TECHNISCHE UNIVERSITÄT CHEMNITZ

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**Masterarbeit**

# Design and implementation of an SDN based authentication and separation mechanism for WiFi users

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**Abstract**

The ever-increasing use of data services on mobile devices, places increased demands on existing networks. Especially in busy areas, such as shopping centers, office buildings or in event centers, the existing network coverage by UMTS and LTE is no longer sufficient. It is, therefore, obvious to direct some traffic through other radio standards. In this case, WLAN is particularly suitable because those frequencies are free to use without any license restrictions and since most mobile devices have long since supported this. However, an uncontrolled number of WLAN access points can interfere with each other. It is, therefore, desirable to install only one set of access points at these locations and manage them centrally. The research project BIC-IRAP (Business Indoor Coverage Integrated Radio Access Points) is a project aimed at providing a seamless coupling between LTE and WLAN.

The separation of data traffic is an important aspect when using shared hardware. No direct data exchange between the networks of different mobile radio providers should be possible. Likewise, the networks of different businesses or companies should be kept strictly separate from each other. Classic VLANs would be used for this purpose. Within the scope of the BIC-IRAP project, however, there were considerations to control parts of the network using SDN. Therefore, the goal of this master thesis is to operate an access point (AP) on an OpenFlow controlled switch. Users can be authenticated against a RADIUS server. The AP should supply at least two separate networks. If possible, the separation of data traffic should already take place in the AP. Optionally the AP should provide Hotspot 2.0 functionality.

The conceptualization and implementation must be documented in detail. The optional components are carried out in consultation with the supervisor. The successful completion of the work is a test set-up. The achievable performance characteristics must be recorded.

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# 1 Introduction

The penetration of mobile internet users has increased many fold from a few thousands to millions over a short span of time. Due to the increasing demand for data among subscribers, mobile operators are pushed to go beyond boundaries to provide efficient and reliable data service to their customers. Although, the existing network services such as UMTS and LTE can handle larger data capacity, their coverage is not always sufficient in crowded places such as office buildings, convention centers, shopping malls etc. There is an urgent need to find a solution on how to offload the mobile data traffic over to other radio standards.

In such case, WLAN is an existing radio standard that has already been deployed in large numbers and has been supported by millions of devices lately. One unique advantage of using WLAN over other radio standards would be its license free usage of its radio frequency for commercial purposes. This WLAN standard, when deployed in a controlled manner can support data traffic routed from the mobile services. The IEEE 802.11 WLAN has already been widely used for commercial enterprises ranging from office networks, shopping malls to educational institutions etc. The deployment rages from a few dozens to hundreds of access points (APs), which serve many users through multitude of devices ranging from mobile devices, laptops to printers and other connected hardware. These networks also provide varied set of services that includes authentication, authorization and accounting (AAA), dynamic channel reconfiguration, interference management, security such as intrusion detection and prevention and providing quality of service.

These enterprise WLAN AP's are usually centrally managed through a controller. The task now is to find a solution to seamlessly direct traffic between LTE and WLAN. The research project BIC-IRAP (Business Indoor Coverage Integrated Radio Access Point) is currently aimed at providing a solution for the seamless coupling between LTE and WLAN.

The growing adoption of Software Defined Networking in the recent years has given rise to providing unique solutions without depending too much on hardware. The advantage of using SDN is that, it separates the network control pane from the physical network topology and uses software control flow to define how traffic is forwarded in the network. For example, the routing table and the flow control of a switch can be easily controlled remotely through a software controller. The characteristic features of

SDN is possible due to the use of OpenFlow, a standardized protocol that is used by many open source controllers to manipulate the flow tables of network switches. This provides more flexibility to programmatically control the behavior of network switches by building network applications that talk to the network controller. Any OpenFlow enabled switch from any vendor provides a common interface to be manipulated via a controller, thus providing flexibility and simplified network management.

## 1.1 Contribution

This thesis provides a novel approach towards separating the data traffic between the different network providers within an access point. This is made possible through the simple, yet effective use of OpenFlow protocol that enables the development of different enterprise WLAN services as applications such as, using software defined network controllers. The performance benefits achieved though this system is possible without any changes to the existing 802.11 client. The proposed system is compatible with the existing enterprise WLAN security protocols like WPA2 enterprise.

## 1.2 Results

The expected outcome of this thesis is to demonstrate a prototype system that runs an AP on an OpenFLow controlled switch. The AP also provides enterprise grade authentication system using WPA2 enterprise alongside a RADIUS server, and host two separate networks.

## 1.3 Research Context[1]

The research described in this thesis was done based on the BIC-IRAP project which is focused on combining the strengths of LTE and Wireless-LAN seamlessly. Through the integration of small and micro cells of LTE with WLAN in the BIC-IRAP system, the two radio technologies are available through a single dynamically configurable hardware configuration.

## 1.4 Thesis Structure

This thesis report is organized as follows, Chapter 2 describes the background for this thesis. Chapter 3 describes in detail about SDN and the different types in use today. Chapter 4 talks about the control and authentication mechanism such as the protocols and technologies used. Chapter 5 talks about the environment required to build the system such as the tools and software's. Chapter 6 describes in detail how the application is developed, from conceptualization to coding in python. Chapter 7 shows how the system is being implemented. Chapter 8 presents the results obtained from the system after series of testing and enhancement. Chapter 9 concludes the thesis and describes further improvements and drawbacks of this method.

# 2 Background

This chapter discusses about the topics relevant this thesis, it includes an introduction to software defined networking, 802.11 protocol, Hotspot 2.0 and BIC-IRAP project.

## 2.1 Software Defined Networking [2]

SDN is nothing but the physical separation of the network control plane from the forwarding plane. The control plane consists of all the logic that the switch requires to correctly setup a forwarding plane, that is, the signaling associated with the switch.

Traditionally, the vendor has the control over the logic necessary for signaling since they run a proprietary firmware. This makes the devices non-interoperable with other vendors which hampers flexibility. Though most of these switches provide SNMP based management solution via CLI, they still do not allow the introduction of custom control plane function or protocol into the switch. This makes experimenting with new protocols cumbersome. Software Defines Networking aims to alleviate these problems by making the switched control plane be easily accessible remotely and be modifiable using the OpenFlow protocol. Any third-party software can than take advantage of this open protocol to manage and orchestrate an entire network.

SDN architecture generally has three components or groups of functionality as shown in the figure 2.1 below.

- **Application Layer:** Consists of programs that communicate the behaviors and needed resources with the SDN controller via the application protocol interfaces (API's). It can also build an abstracted view of the network by collecting information from the controller.
- **Control Layer:** This logical layer functions as a relay that sends the instructions or resources sent by the application layer to the networking components.
- **Infrastructure Layer:** This holds the SDN networking devices that control the forwarding and data processing capabilities of the network including the function to forward and process the data paths.

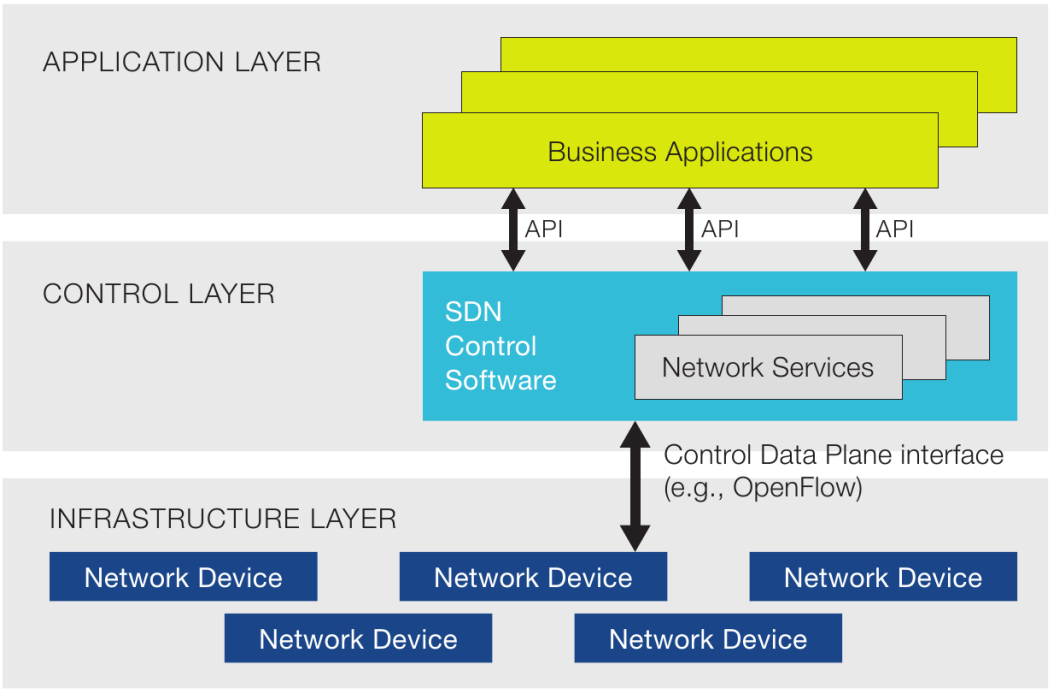



*Figure 2.1:* SDN architecture diagram[17]

## 2.2 IEEE 802.11 MAC [3]

The IEEE 802.11 Media Access Control Layer (MAC) [3] defines the protocol for stations to establish connections with each other and transmit data frames. Medium access in 802.11 is performed by a distributed coordination function (DCF), which uses carrier sense multiple access with collision avoidance (CSMA/CA) to enable random medium access among all contending stations (STAs). Hence, it reduces the amount of collisions. Logically, the MAC is divided into two parts, an upper MAC, and a lower MAC. The upper MAC handles management frames, which include probe, authentication, association requests and their corresponding responses. The lower MAC handles control frames, which includes acknowledgement (ACK) frames, along with request-to-send (RTS) and clear-to-send (CTS) frames. The frames handled by the lower MAC have real-time constraints. For instance, ACK frame timeouts are within the order of micro-seconds. For this reason, control frames are handled and generated within hardware. Management frames, however, have softer time constraints, and can be handled in software locally (as is the case in Linux systems that use hostapd [34]), or remotely (as is the case when using a centralized WLAN controller [35] ).

An 802.11 based wireless interface can operate under the following operating modes: STA (client), access point (AP), mesh, ad-hoc and item Monitor mode. The most common mode of operation is the infrastructure mode (which includes enterprise WLAN environments). In this mode of operation, clients connect to the AP using a series of message exchanges in a process called "association". The decision on which AP to associate with is left entirely to the client. Clients learn about APs either passively through beacon frames that are periodically broadcasted by the access points, or actively by performing a probe scan.

In a probe scan, clients first send out probe request frames over all channels. APs that receive these frames and are willing to accept a connection from a client respond with a probe response frame. All APs from which the client receives probe responses are candidates for the client to associate with. Next, the client sends an authentication frame, and waits for an authentication response from the AP. This is followed by the client sending an association request, and receiving an association response from the AP. If the network is operating in open authentication mode, the client is considered to be associated at this point, and can now transmit data frames to be forwarded by the AP. If the AP is configured to use WPA, WPA2, or WPA2 Enterprise, the corresponding 802.1X [34] handshake is performed after the association phase before clients can forward data frames through the AP.

## 2.3 Hotspot 2.0 [4]

It is a new wireless network standard that is designed to make connection to public Wi-Fi hotspots more easy and secure. They are already supported on many mobile devices running some of the popular operating systems such as Windows 10, Mac OS 10.9 or newer, Android 6.0 or newer, and iOS 7 or newer.

The main purpose of Hotspot 2.0 is to provide seamless mobility like cellular style "roaming" for Wi-Fi networks. The device will automatically connect to the available networks based on the networks partners on the home networks while roaming globally. This is made possible using the latest 802.11u [36] protocol designed for the same purpose. Some organizations also call this as Passpoint [37].

# 3 Software Defined Networking

The Open Network foundation, a non-profit organization, has been undertaking an extensive research for the past couple of years in designing and standardizing open network components such as OpenFlow, SDN etc. which, after being rolled out on to a variety of network devices and software's from different vendors has been delivering substantial benefits to both enterprises and carriers include: [38]

- **Directly Programable:**Network directly programmable because the control functions are decoupled from forwarding functions, which enable the network to be programmatically configured by proprietary or open source automation tools.
- **Centralized Management:** Network intelligence is logically centralized in SDN controller software that maintains a global view of the network, which appears to applications and policy engines as a single, logical switch.
- **Reduce CapEx:** Software Defined Networking potentially limits the need to purchase purpose-built, ASIC-based networking hardware, and instead supports pay-as-you-grow models
- **Reduce OpEX:** SDN enables algorithmic control of the network of network elements (such as hardware or software switches/routers that are increasingly programmable, making it easier to design, deploy, manage, and scale networks. The ability to automate provisioning and orchestration optimizes service availability and reliability by reducing overall management time and the chance for human error.
- **Deliver Agility and Flexibility:** Software Defined Networking helps organizations rapidly deploy new applications, services, and infrastructure to quickly meet changing business goals and objectives.
- **Enable Innovation:** SDN enables organizations to create new types of applications, services, and business models that can offer new revenue streams and more value from the network.

## 3.1 Existing SDN Controllers

For this Master thesis, a few available SDN controllers are first studied for its functionality that can be manipulated for data path segregation. A brief overview on each controller is discussed in the following sections.

### 3.1.1 Ryu Controller [5]

Ryu is a component-based software defined networking framework. It provides software components with well-defined API that make it easy to create new network management and control applications. The component that is of particular interest for this master thesis is the switching hub by using OpenFlow.

Switching hubs have a variety of functions, some of which are discussed below.

- Learns the MAC address of the host connected to a port and retains it in the MAC address table.
- When receiving, packets addressed to a host already learned, transfers them to the port connected to the host.
- When receiving, packets addressed to an unknown host, performs flooding.

The main reason to choose RYU over other controllers is due to its customizability and easy to create core applications using Python. RYU allows users to modify core functions or use these functions to create custom applications that suits specific needs, in this case, it was used to create a switching application that can segregate users within the OpenVswitch, instead of being controlled each time by the controller.

The software components provided by RYU with well-defined Application Programming Interface (API's), makes it easy for developers to create custom network management or control applications. The existing components can be quickly and easily modified or implement a custom component so that the underlying network can meet the changing demands of the application. RYU is designed to increase the agility of network by being more easily manageable and adapt how traffic is handled.

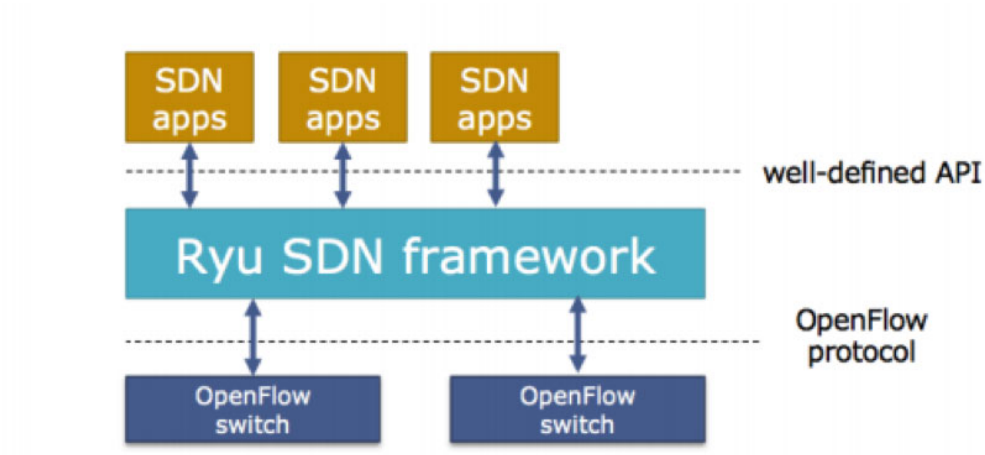



*Figure 3.1:* RYU SDN Controller Framework [18]

RYU Controller is supported by NTT of Japan and has a strong open source RYU community that maintain and manage the code which is hosted at GitHub. OpenStack also supports deployment of RYU as network controller in its cloud operating systems.

### 3.1.2 Floodlight Controller [6]

It is yet another open source SDN controller similar to RYU. The benefit of using this controller is the ability to easily develop applications using Java, which is widely used for high level programming by developers and to adapt the software as per requirement. Flood Light offers Representational state transfer application program interface (REST API's) which help developers to easily program interfaces with the product.

Floodlight is used to run as the network backend for OpenStack. When used with the Neutron plugin with OpenStack, the Floodlight controller functions as a network-as-a-service model with the help of REST API offered by Floodlight. The following diagram below shows the architecture of Floodlight controller.

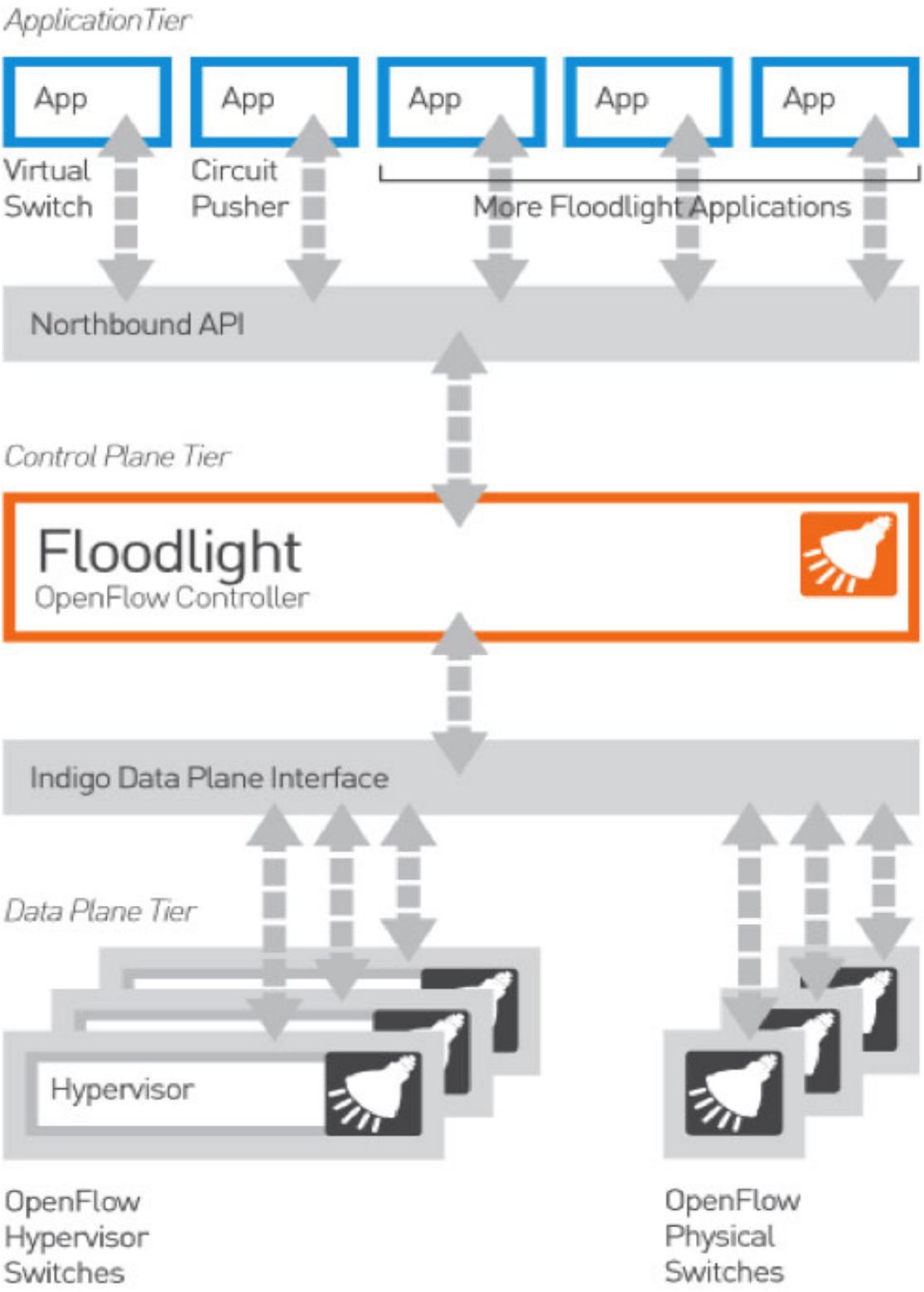



*Figure 3.2:* Floodlight Controller architecture [19]

### 3.1.3 OpenDaylight

OpenDaylight controller is based on JVM, similar to Floodlight, which was a derivative of OpenDaylight that can be deployed on any systems that supports Java. OpenDaylight controller uses the following tools as its framework:

- **Maven:** OpenDaylight uses Maven, which uses Project Object Model to script the dependencies between the bundles for easier build automation.
- **OSGi:** It works as the back-end for OpenDaylight as it loads bundles dynamically and packages JAR files and binding them together for exchange of information.
- **JAVA interfaces:** They are used for event listening, specifications, and forming patterns.
- **REST APIs:** These are the northbound APIs that manage the topology, flow program, host tracking, static routing and so on.

The following figure shows the framework of OpenDaylight with the above tools mentioned:

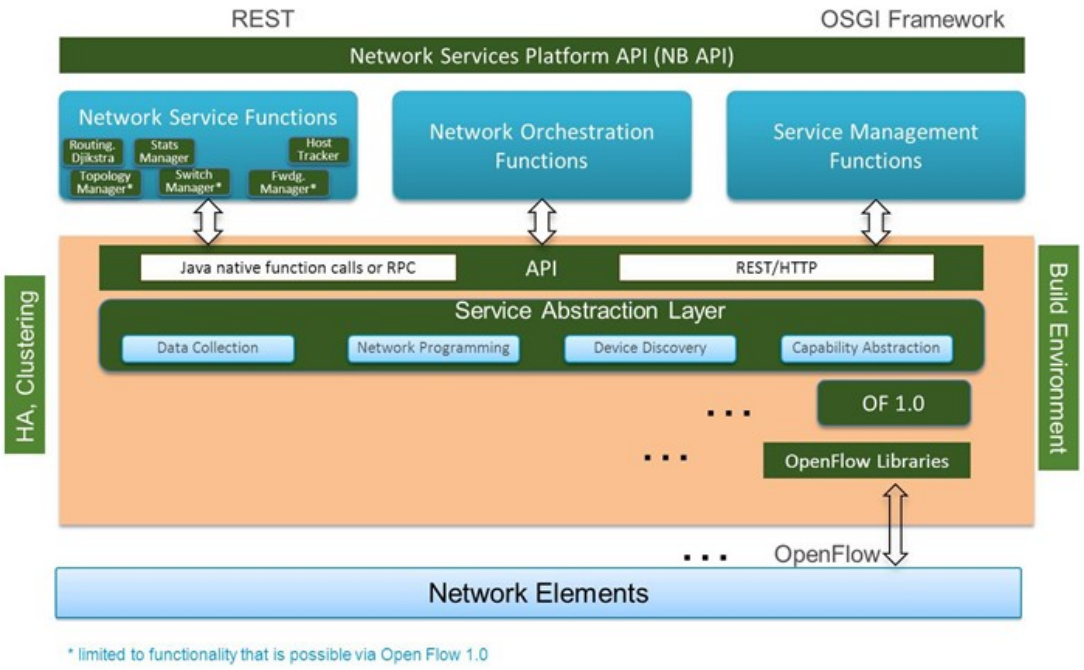



*Figure 3.3:* OpenDaylight Architecture Framework [20]

## 3.2 Applications of SDN

Many research efforts has been done till now in writing SDN applications. Jose et. al. [39] propose using commodity OpenFlow enabled switches for traffic measurement. The authors propose a framework where a collection of rules are installed on OpenFlow switches, and having a controller track the corresponding flow match counters. The controller can then draw inferences from the counters and dynamically tune the rules as required in order to identify different traffic aggregates.

Resonance [40] is another application uses programmable switches to enforce access control in the network. The authors try to prove that today's enterprise networks rely on different combinations of middle boxes, intrusion detection systems, and network configurations in order to enforce access control policies, whilst placing a burden on end-hosts in the system to remain patched and secure. The proposed system uses an SDN approach comprising programmable switches and a controller, which together implement a network monitoring framework, a policy specification framework, and the ability to trigger specific actions at the switch level.

OpenSAFE [41] is a framework that enables network monitoring using OpenFlow. It addresses the problem of routing traffic for network analysis in a reliable manner without affecting normal traffic.

Hedera [42] is an adaptive flow scheduling system for data center networks. The premise for Hedera is that existing IP multipathing techniques used in data centers usually rely on per-flow static hashing, which can lead to under-utilisation of some network paths over time due to hash collisions. The system works by detecting large flows at the edge switches of a data center, and using placement algorithms to find good paths for the flows in the network. Experiments performed using simulations indicate significant improvements over static load balancing techniques.

In the paper *OpenFlow based server load balancing gone wild* [43], the authors address the problem of server load balancing using OpenFlow switches. The number of flow entries that can be saved on an OpenFlow switch is much less than the number of unique flows that a switch might need to handle in data center workloads. Thus, micro flow management using per-flow rules is not practical for performing distributing flows between different servers using a switch. The authors thus take advantage of OpenFlow's wildcard based rules capability, and propose algorithms to compute concise wildcard rules that achieve a specific distribution of traffic.

These are some of the applications that have been written for SDN controllers but none of them address the challenge to dynamically redirect packets in real time, based on different clients and their credentials used for authentication. This thesis proposed to build one such application that can segregate packets coming from different clients

in such a way that there is no possible connection between multiple clients associated within the same access point.

## 3.3 Open vSwitch [7]

It is a production quality multilayer virtual switch, designed to enable massive automation through programmatic extension. It also supports standard management interfaces and protocols such as NetFlow, sFlow, CLI, port mirroring, VLAN's, LACP etc. In addition to this, it is also designed to support distribution across multiple physical servers similar to VMWare's vNetwork distributed vswitch. Open vSwitch was developed by the Linux foundation and is licensed under Apache 2.0.

The virtual switch is a software layer that resides in a server that is hosting virtual machines. VM's and also now, containers such as Docker have logical and virtual Ethernet ports. These logical ports connect to a virtual switch. The diagram below shows the features of an Open vSwitch. [44]

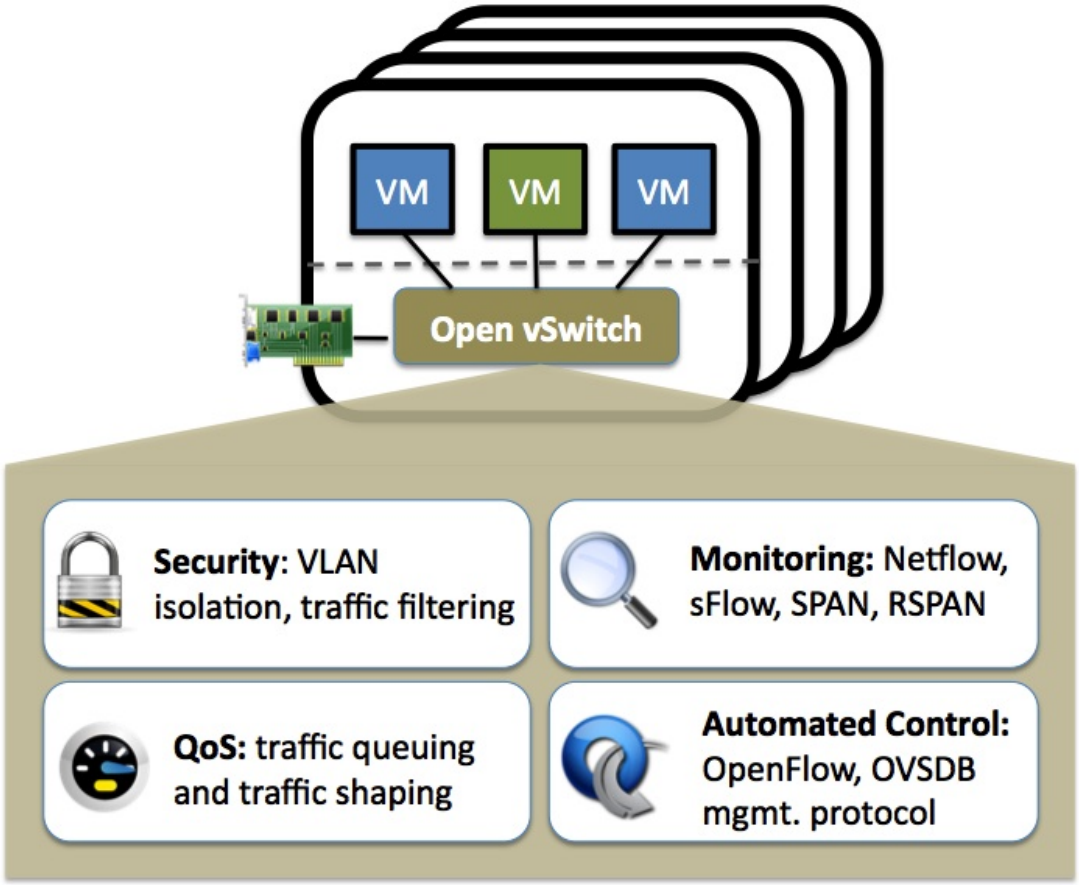



*Figure 3.4:* Open vSwitch features [21]

From the management and control perspective, Open vSwitch leverages on the OpenFlow and the Open vSwitch Database (OVSDB) management protocol, which means it can work as both a soft switch running within the hypervisor and as the control stack for switching operations on the physical switches. Other ways in which OVS is used in Software Defined Networking include:

- SDN's deployed in data centers use OVS because it connects all the virtual machines (VMs) within a hypervisor instance on a sever.
- It is the ingress point in overlay networks running on top of the physical networks in the data center and it is the first point of entry for all the VM's sending traffic to the network.
- In datacenter SDN deployments, using OVS for virtual networking is considered the core element since its main use case is a multi-tenant network virtualization.

- In some service chaining use cases, OVS is sometimes used to direct traffic between network functions.

Open vSwitch is designed in such a way that it is meant to be managed and controlled by a third-party controllers and managers. OVS can also directly work with OpenStack using a plugin or directly from an SDN controller, such as OpenDaylight. It is also possible to deploy OVS on all servers in an environment and let it operate with the MAC learning functionality.

# 4 Control and Authentication Mechanism

In this chapter, the softwares and protocols used for providing authentication and for controlling the access point is discussed. A brief introduction to OpenWrt and the different protocols such as OpenFlow, RADIUS is described in the flowing topics.

## 4.1 OpenWrt [8]

OpenWrt is a Linux distribution that works like any other Linux distro designed for embedded devices. OpenWrt offers bult-in package manager that allows to install packages from its repository or manually build your own firmware file using your custom-built package. The packages range anything from an SSH server, VPN, traffic-shaping, enterprise wireless solutions, BitTorrent client, or even as a hotspot manager.

OpenWrt is designed for power users that wants customizability to the stock firmware provided by the manufacturer. There are many custom firmware's such as DD-WRT available for most popular routers, for this thesis, OpenWrt is chosen because of its flexibility and more stable than most custom firmware's or sometimes even the stock firmware.

OpenWrt has many features that can be mentioned but out of scope for this thesis, a run-down version of the most relevant features are listed below that are related to this thesis.

- **SSH server for terminal access:** Provides SSH server, which allows to connect directly to the routers terminal via SSH and when the router is configured to the internet, allows to remotely configure the router.
- **Capture and Analyse network Traffic:** Tcpdump tool is included in the build to analyze the packets that are traversing thru the router. The tool can also be used to create packet logs that can be open in packet analyzer tools such as Wireshark.
- **GUI Interface:** OpenWrt also includes a GUI interface for managing most of the router's configuration, the built in one is named as LuCi.

- **OpenvSwitch:** The virtual switch is also available as a package on OpenWrt repository that is used in this thesis to be installed in the router for creating a virtual switch within the router that can also work along with the physical switched present.
- **Wireless Utilities:** OpenWrt provides many different packages for managing wireless sockets in the router, for this thesis, Hostapd package is chosen because of its fully featured support for a wide range of authentication mechanisms such as IEEE 802.1x/WPA/EAP/RADIUS with EAP protocols. It can be configured in the file located at /etc/hostapd.conf in the routers folder.
- **Freeradius:** The open source RADIUS server is also available as a package for the OpenWrt build but is not used in the firmware for this thesis because of memory unavailability of the TP Link WR-4300 router.
- **MySQL:** The is a fully featured MySql server also available as the packages that can be installed on the router but again could not be used in this thesis due to memory restrictions of the router.

The following figures below shows the SSH interface of OpenWrt terminal and the LuCi web interface.

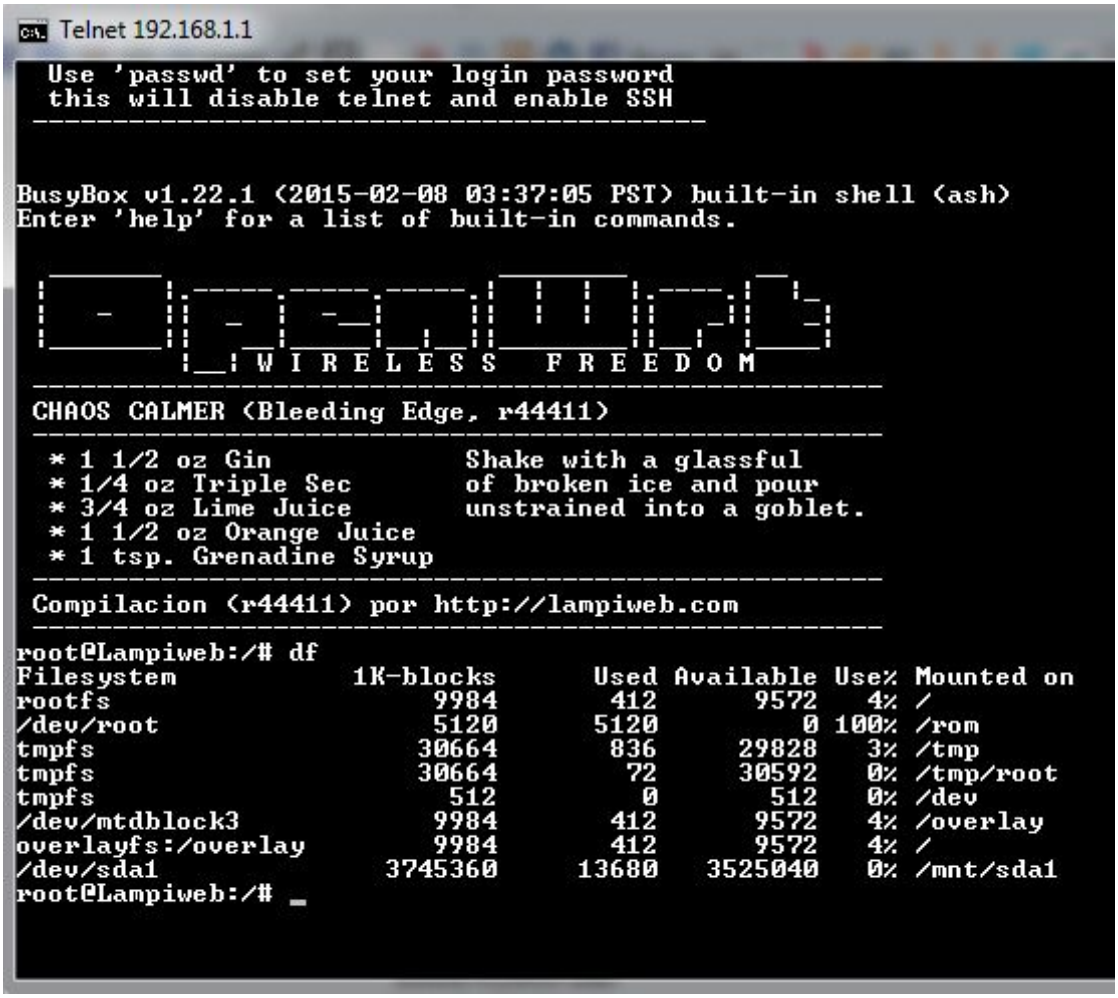



*Figure 4.1:* OpenWrt Terminal View [22]

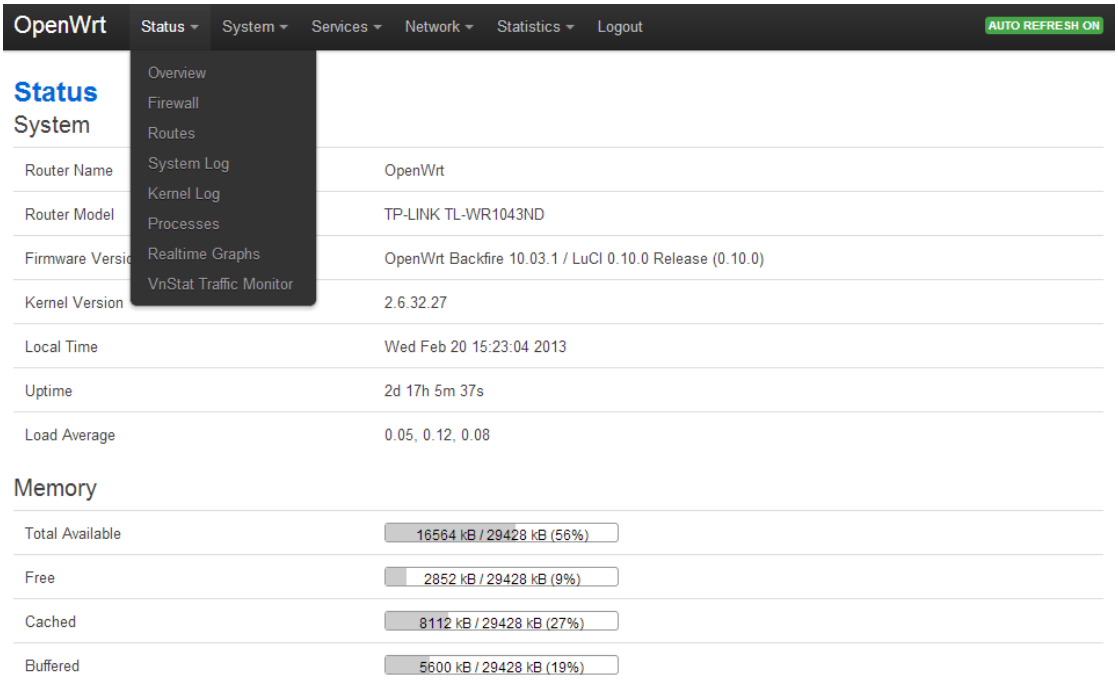



*Figure 4.2:* OpenWrt GUI Interface [23]

## 4.2 Protocols

For this thesis, protocols such as OpenFlow, RADIUS and 802.1x security are used extensively and are discussed in detail below, explaining their use cases and features.

### 4.2.1 OpenFlow [9]

It is a standard communication interface defined between the control and forwarding layers of the SDN architecture, allowing direct access for manipulating the forwarding plane of the network devices such as switches and routers, both physical and virtual (hypervisor based).

OpenFlow, along with SDN technologies have helped IT to manage and address the high-bandwidth, and dynamic nature of today's applications. It also has helped adapt the network to ever-changing business needs, and significantly reduce the complexity in maintenance and operations.

Some of the best features of OpenFlow is explained in the following figure.

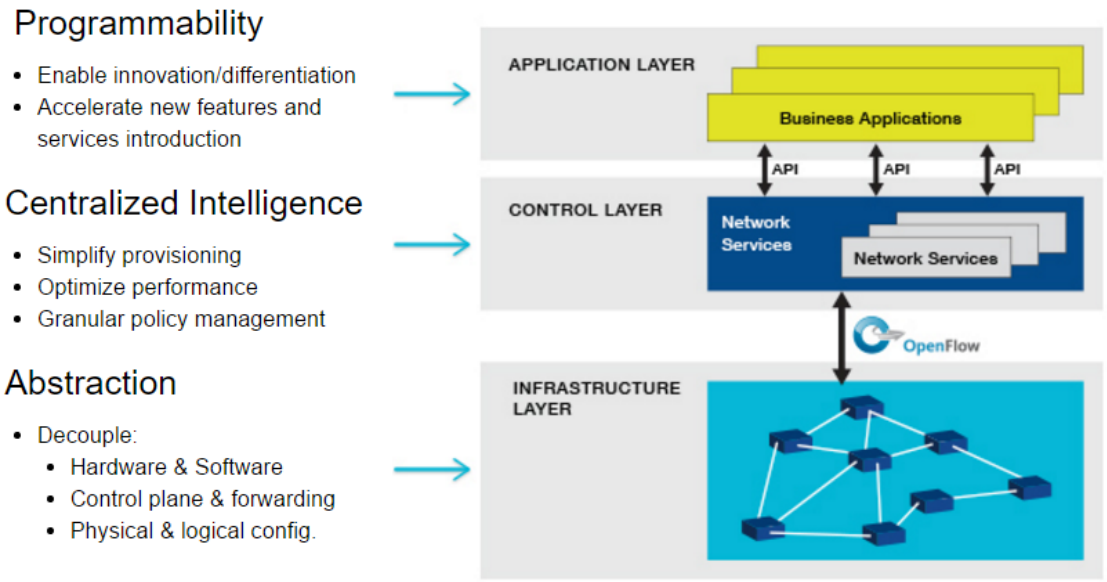



*Figure 4.3:* OpenFlow features [24]

### How does OpenFlow Work? [45]

In a traditional switch or a router, the packet forwarding and high level routing decisions occur on the same device. In an OpenFlow switch, the routing and forwarding functions are separated. The data path portion is still on the switch and the routing decisions are handled by a separate controller, typically it's a standard server. The OpenFlow switch and controller communicate using the OpenFlow protocol, which defines messages such as packet-in, packet-out modify-forwarding path and get stats.

### OpenFlow Specification [46]

The protocol can be split into 4 components namely: message layer, state machine, system interface and configuration.

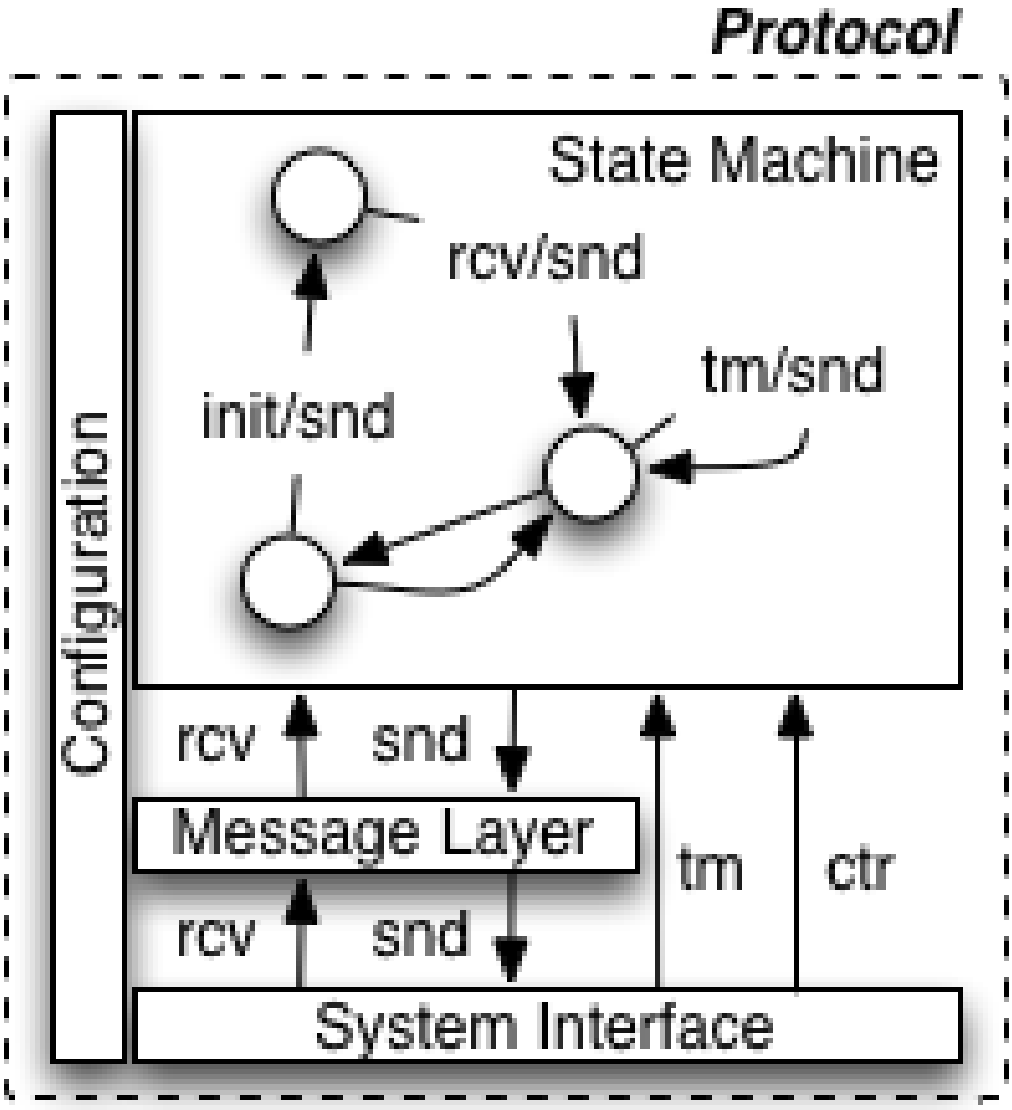



*Figure 4.4:* OpenFlow Protocol [25]

- **Message Layer:**
  It is the core of the protocol stack. It also supports the ability to construct, copy, compare, manipulate and print the messages. The message layer defines the valid structure and semantics for all messages.
- **State Machine:**
  It defines the core level behaviour of the protocol. It is typically used to describe

the actions such as: flow control, negotiations, delivery, capability discovery etc.

- **System Interface:**
  It typically defines how the protocol interacts with the other protocols in the outside world. The system interface identifies the necessary and optional interfaces along with its intended use such as TLS and TCP as transport channels.
- **Configuration:**
  Almost every protocol has its own configuration or initial values. It can cover anything from buffer size, reply intervals to X.509 certificates.
- **Data Model:**
  Each switch maintains the attributes of each OpenFlow abstration in a relational data model. The attributes either describe its configuration state, or some set of current statistics or the abstraction capability.

### OpenFlow Switch [47]

An OpenFlow switch is made up of two components namely the switch agent and the data plane. The switch agent takes care of the communication between two or more controllers and also with the data plane using the requisite internal protocol. The switch agent translates the commands into low-level instructions to send to the data plane and the data plane notifications to the OpenFlow messages that are forwarded to the controller. The data plane takes care of the packet manipulation and forwarding and sometimes sends packets to the switch agent for further handling based on its configuration.

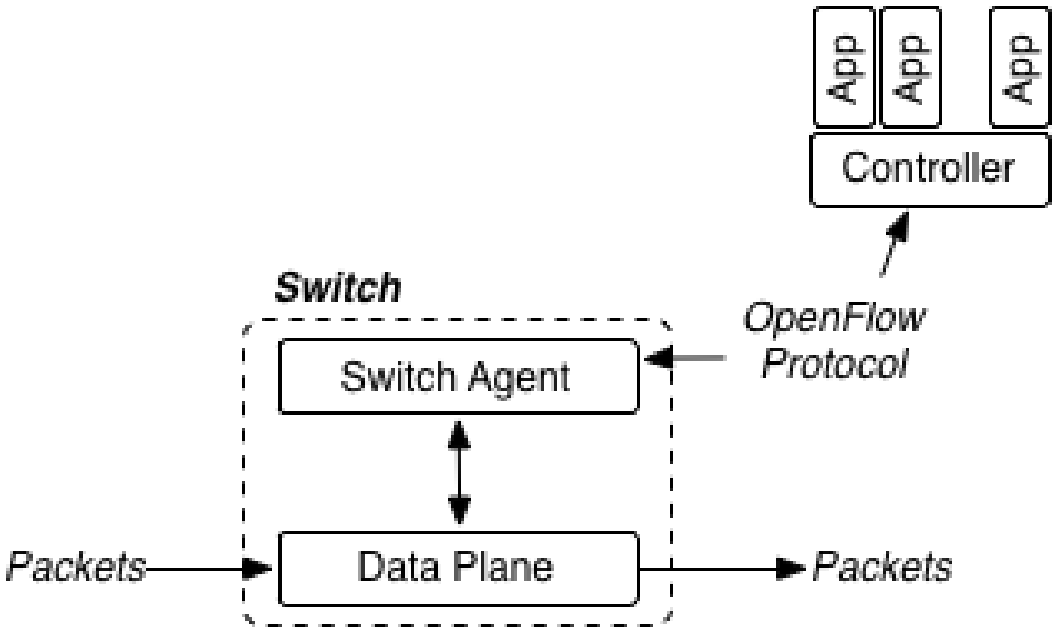



*Figure 4.5:* OpenFlow Switch Anatomy [26]

### OpenFlow Switch Agent [47]

The following figure shows how the switch agent works, its components are explained the table following the figure.

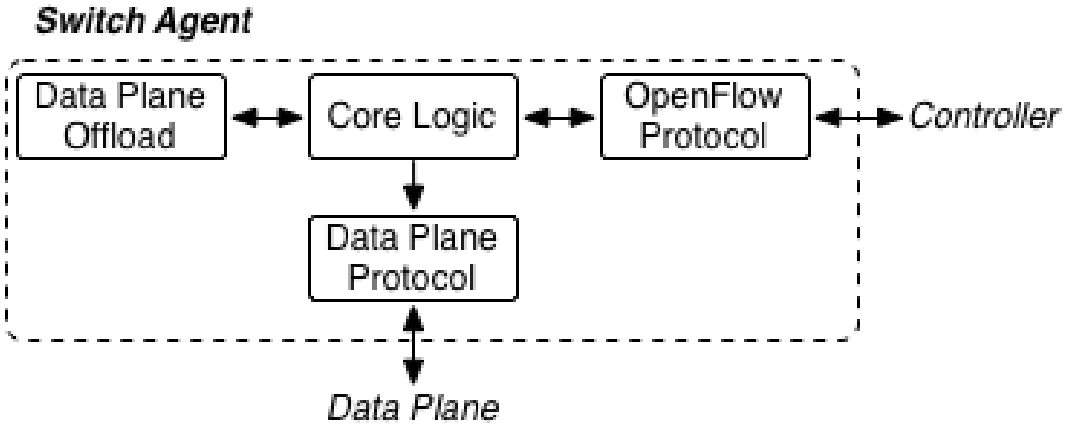



*Figure 4.6:* OpenFlow Switch Agent [27]

- **OpenFlow protocol:** This instance is on the switch side

- **Core Logic:** Switch management, command execution to the data plane and manage the data plane offload etc.
- **Data Plane Offload:** Some functionality present in the OpenFlow will be offloaded by the control plane which is not provided in the existing data plane implementation.
- **Data Plane protocol:** This protocol is internal which is mostly used for configuring the data plane state.

### Data Plane [47]

The data plane consists of the ports, flow tables, flows, classifiers and actions. Packets traverse through the system on ports. When each packet arrives, it is matched with the flows in the flow table using classifiers. The flows contain the set of actions that are applied to each packet that matches.

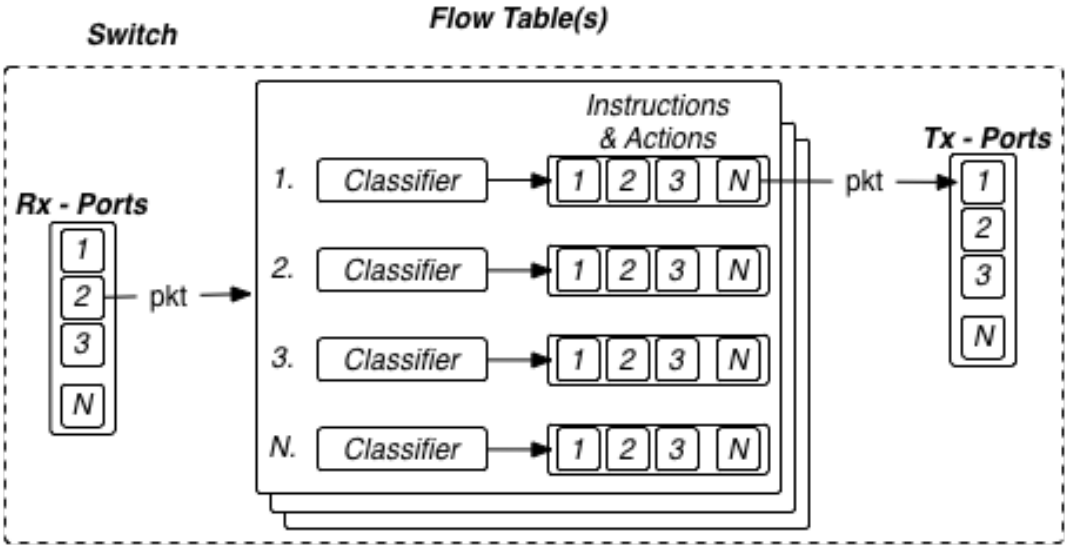



*Figure 4.7:* OpenFlow Data Plane Schematic [28]

### Data Plane - Packet Lifecycle [47]

Each packet is processed in the following sequence as explained in the table below.

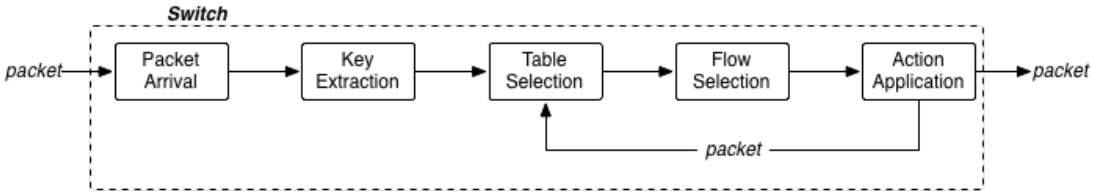



*Figure 4.8:* Packet Lifecycle [29]

- **Step 1: Packet Arrival**
  Packets arrive in either a physical or virtual port, it is necessary to make note of the arrival port for source-based processing later.
- **Step 2: Key Extraction**
  When each packet arrive on the port, a small meta data is built called the key. This key contains information about the packet such as header values, buffered packet, arrival port, arrival time etc.
- **Step 3: Table Selection**
  When a packet goes through the pipeline, the packet is matched with the first table by default and if multiple tables exist then subsequent tables will be selected through hit or miss actions.
- **Step 4: Flow Selection**
  The Key extracted in the initial step is used for selecting the flow from the table. The first flow where the classifier subsumes the key become the selected flow.
- **Step 5: Application Selection**
  Each flow contains a set of actions, which is applied to the packet when a flow is matched. The actions can modify the state of the packet or change how the packet is treated.

### 4.2.2 RADIUS [10]

RADIUS stands for Remote Authentication Dial-In User Service, which is an access server for authentication and accounting protocol. RADIUS is an AAA protocol used for network access applications.

#### What is AAA Protocol? [48]

AAA stands for Authentication, Authorization and Accounting.

- **Authentication:** It is the confirmation to the validation of the user who is requesting a service. It is normally done by providing some credentials such as username and password.
- **Authorization:** Providing specific services based on the user's authentication such as physical location restrictions, multiple login access restrictions etc.
- **Accounting:** keeping track of all the users and their network resource consumption is provided by the accounting service, it's like a log for every user who gained access to the network. Typical information includes user identity, nature of service delivered etc. This information may probably be used for billing, management purposes.

### Key Features of RADIUS: [10]

- **Client / Server Model:**
  The network server acts as the client of RADIUS, which passes the user information to designated RADIUS server. The responsibilities of the radius server include receiving connection requests, authenticating users, providing all the configuration details necessary for the client to deliver service to the user.
- **Network Security:**
  The communication between the client and the RADIUS server is encrypted so, any user password sent is encrypted. In addition, the client and the RADIUS server transactions are authenticated over a shared secret which is never sent over the network.
- **Flexible Authentication Mechanisms:**
  The RADIUS server supports several method's for a user to authenticate such as PPP, PAP or CHAP etc.
- **Extensible Protocol:**
  All transactions are of variable length Attribute-value-length 3 tuples. Supports addition of new attribute values without disturbing the existing implementation of the protocol.

### RADIUS Components [49]

The following components are part of the RADIUS infrastructure.

- Access Clients
- Access Servers (RADIUS clients)

- RADIUS servers
- RADIUS proxies
- User account databases (Active Directory, any database such as MySQL)

The components are showing in the following figure.

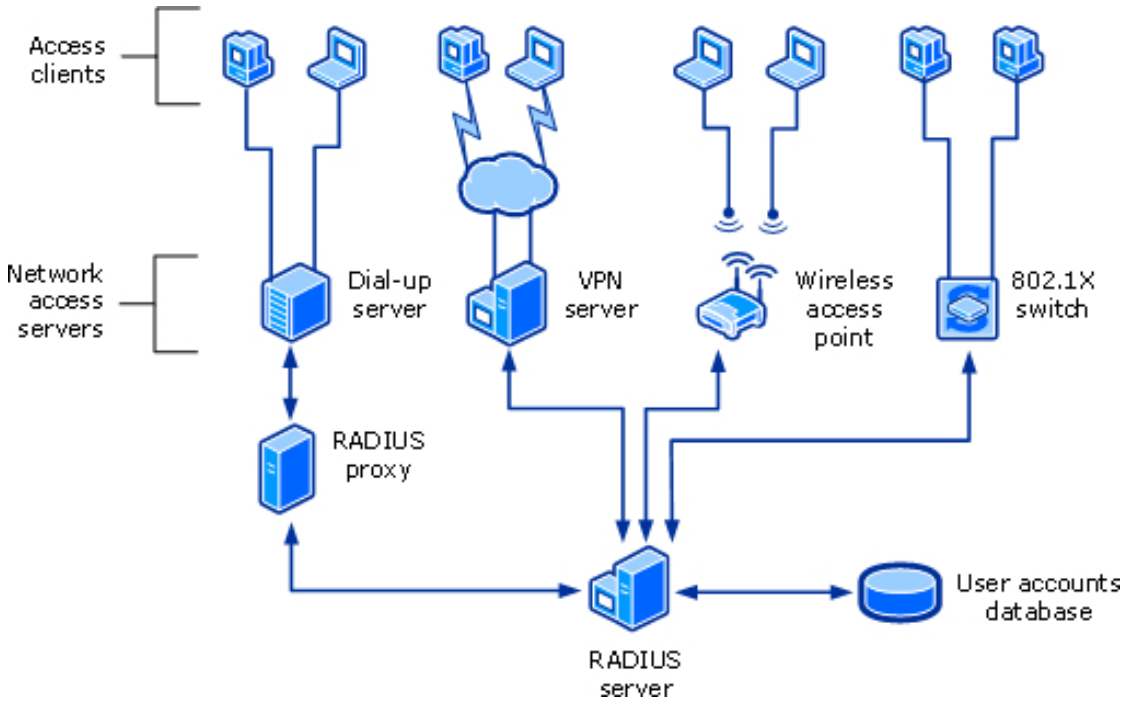


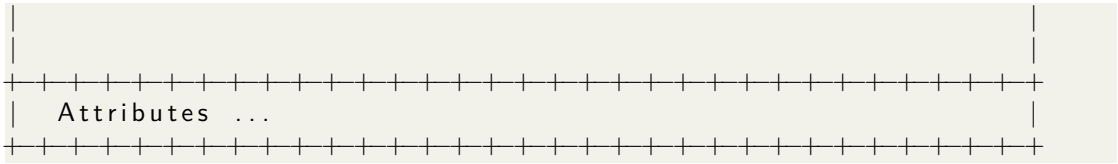

*Figure 4.9:* RADIUS Components [30]

### RADIUS Operation [49]

RADIUS messages are sent as UDP messages using the port 1812 for authentication and port 1813 for accounting messages. Some network access servers (NAS) use 1645 and 1646 for authentication and accounting respectively.

A RADIUS data format looks as shown below where the fields are transmitted from left to right.

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Code      |  Identifier   |            Length             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                                                               |
|                         Authenticator                         |
```




The code field as shown in the data frame above uses one octet which help identify the type of RADIUS packet.

- **Access-Request:** Sent by the RADIUS client requesting authentication and authorization for a connection.
- **Access-Accept:** It's the response from the RADIUS server to the client stating that the connection was authenticated and authorized.
- **Access-Reject:** It's a response from the RADIUS server to the client that the connection attempt failed in authentication.
- **Access-Challenge:** Sometimes the RADIUS server requires more information from the client and sends a challenge as a response the Access-Request message.
- **Accounting-Request:** Sent by the RADIUS client to specify accounting information for an accepted connection.
- **Accounting-Response:** The RADIUS server sends the acknowledgement for the successful receipt and processing of the Accounting-Request message.

### RADIUS Authentication Mechanism

RADIUS uses the following message codes when communicating between the RADIUS client and server as shown in the figure below.

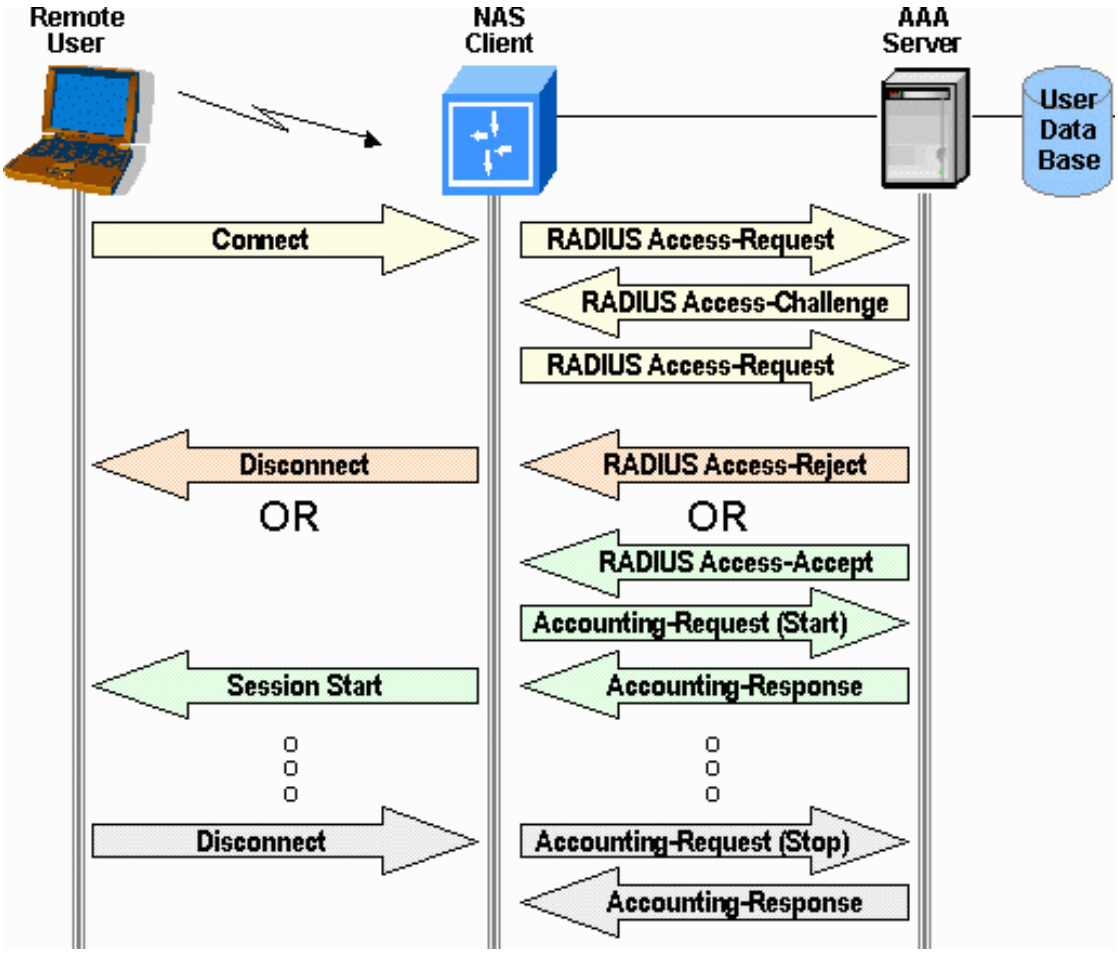



*Figure 4.10:* RADIUS Architecture [31]

- **STEP 1:**When a user makes a connection request, the NAS client sends an Access-Request message to the AAA server, in this case a RADIUS server.
- **STEP 2:**The RADIUS sever responds by sending an Access-Challenge message requesting more information from the user.
- **STEP 3:**The client responds with an Access-Request message with the requested information back to the RADIUS server. The response is typically a username and password information in the form of PPP, PAP or CHAP authentication mechanisms.
- **STEP 4:**The RADIUS server once after validating the received information sends back an Access-Accept information. If not validated, then it sends a Access-Reject message back to the client.

- **STEP 5:**Upon successfully establishing a connection, the client sends an Accounting-Request message to request to start accounting the user.
- **STEP 6:**The RADIUS server responds by sending an Accounting-Response message after successfully starting an accounting session for the connection. Thus, concludes the connection process of the user to the network.

### 4.2.3 WLAN 802.1x Security [11]

Wi-Fi or Wireless Local Area Networks (WLAN's) have become increasingly more popular in the recent years. The wireless standard IEEE 802.11 has become the most widely adopted standards for wireless broadband internet access. The security considerations however are more complicated in the wireless environment compared to the wired ones. IEEE 802.11 has defined the following two basic security mechanisms for secure access to wireless network.

- Entity authentication including shared key and open-system.
- Wired Equivalent Privacy (WEP)

Both these mechanisms are proven to be severely vulnerable. To enhance the security in wireless networks, 802.11i standard was proposed. This 802.11i standard defines encryption and authentication improvements in addition to introducing protocols for key management and establishment. 802.11i also incorporates the IEEE 802.1x standard as its authentication enhancement. The IEEE 802.1x is a port based network access control used for authenticating and authorizing devices connected by various LAN's.

The IEEE 802.1x standard is based upon the Extensible Authentication Protocol (EAP), and can use a number of authentication mechanisms which is beyond the scope of the IEEE 802.1x standard. Many authentication mechanisms such as MD5, TLS, TTLS, and PEAP can be used. The IEEE 802.1x uses EAP over LAN (EAPoL) for encapsulating EAP messages between the authenticator and the supplicant.

There are three main components in the IEEE 802.1x system namely, the supplicant, authenticator and the authentication server. In case of WLAN, the supplicant is usually the mobile device or node, the Access Point (AP) serves as the authenticator and the RADIUS server as the authentication server. The Port Access Entity (PAE) authenticator relays all the messages between the authentication server and the supplicant. 802.1x is used in this place to enforce the specific authentication mechanism.

### 802.1x Authentication Process

Authentication methods of 802.1x include PEAP, MD5 etc. Each method has its own authentication process. The following figure shows the basic EAP based authentication process in Eduroam networks.

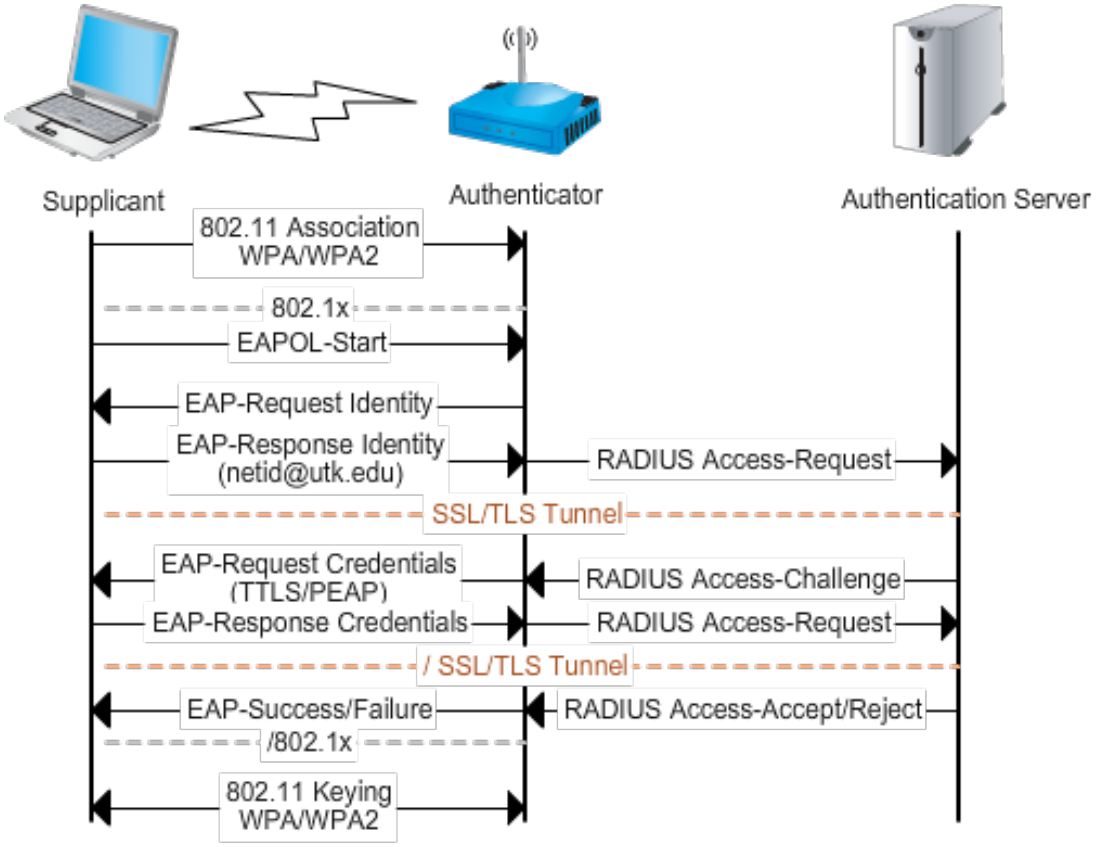



*Figure 4.11:* IEEE 802.1x WLAN authentication process [32]

- **Step 1:**
  After the association of the supplicant with the authenticator or AP via WPA or WPA2 enterprise, the 802.1x application initiates the EAPOL start message with the authenticator.
- **Step 2:**
  The authenticator responds by send a EAP-Request identity message from the supplicant.
- **Step 3:**
  Once receiving the username as a EAP response from the supplicant, the authen-

ticator then initiates a RADIUS Access-request message with the authentication server.

- **Step 4:**
  The authenticator receives the RADIUS access challenge from the authentication server and forwards that via a secure SSL/TLS tunnel to the supplicant by encapsulating the EAP-Request credentials message with TTLS/PEAP.
- **Step 5:**
  The supplicant responds with a EAP-Response Credentials message which is typically a username and password to the authenticator via the same secure tunnel, the authenticator forwards the received information as a RADIUS Access-Request message with encapsulation to the authentication server.
- **Step 6:**
  The authentication server responds with a RADIUS Access-Accept/Reject message to the authenticator. The Authenticator sends this information as a EAP Success/Failure message to the supplicant.
- **Step 7:**
  The supplicant is now fully associated with the network.

# 5 Build Environment

This chapter discusses on how the development environment is set up starting with the RYU controller from Git repository and OpenWrt to build firmware for the TP-Link WDR4300 test router.

## 5.1 RYU in Python virtual environment [12]

Python by default stores all its packages in a global location accessible from any were within the system. Though this may sound advantageous, like many other programming language, uses its own way to store, download and retrieve its packages. Python uses same site packages directory to install 3rd-party packages and different versions of python also reside in the same location.

Python couldn't differentiate between different versions and thus creates dependency issues. To resolve this problem, a virtual environment is used for setting up an isolated location for Python projects. In a virtual environment, each project can have its own dependencies. There is also no limit to the number of environments that can be created since they are just directories containing scripts.

### 5.1.1 Installation and Access [12] [13]

To install the virtual environment in Linux, the following python package manager (PIP) commands are used in the terminal.

- Installing the virtual environment :

```
1    $ pip install virtualenv
2
```

- Create a directory in virtualenv for python packages:

```
1    $ virtualenv ryu-virtualenv
2
```

- In the newly created environment, there is an activate shell script to change the *path* to the /bin directory in the virtualenv:

```
$ source bin/activate
```

- To install RYU in this virtual environment:

```
$ pip install ryu
```

- Building RYU applications requires the RYU repo from Git which can be downloaded from the command:

```
$ git clone  git://github.com/osrg/ryu.git
```

- Once the installation is complete and the repo downloaded, *ryu-manager* command is used to run the RYU Python applications.

## 5.2 OpenWrt Build System [14]

OpenWrt supports building custom firmware to any supported hardware. For this thesis, TP-Link WDR4300 is chosen because of its compatibility with OpenWrt, a larger RAM and ROM for adding more packages and functionality, and a dual band WLAN which is necessary for this thesis in order to simulate two different network.

### 5.2.1 Hardware Prerequisites

The following requisites must be met to generate an installable firmware on a supported hardware.

- At least 3-4 Gb of hard disk space for OpenWrt build system, source packages and its feeds, and to generate firmware files.
- At least 3-4 GB of RAM to build OpenWrt.

### 5.2.2 Installation steps on GNU/Linux

1. Install Git to conveniently manage and download repository such as OpenWrt and RYU, build tools for cross compilation process:

```
$ sudo apt-get install update
$ sudo apt-get install git-core build-essential libssl-dev
libncurses5-dev unzip gawk zlib1g-dev

```

2. Clone the Git repository on local machine:

```
$ git clone https://github.com/openwrt/openwrt.git

```

3. Install available all available feeds for OpenWrt:

```
$ cd openwrt
$ ./scripts/feeds update -a
$ ./scripts/feeds install -a

```

4. To check for any missing packages the following command is used for a GUI applicaton popup in terminal:

```
$ make menuconfig

```

5. The chapter on implementation discusses in detail on building custom OpenWrt firmware with custom packages such as OpenvSwitch.

# 6 Designing the Application

This chapter delves into the design objectives of the application, the architectural frame work of the RYU controller and converting the design into a Python code.

## 6.1 The Design Objectives

The finished application should be compatible with the RYU controller and be able to handle packets in real time. The following timing diagram shows how the RADIUS control flow should happen in the application for authentication.

### 6.1.1 RADIUS Procedure

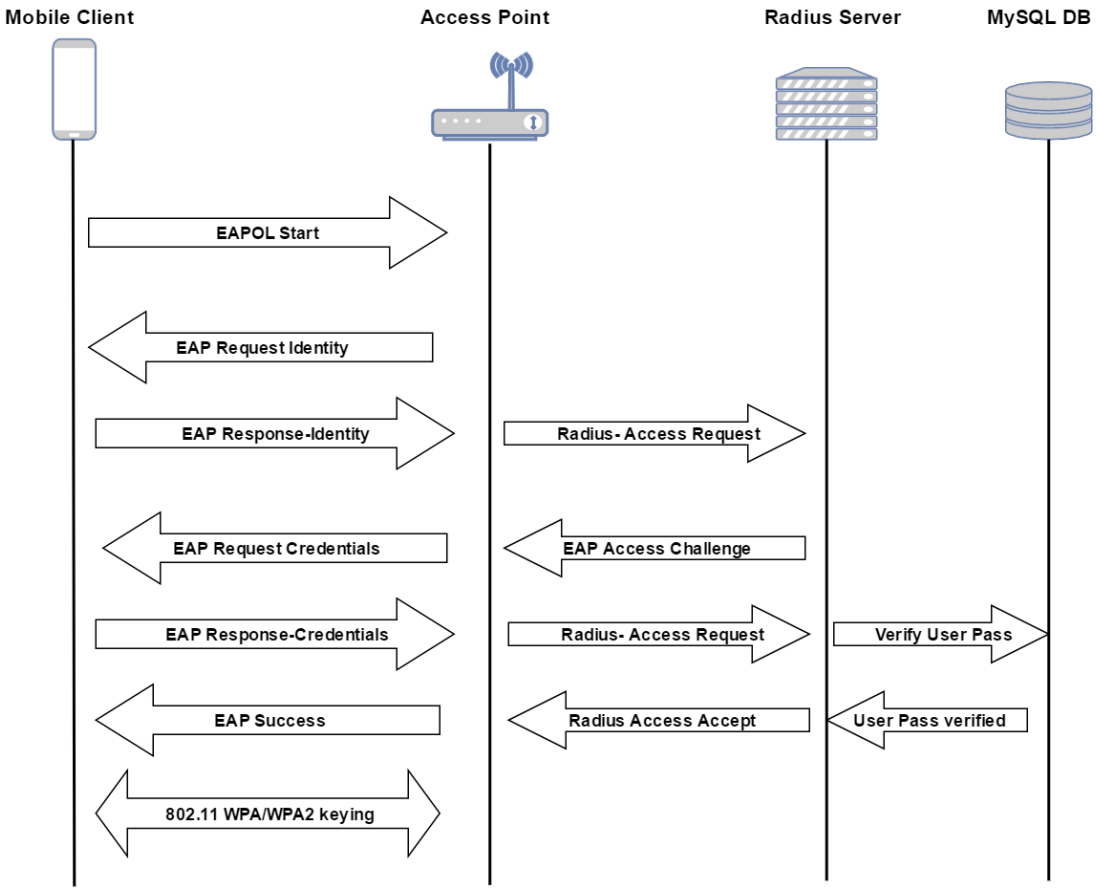



*Figure 6.1:* RADIUS Authentication Procedure - Timing Diagram

- The mobile client first initiates a radius authentication request with the Access Point.
- The packet is verified and authenticated by the RADIUS request and response messages.
- If the authentication is a success, the connection is setup with the access point with WPA2 enterprise keying.
- Once the client is authenticated, it makes a DHCP request with the access point.

The following flow chart shows the authentication procedure of the RADIUS server.It also shows the step by step actions that take place in authenticating a client.

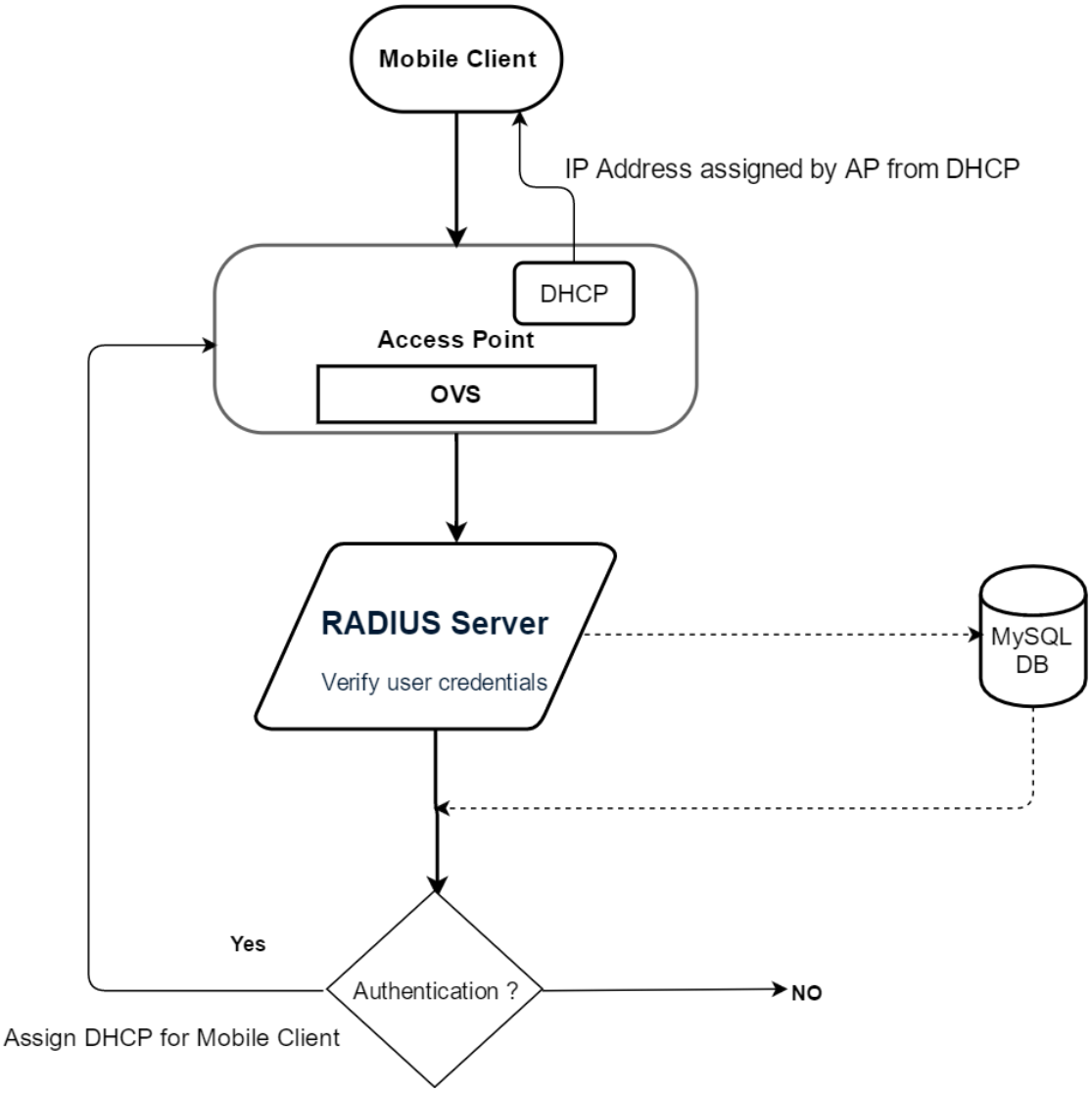



*Figure 6.2:* RADIUS Authentication Procedure - Flowchart

### 6.1.2 RYU Control Procedure

The following timing diagram shows how the RYU is supposed to listen to the MAC address of the client and parse the packet to assing the destination port id for the client.

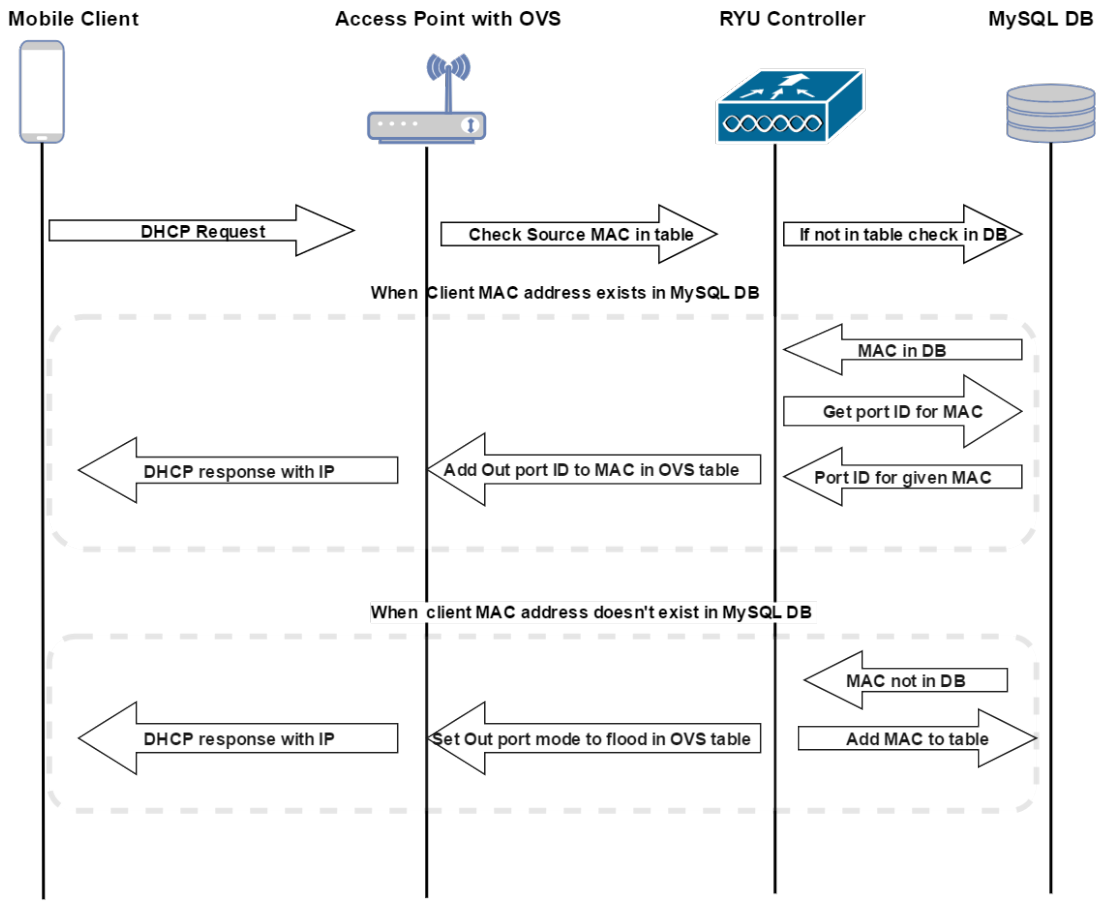



*Figure 6.3:* RYU Control Procedure - Timing Diagram

- When the client initiates a DHCP request to the access point, the RYU controller listens to the clients MAC address and checks if it exists in the OVS flow table.
- If it exists, apply the corresponding rule associated with the MAC. If it doesn't exist, check the MAC in the MySQL database.
- In the first scenario, if the MAC address exists in the MySQL DB, get the port ID associated with the MAC.
- Apply this out port id from the database to the MAC address and add the flow to the OVS flow table and complete the DHCP response.
- In the second scenario, if the MAC address does not exist in MySQL DB, add the MAC to the table and set the port id to flood mode in the OVS flow table in the access point.
- Complete the DHCP response by providing an IP to the client.

The following flow chart will provide an overview of the control flow that would take place in the RYU controller and the OVS. Starting from learning the MAC address to assigning the port id to the MAC.

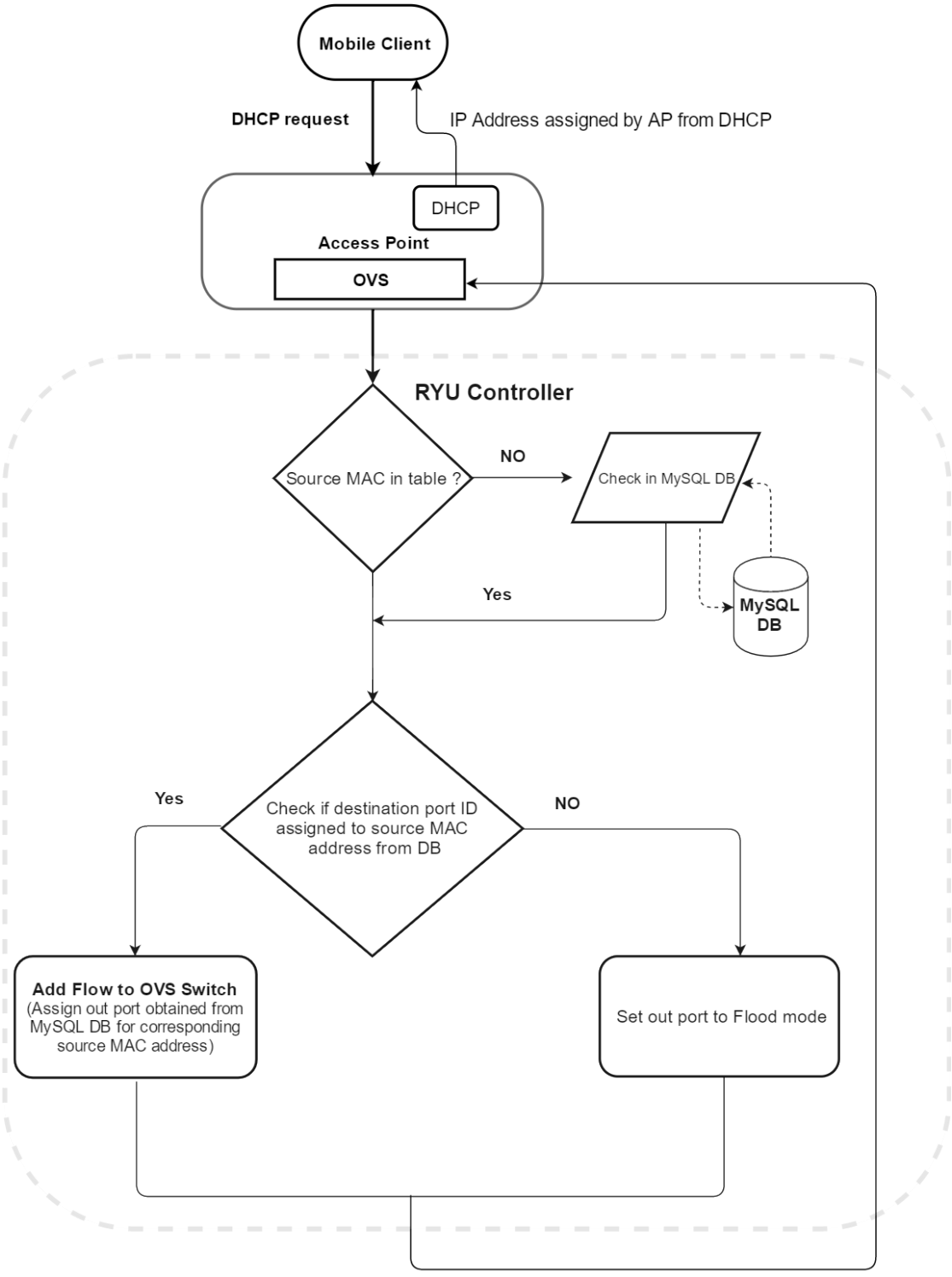



*Figure 6.4:* RYU Control Procedure - Flowchart

## 6.2 RYU Manager Process [15]

For designing the application, the RYU manager process is considered. This is explained using the following diagram.

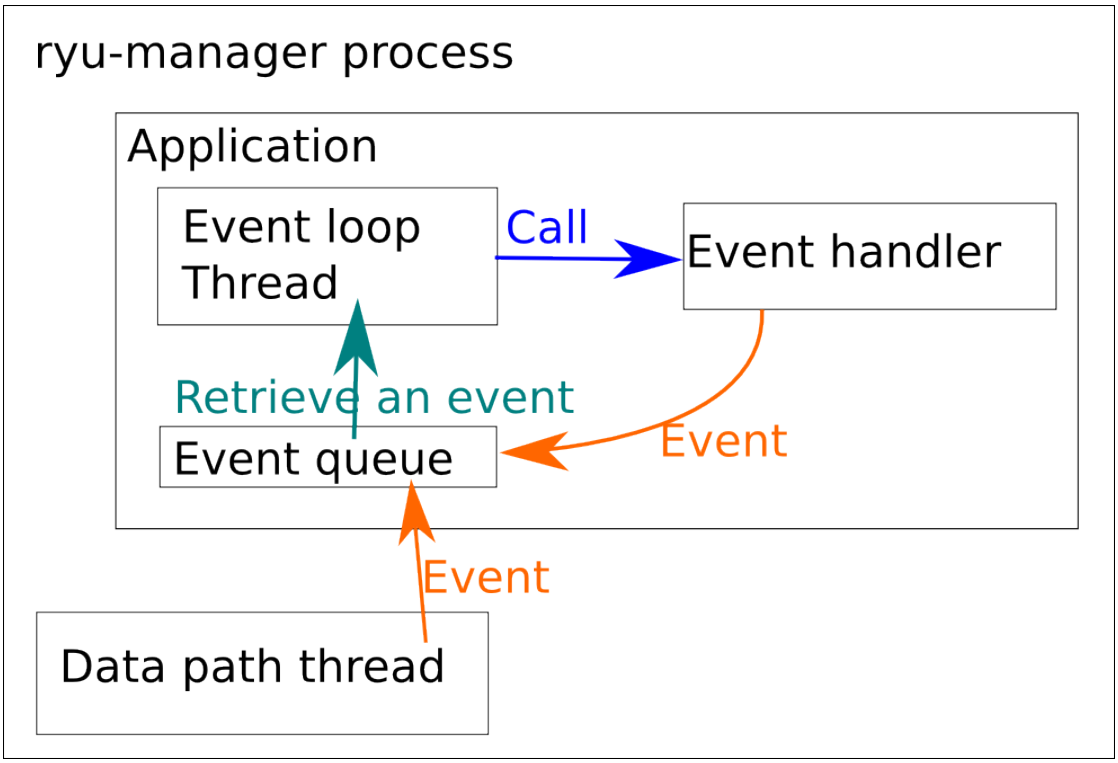



*Figure 6.5:* RYU Manager Event Process [33]

To build the application in python, the following classes are mainly used which are explained below.

- Application is nothing but the user logic that explains how the application should behave. The Application is a class that inherits the *ryu.base.app_manager.RyuApp*.
- Events are nothing but class objects that are used in communication between applications. It inherits the class *ryu.controller.event.EventBase*.
- Event queues are the single queues that each application has for receiving events.
- RYU uses eventlets to run in multi-threaded environment. These threads are non-preemptive.

- Event Loops: A thread that is created for each application runs an event loop. When there is an event in the queue, this loop will load the event and call the corresponding handler.
- Event Handlers: They are user defined handlers designed to handle when a specific type of event occurs. They reside in the event loop of an application. Event handlers can be defined by decorating the application class method with the *ryu.controller.handler.set_ev_cls* decorator.

## 6.3 Python Coding

The code is built using an existing RYU MAC learning application and is modified for user segregation.

The *set_ev_class* sets the event handler for packet-in event and passing it on to the method *_packet_in_handler* to parse the incoming packet. The packet is parsed by the method and details about the packet are extracted such as the in-port, datapath, payload etc.

```
    @set_ev_cls(ofp_event.EventOFPPacketIn, MAIN_DISPATCHER)
    def _packet_in_handler(self, ev):
        # If you hit this you might want to increase
        # the "miss_send_length" of your switch
        if ev.msg.msg_len < ev.msg.total_len:
            self.logger.debug("packet truncated: only %s of %s bytes"
    , ev.msg.msg_len, ev.msg.total_len)
        msg = ev.msg
        datapath = msg.datapath
        ofproto = datapath.ofproto
        parser = datapath.ofproto_parser
        in_port = msg.match['in_port']
        pkt = packet.Packet(msg.data)
        eth = pkt.get_protocols(ethernet.ethernet)[0]
        udp_payload = pkt.get_protocols(udp.udp)
```

Once the source and destination MAC address is retrieved from the packet, the source MAC address is then checked in the MySQL DB as shown in the figure above. The statement *cursor.execute* also retrieves the port id from the database for the corresponding MAC if it is found as shown in the code snippet below.

```
    #creating a mysql connection to database

    connection = MySQLdb.connect(host = "192.168.1.169", user = "
    freerad", passwd = "pass", db = "radius")
    cursor = connection.cursor ()
```

```
5
6       #cursor.execute ("select CallingStationId from radpostauth order
        by id desc LIMIT 1")
7       #data = cursor.fetchall ()
8       cursor.execute ("SELECT portid FROM radcheck WHERE username IN (
        SELECT user FROM radpostauth WHERE CallingStationId = %s AND id =
        (SELECT MAX(id) from radpostauth) )", src)
9       outport_for_src = cursor.fetchone ()
10      self.logger.info ("outport_for_src tuple is %s", outport_for_src)
11      #portid = outport_for_src[0]
12      self.logger.info ("Data is %s", src)
13      cursor.close()
14      connection.close ()
15      # Mysql verification end
```

In this step, the incoming port id (*in_port*) is stored in the *self.mac_to_port* array. The first *if* condition then checks if the destination MAC address is in the array *self.mac_to_port*, if it exists then the second condition checks if the out port retrieved form the database is not empty or null. Then the third condition checks if the retrieved out port id from the database is the same as the one retrieved from the packet coming from the client, then the port id in the array *self.mac_to_port* is assigned to the *out_port* variable.

```
1           self.mac_to_port[dpid][src] = in_port
2
3       self.logger.info ("DST is %s", dst)
4           if dst in self.mac_to_port[dpid]:
5           test = self.mac_to_port[dpid][dst]
6           self.logger.info ("self.mac_to_port[dpid][dst] value %s",
        test)
7           self.logger.info ("Out_Port before condition %s",
        outport_for_src)
8           if outport_for_src != None and all(outport_for_src):
9               if int(outport_for_src[0]) == self.mac_to_port[dpid][dst
        ]:
10                  out_port = self.mac_to_port[dpid][dst]
11                  self.logger.info ("Out_Port is the same as in
        database table %s", out_port)
12              else:
13                  self.logger.info ("Out_Port is not allowed, dropping
        packet")
14                  return
15          else:
16              #except (TypeError,UnboundLocalError):
17              out_port = self.mac_to_port[dpid][dst]
18              self.logger.info ("Out_Port not defined in database,
        using learned port")
```

The flowing code snipped explains the scenario when there is no out-port id is mentioned in the database for the corresponding MAC address.

```
    else:
    #except (TypeError,UnboundLocalError):

        out_port = ofproto.OFPP_FLOOD
    #out_port = 4
        self.logger.info ("Out_Port is Flooded %s", out_port)

self.logger.info ("Above actions Out_Port %s", out_port)
    actions = [parser.OFPActionOutput(out_port)]
self.logger.info ("Actions is %s", actions)
```

The variable *out_port* is assigned a FLOOD mode and the parser *parser.OFPActionOutput* is called to parse the *out_port* mode set in the previous conditions.

A new flow is then assigned to the OVS switch with the obtained *out_port* conditions. The code snipped below shows the usual procedure to add the flow by using *add_flow* method providing values such as datapath, match conditions, and actions like setting the out port and buffer id if it exists. The packet is updated with the new information and sent out using the *send_msg* method that sends it to the OVS switch and a new flow entry is created in the OVS flow table.

```
        # install a flow to avoid packet_in next time
        if out_port != ofproto.OFPP_FLOOD:
        self.logger.info ("Out_Port not flooded adding flow ")
            match = parser.OFPMatch(in_port=in_port, eth_dst=dst)
            #match = parser.OFPMatch(in_port=in_port, eth_dst='a0:f3:
    c1:77:d8:36')
            # verify if we have a valid buffer_id, if yes avoid to
    send both
            # flow_mod & packet_out
            if msg.buffer_id != ofproto.OFP_NO_BUFFER:
                self.add_flow(datapath, 1, match, actions, msg.
    buffer_id)
                return
            else:
                self.add_flow(datapath, 1, match, actions)
        data = None
        if msg.buffer_id == ofproto.OFP_NO_BUFFER:
            data = msg.data
        out = parser.OFPPacketOut(datapath=datapath, buffer_id=msg.
    buffer_id, in_port=in_port, actions=actions, data=data)
        datapath.send_msg(out)
```

# 7 Implementation

This chapter will discuss about the procedures involved such as flashing the router with OpenWrt, building the OpenWrt firmware with OVS modules, configuring OVS, setting up RADIUS server in a virtual machine and creating a MySQL database with custom table for access to out port id etc.

## 7.1 Building and Flashing Custom OpenWrt Firmware

To build the custom firmware for the OpenWrt, we use the Make Menuconfig command in terminal from the directory where the OpenWrt repository has been cloned. The following steps will explain which modules to choose from the Menu and to compile the custom build.

1. Navigate to the directory *<buildroot_dir>* in terminal and then enter the command *make menuconfig*.
2. In the menu that appears, select the target system by using the arrows and enter key to navigate the menu.
3. In the target system, choose **Atheros AR7xxx/AR9xxx**.
4. Now, select target profile and choose **TP-Link WDR4300** from the list.
5. In the main configuration menu, select the **Luci** menu and enable luci web interface.
6. Now, going back to the main menu, choose the Network option in the list.
7. Within the Network menu, select the sub menu **Open Vswitch** as shown in figure7.1 and enable all options using space key <*>.
8. In the Network menu, first de-select the option **Wpad mini** and then select **Hostapd** as shown in figure7.2 with full features. This provides the necessary enterprise 802.1x authentication features.

9. In the main configuration menu, navigate to **Utilities** option and select editors and choose either **vi** or **nano** as the text editor of choice.
10. Exit the menu and select save to save the configuration.
11. Back in the terminal, enter the command *make world*. This will compile the changes made in the configuration and build the firmware for the selected hardware profile, in this case TP-Link WDR4300.
12. The freshly built images are available in the root directory of OpenWrt *<build-root_dir>/bin/ar71xxx*.
13. Connect the router to the computer via ethernet and login to the OEM interface using the ip 192.168.0.1 with user/pass as admin/admin.
14. Select the option firmware upgrade in the device settings.
15. In the OpenWrt bin directory, select the image *openwrt-ar71xx-generic-tl-wdr4300-v1-squashfs-factory.bin* and rename it to *wdr4300v1_en_3_14_3_up_boot(150518).bin*.
16. Now, in the OEM web interface, select the renamed file and choose upgrade. It will update the router and reboot.
17. OpenWrt has been successfully installed in the router.

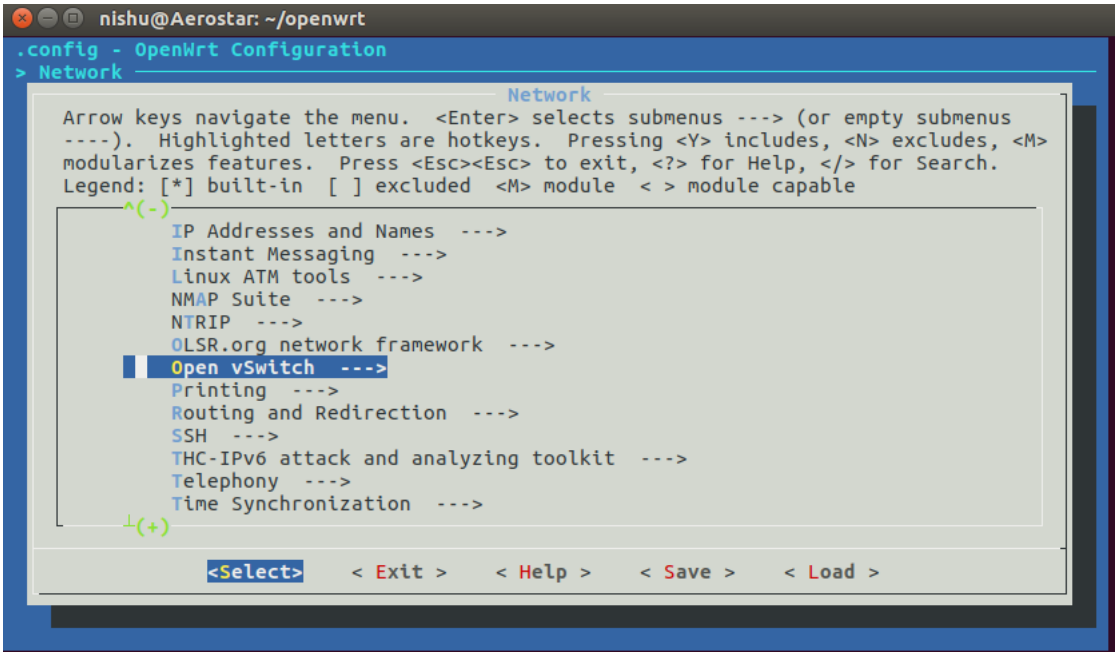



*Figure 7.1:* Open vSwitch option in OpenWrt build configuration menu

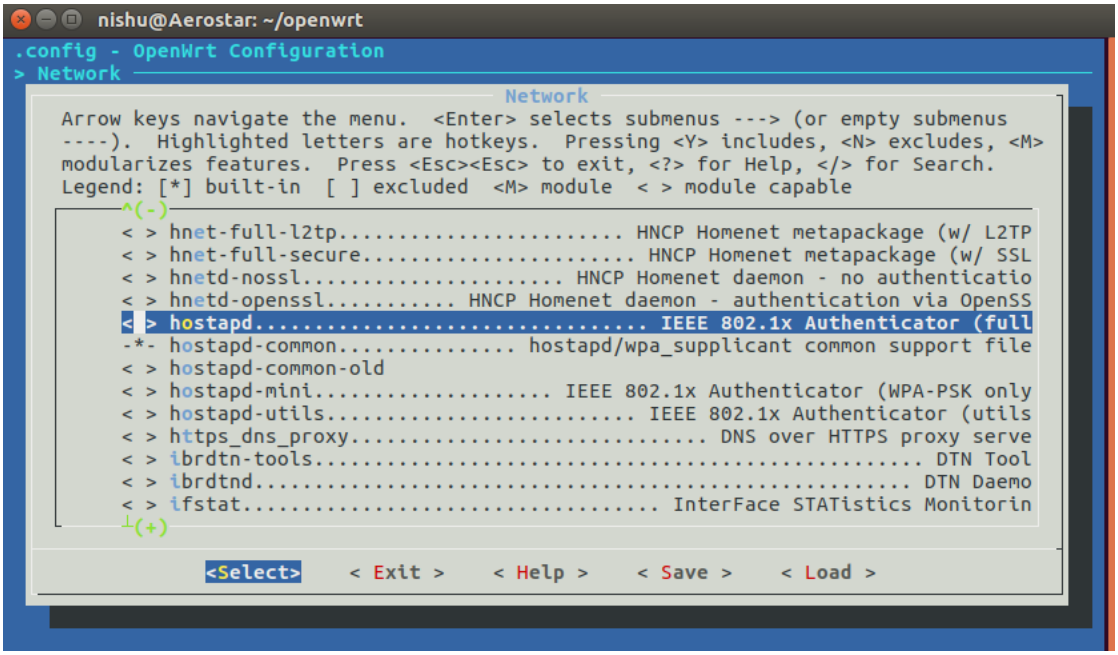



*Figure 7.2:* Hostapd option in OpenWrt build configuration menu

## 7.2 Router Configuration

The router has been freshly updated with the OpenWrt firmware. To configure the router, it is first connected via shell which will be discussed in steps below.

1. Connect to the router using the command ssh 192.168.1.1 and accept the key signatures. It will now show the configuration window with *root@openwrt*.
2. To create two wifi networks in the router, first open the networks configuration in the editor using vi or nano with the following command *nano /ect/config/wireless*.
3. The configurations are changed to look like the one shown below.

```
config wifi-device 'radio0'
option type 'mac80211'
option channel '11'
option hwmode '11g'
option path 'platform/ar934x_wmac'
option htmode 'HT20'
option txpower '20'
option country 'DE'
option disabled '0'

```

```
11      config wifi-iface
12      option device 'radio0'
13      option mode 'ap'
14      option ssid 'OpenWrt'
15      option server '192.168.1.169'
16      option key 'testing123'
17      option encryption 'wpa2'
18      option network 'wifi'
19
20      config wifi-device 'radio1'
21      option type 'mac80211'
22      option channel '36'
23      option hwmode '11a'
24      option path 'pci0000:00/0000:00:00.0'
25      option htmode 'HT20'
26      option txpower '17'
27      option country 'DE'
28
29      config wifi-iface
30      option device 'radio1'
31      option mode 'ap'
32      option server '192.168.1.169'
33      option key 'testing123'
34      option ssid 'OpenWrt 5G'
35      option encryption 'wpa2'
36      option network 'wifi'
37
```

4. Save the file using ctrl + x and enter. Now open the network configuration file from the command *nano /etc/config/network* and change it to look as shown below.

```
1       config interface 'loopback'
2       option ifname 'lo'
3       option proto 'static'
4       option ipaddr '127.0.0.1'
5       option netmask '255.0.0.0'
6
7       config globals 'globals'
8       option ula_prefix 'fd04:beb4:615d::/48'
9
10      config interface 'wan'
11      option ifname 'eth0.1'
12      option proto 'dhcp'
13
14      config interface 'wan6'
15      option ifname 'eth0.1'
16      option proto 'dhcpv6'
17
```

```
18      config interface 'lan'
19      option type 'bridge'
20      option ifname 'eth0.2'
21      option proto 'static'
22      option ipaddr '192.168.1.1'
23      option netmask '255.255.255.0'
24      option ip6assign '60'
25
26      config interface 'wifi'
27      option type 'bridge'
28      option ifname 'eth0.3'
29      option proto 'static'
30      option ipaddr '192.168.3.1'
31      option netmask '255.255.255.0'
32      option ip6assign '60'
33
34      config interface 'lan3'
35      option ifname 'eth0.3'
36
37      config interface 'lan4'
38      option ifname 'eth0.4'
39
40      config interface 'lan5'
41      option ifname 'eth0.5'
42
43      config switch
44      option name 'switch0'
45      option reset '1'
46      option enable_vlan '1'
47
48      config switch_vlan
49      option device 'switch0'
50      option vlan '1'
51      option ports '1 0t'
52      option vid '1'
53
54      config switch_vlan
55      option device 'switch0'
56      option vlan '2'
57      option ports '2 0t'
58      option ipaddr '192.168.3.1'
59      option netmask '255.255.255.0'
60      option ip6assign '60'
61
62      config interface 'lan3'
63      option ifname 'eth0.3'
64
65      config interface 'lan4'
66      option ifname 'eth0.4'
```

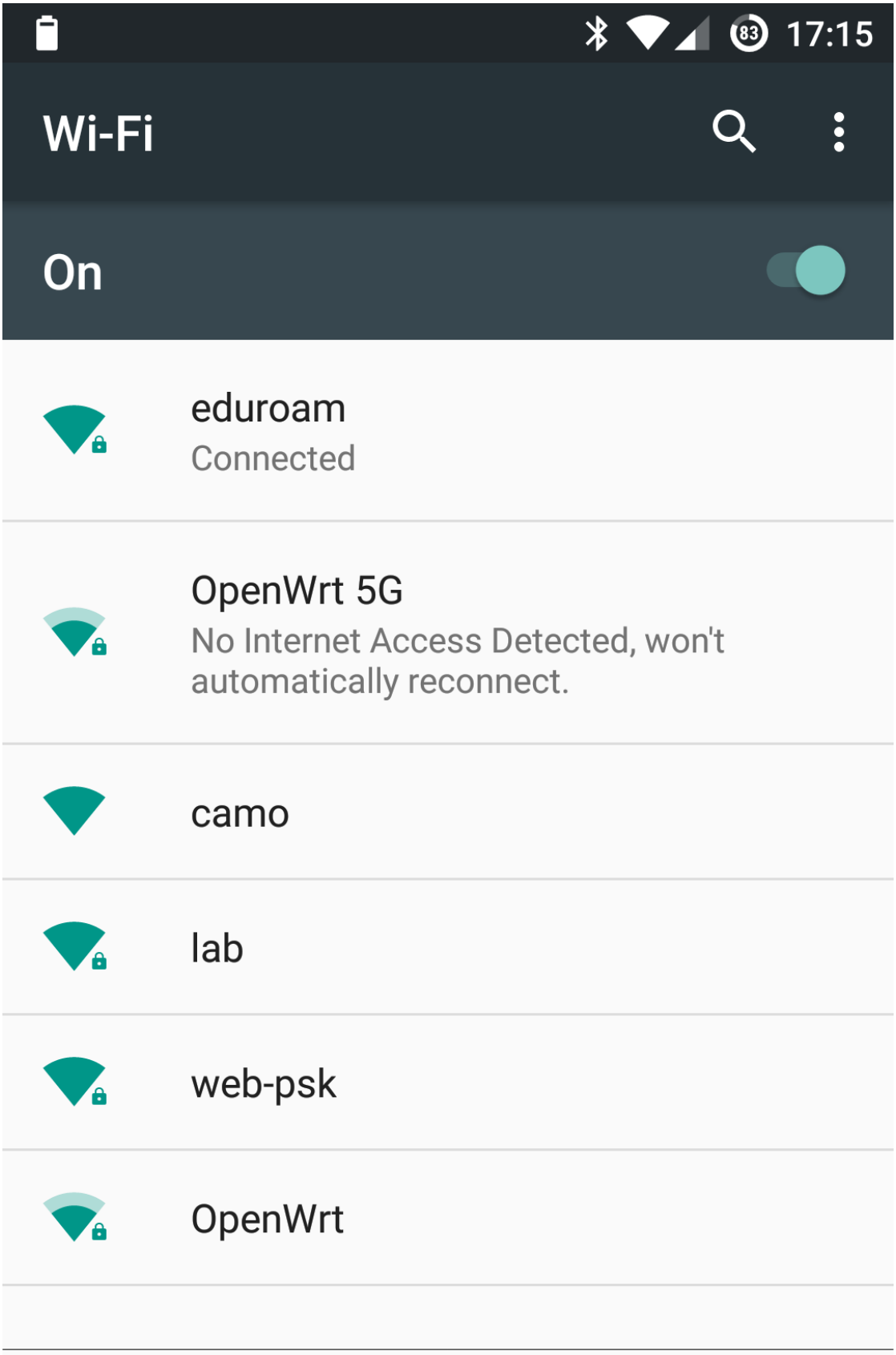
```
67
68      config interface 'lan5'
69      option ifname 'eth0.5'
70
71      config switch
72      option name 'switch0'
73      option reset '1'
74      option enable_vlan '1'
75
76      config switch_vlan
77      option device 'switch0'
78      option vlan '1'
79      option ports '1 0t'
80      option vid '1'
81
82      config switch_vlan
83      option device 'switch0'
84      option vlan '2'
85      option ports '2 0t'
86      option vid '2'
87
88      config switch_vlan
89      option device 'switch0'
90      option vlan '3'
91      option ports '3 0t'
92      option vid '3'
93
94      config switch_vlan
95      option device 'switch0'
96      option vlan '4'
97      option vid '4'
98      option ports '0t 4'
99
100     config switch_vlan
101     option device 'switch0'
102     option vlan '5'
103     option vid '5'
104     option ports '0t 5'
105
```

5. The DHCP for the second network is configured in the file */etc/config/dhcp* and the following entry is added to the file.

```
1       config dhcp 'lan4'
2           option interface 'lan4'
3           option ignore '1'
4
```

6. Save the configuration and reboot the router.

7. The web interface of OpenWrt can be opened using the ip **192.168.1.1**. Enable the wireless interfaces in the Networks menu as they are disabled by default. Now, there should be two network ssid openwrt and openwrt 5G available in the client device.


17:15
Wi-Fi
On
eduroam
Connected
OpenWrt 5G
No Internet Access Detected, won't automatically reconnect.
camo
lab
web-psk
OpenWrt

## 7.3 Configuring Open vSwitch

The Open vSwitch is configured to connect with the RYU controller and assign ports to be managed by the controller. The configuration is made by using the following commands in the OpenWrt shell terminal.

1. Login to OpenWrt router using shell via the command *sudo ssh 192.168.1.1*.
2. The installation of OVS is checked using the following command *ovs-vsctl show*, if it says there is no such command, then there is no OVS installed. Instead if it shows an empty entry then OVS is installed but not configured.
3. The OVS bridge is created using the command *ovs-vsctl add-br br0*
4. To set the controller for OVS, the command *ovs-vsctl set-controller br0 tcp:192.168.1.207:6633* is used, where 6633 is the standard OpenFlow port.
5. The failsafe mode in a OVS switch tell the switch how to function in case of a connection failure with the controller. There are two modes, **secure** and **stand_alone**. The **secure** mode will not allow any packets to pass through whereas the **stand_alone** mode will function as a normal switch. For this project, the failsafe mode is set to secure to isolate the network using the following command *ovs-vsctl set-fail-mode br0 secure*.
6. The ports that needs to be managed are added to the bridge using the commands

```
1        ovs-vsctl add-port br0 eth0.3
2        ovs-vsctl add-port br0 eth0.4
3        ovs-vsctl add-port br0 eth0.5
4
```

7. The configuration is verified by the command ovs-vsctl show, this will show the configuration that was made in the OVS.

## 7.4 MySQL Setup

The following steps explain the procedure to install and configure MySQL server and populate its database to work with Freeradius server on the ubuntu virtual machine.

1. MySQL is downloaded and installed on the Linux PC using the following command in terminal *sudo apt-get install mysql-server*
2. Once the server is installed, a database called radius is created using the following command.

```
mysql -uroot -p
CREATE DATABASE radius;
    GRANT ALL ON radius.* TO radius@localhost IDENTIFIED BY
"radpass";
exit

```

3. The schema for **Freeradius** is added to the database using the following command: *mysql -u root -p radius < /etc/freeradius/sql/mysql/schema.sql*
4. To manage the database a **PHPMyadmin** tool is installed and configured to connect with the MySQL database. It provides a web interface to manipulate the complete database.
5. **Radcheck** table contains the user credentials, it was modified to add a port id column where a port id is manually assigned to each user.

## 7.5 Installing Ubuntu Virtual Machine and Freeradius Server [16]

The initial method to configure the Freeradius and MySQL server within the OpenWrt router failed due to memory restrictions. Therefore, the Freeradius is installed in an Ubuntu virtual machine configured in a Virtual Box environment. The steps involved is discussed as follows.

1. A new virtual machine is created using the latest *Ubuntu 16.10 iso* image in Virtual Box with 2GB RAM and the network is bridged with eth1 which is connected to the internet, initially to download and install Freeradius.
2. Freeradius is downloaded and installed using the following command *sudo apt-get install freeradius*.
3. The radius service is started using the command *freeradius -x* if it throws an error, then error shown is debugged and fixed.
4. Edit the **clients.config** file in */etc/freeradius/* directory and add the following line in the file

```
client 192.168.1.1{
        secret = testing123
}

```

5. Now, the Freeradius server is configured to use MySQL database for authentication and accounting. To configure, the file **radiusd.conf** in the directory */etc/freeradius/* and the following steps are taken.

   a) Include **sql.conf** is uncommented.

   b) In the file **sql.conf** which is in the same directory, the database name is added in the line *database = "mysql"*

   c) Under connection info add

```
        server = "localhost"
        login = "radius"
        password = "radpass"
        radius_db = "radius"

```

6. To store the clients MAC address in the DB, the calling-station-id information is added in the schema file **dialup.conf** which resides in */etc/freeradius/sql/mysql/* directory. The information is added in the **radpostauth** table under Authentication Logging Queries section in the file.

```
    postauth_query = "REPLACE INTO ${postauth_table} \
    (user, pass, reply, date, CallingStationId) \
    VALUES ( \
    '%{User-Name}', \
    '%{%{User-Password}:-%{Chap-Password}}', \
    '%{reply:Packet-Type}', '%S', '%{Calling-Station-Id}')"

```

7. Finally, the Freeradius server is tested using the following to check if authentication works properly by using the following command *radtest test radpass 127.0.0.1 0 testing123* where testing123 is the radius key configured in the access point. Access-accept message is received when authentication is successful else, the error can be debugged using the command *sudo freeradius -X* in the terminal

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# Appendix

# Versicherung

Hiermit versichere ich, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe; die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sind als solche kentlich gemacht.
Bei der Auswahl und Auswertung des Materials sowie bei der Herstellung des Manuskripts habe ich Unterstützungsleistungen von folgenden Personen erhalten:

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Die Arbeit wurde bisher weder im Inland noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde vorgelegt.

Chemnitz, April 8, 2017

Nishant Ravi