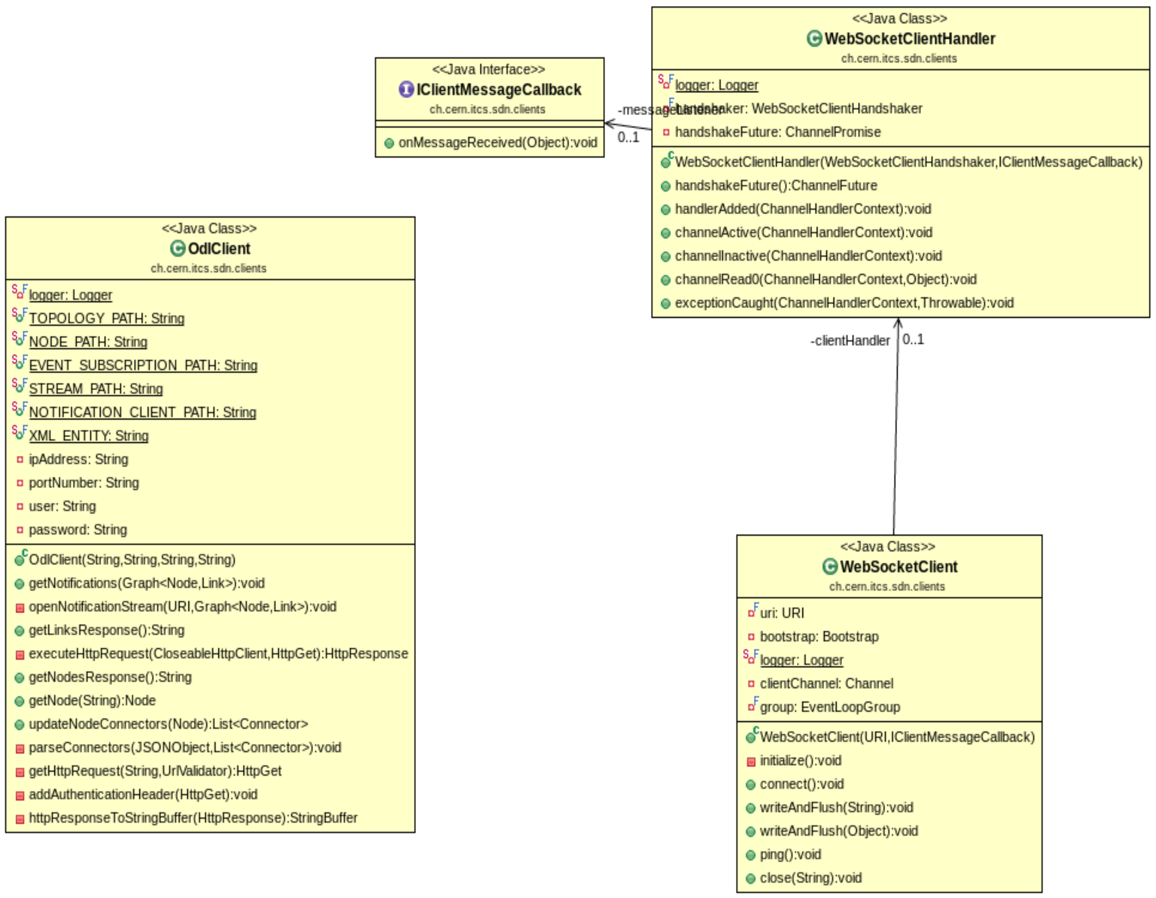
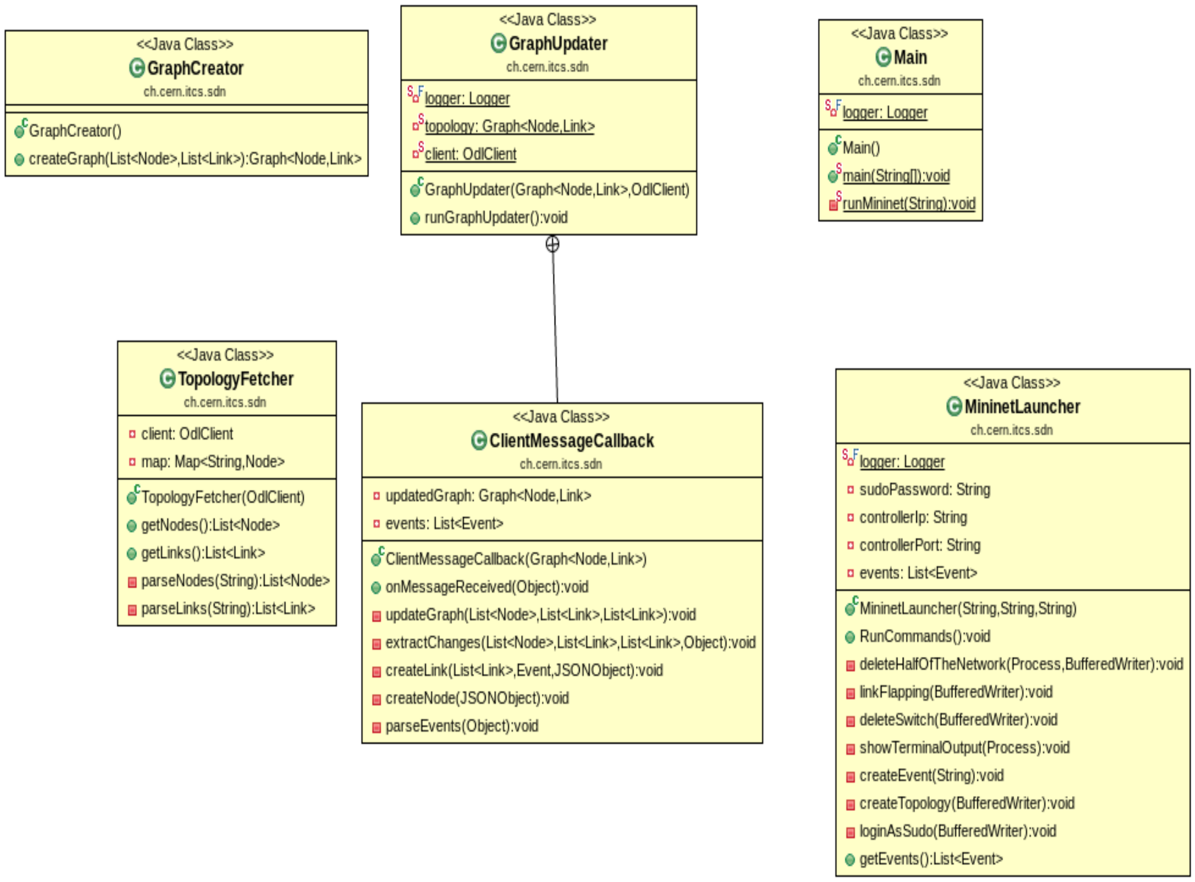

<<Java Interface>>
IClientMessageCallback
ch.cern.itcs.sdn.clients
onMessageReceived(Object):void
-messageListener
0..1
<<Java Class>>
WebSocketClientHandler
ch.cern.itcs.sdn.clients
logger: Logger
handshaker: WebSocketClientHandshaker
handshakeFuture: ChannelPromise
WebSocketClientHandler(WebSocketClientHandshaker,IClientMessageCallback)
handshakeFuture():ChannelFuture
handlerAdded(ChannelHandlerContext):void
channelActive(ChannelHandlerContext):void
channelInactive(ChannelHandlerContext):void
channelRead0(ChannelHandlerContext,Object):void
exceptionCaught(ChannelHandlerContext,Throwable):void
-clientHandler
0..1
<<Java Class>>
OdlClient
ch.cern.itcs.sdn.clients
logger: Logger
TOPOLOGY_PATH: String
NODE_PATH: String
EVENT_SUBSCRIPTION_PATH: String
STREAM_PATH: String
NOTIFICATION_CLIENT_PATH: String
XML_ENTITY: String
ipAddress: String
portNumber: String
user: String
password: String
OdlClient(String,String,String,String)
getNotifications(Graph<Node,Link>):void
openNotificationStream(URI,Graph<Node,Link>):void
getLinksResponse():String
executeHttpRequest(CloseableHttpClient,HttpGet):HttpResponse
getNodesResponse():String
getNode(String):Node
updateNodeConnectors(Node):List<Connector>
parseConnectors(JSONObject,List<Connector>):void
getHttpRequest(String,UrlValidator):HttpGet
addAuthenticationHeader(HttpGet):void
httpResponseToStringBuffer(HttpResponse):StringBuffer
<<Java Class>>
WebSocketClient
ch.cern.itcs.sdn.clients
uri: URI
bootstrap: Bootstrap
logger: Logger
clientChannel: Channel
group: EventLoopGroup
WebSocketClient(URI,IClientMessageCallback)
initialize():void
connect():void
writeAndFlush(String):void
writeAndFlush(Object):void
ping():void
close(String):void

Figure 7 Package clients - class diagram

3.2.3 Sdn

The class diagram of the *sdn* package is illustrated in Figure 8. The package contains the following classes:

- **GraphCreator –** used to create a graph data structure. The *createGraph* method requires as input a lists of nodes and a list of links.
- **TopologyFetcher –** used to parse responses from OdlClient and to create lists of nodes and links.
- **MininetLauncher –** used to measure the time between running commands that alter the network state and the reception of topology changes notifications. The constructor input arguments are the controller IP address and port, as well as the super user password. There are methods to delete one node, half of the nodes of the network and also to simulate link flapping.
- **GraphUpdater –** used to start updating a graph.
- **ClientMessageCallback –** used to parse events form notifications. These events are used to update the graph.
- **Main** – main method. Input arguments are controller IP address and port, and username and password for controller login. It *first* creates a graph based on the information retrieved by the *TopologyFetcher* and then it runs *GraphUpdater* in order to maintain the graph up to date. It also has the option for calling the *runMininet* method for testing purposes.



<<Java Class>>
GraphCreator
ch.cern.itcs.sdn
GraphCreator()
createGraph(List<Node>,List<Link>):Graph<Node,Link>
<<Java Class>>
GraphUpdater
ch.cern.itcs.sdn
logger: Logger
topology: Graph<Node,Link>
client: OdlClient
GraphUpdater(Graph<Node,Link>,OdlClient)
runGraphUpdater():void
<<Java Class>>
Main
ch.cern.itcs.sdn
logger: Logger
Main()
main(String[]):void
runMininet(String):void
<<Java Class>>
TopologyFetcher
ch.cern.itcs.sdn
client: OdlClient
map: Map<String,Node>
TopologyFetcher(OdlClient)
getNodes():List<Node>
getLinks():List<Link>
parseNodes(String):List<Node>
parseLinks(String):List<Link>
<<Java Class>>
ClientMessageCallback
ch.cern.itcs.sdn
updatedGraph: Graph<Node,Link>
events: List<Event>
ClientMessageCallback(Graph<Node,Link>)
onMessageReceived(Object):void
updateGraph(List<Node>,List<Link>,List<Link>):void
extractChanges(List<Node>,List<Link>,List<Link>,Object):void
createLink(List<Link>,Event,JSONObject):void
createNode(JSONObject):void
parseEvents(Object):void
<<Java Class>>
MininetLauncher
ch.cern.itcs.sdn
logger: Logger
sudoPassword: String
controllerIp: String
controllerPort: String
events: List<Event>
MininetLauncher(String,String,String)
RunCommands():void
deleteHalfOfTheNetwork(Process,BufferedWriter):void
linkFlapping(BufferedWriter):void
deleteSwitch(BufferedWriter):void
showTerminalOutput(Process):void
createEvent(String):void
createTopology(BufferedWriter):void
loginAsSudo(BufferedWriter):void
getEvents():List<Event>

Figure 8 Package sdn - class diagram

3.3 Performance measurements

The most important performance metric for the topology tracking service is the delay between the moment when changes in the network occur and the time when the module receives a notification about the change from the controller. Tests were performed for measuring this delay using both Mininet (using the *MininetLauncher* class) and the lab network made of real devices (triggering changes via the devices CLI) The results are summarized in Table 1.

Type of event	Time between event and notification	
	Mininet	Real network
Node created	1 s	1 s
Node deleted	1 s	1 s
Link created	5 s	5 s
Link deleted	15 s	15 s

Table 1 Test results - time between event and notification

The time to detect that a link was deleted can be explained by OpenDaylight's topology discovery engine. OpenDaylight sends LLDP (Link Layer Discovery protocol) packets every 5 seconds to detect network topology. After a link goes down it takes 15 seconds to detect the link was deleted, because the controller topology discovery mechanism has an aging time of 15 seconds (corresponding to 3 consecutive LLDP probes). The LLDP probe sending interval and ageing timers are configurable in OpenDaylight's topopology-discover-lldp.xml parameters [6].

The 5 seconds link creation detection delay also influences the reactivity of the *GraphUpdater* class for nodes creation. OpenDaylight first notifies a node creation with only basic information (i.e. node IP and name) and only after 5 seconds it provides full information about the node's connectors.

3.3.1 Possible improvements

While OpenDaylight's link deletion mechanism is functional, OpenFlow has support for faster detection of link deletions via the asynchronous Port Status messages [7]. The Port Status asynchronous message generation was tested on Brocade switches[1]. The results summarized in Table 2 show that OpenDaylight could leverage OpenFlow's Port Status asynchronous message to significantly decrease the link deletion time for cases when the devices ports link status goes down.

Type of event	Time between event and Port Status packet received
Link deleted	1 s
Link created	4 s

Table 2 Test results - time between event and Port Status packet

[1] Wireshark [8] 2.0, featuring a built-in OpenFlow dissector, was used to sniff the communication between the switches and the controller.

4 Usage

The module requires as input parameters the controller IP address and port, and the user name and password for authenticating to the controller. The module fetches the current topology status, builds the corresponding graph and displays the current number of nodes and links. Subsequently, the module listens for notifications and upon receiving a notification it displays the ID of the network element that has been affected and the event type (created/deleted). After that it updates the topology graph according to the changes and displays the new number of nodes and links.

5 Conclusion

Throughout this project OpenDaylight proved to be a mature SDN controller platform. Setting up the environment and working with all these technologies were reasonably straightforward. Still, the performance tests done during development, showed there is room for improving OpenDaylight's reactivity for detecting network topology changes, notably link deletions caused by switch ports going down.

The module developed in this project can easily be leveraged by Brocade's SDN applications for improving network topology awareness. A possible use case is to integrate it with sFlow network traffic monitoring in order to provide efficient traffic flow path detection.

6 References

[1] Software-Defined Networking (SDN)
https://en.wikipedia.org/wiki/Software-defined_networking

[2] OpenDaylight: Open Source SDN Platform
https://www.opendaylight.org/

[3] Mininet An Instant Virtual Network on your Laptop (or other PC)
http://mininet.org/

[4] SDN Series Part Six: OpenDaylight, the Most Documented Controller
http://thenewstack.io/sdn-series-part-vi-opendaylight/

[5] https://www.opendaylight.org/downloads

[6] https://github.com/opendaylight/openflowplugin/blob/master/applications/topology-lldp-discovery/src/main/resources/org/opendaylight/blueprint/topology-lldp-discovery.xml

[7] ONF - OpenFlow Switch Specification v1.3.3, section 7.4.3 – Port Status Message
https://www.opennetworking.org/images/stories/downloads/sdn-resources/onf-specifications/openflow/openflow-spec-v1.3.3.pdf

[8] Wireshark - network protocol analyser
https://www.wireshark.org/