Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Networked Systems
ETH Zürich — seit 2015

Communication Networks

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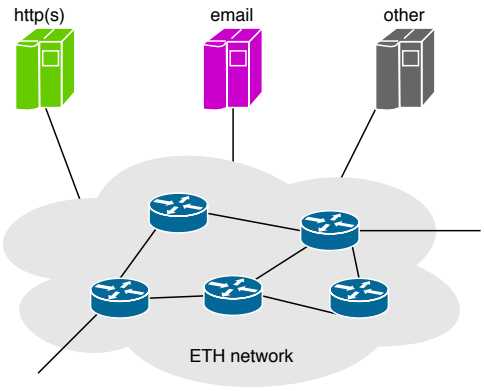
Solution: Exercise 11 – Programmable Networks

11.1 Network Virtualization with OpenFlow



(Fictional) ETH network with three OpenFlow controllers.

OpenFlow simplifies *network virtualization*, i.e. managing different parts of your network or traffic separately.

Assume that ETH has installed OpenFlow Switches and wants to benefit from network virtualization. Let there be three teams: One responsible for *web-traffic, i.e. HTTP(s)*, one for *emails*, and one for everything else. Each team operates their own OpenFlow Controller.

As you have learned, if an OpenFlow switch does not know what to do with a packet, it forwards the packet to the controller. However, it is also possible to install an explicit matching rule to send packets to a controller, which we want to use for network virtualization.

Use the following pseudo-code command to install such a matching rule (and remember that all OpenFlow matching rules are ordered by the *priority* you assign to them):

```
send_to_controller(match, priority, controller)
```

where controller can simply be *web*, *email*, or *other* and you can use the following syntax for matches:

```
{src=42.0.0.*, dst=*}
```

You may use any fields you need, and use `*` as a wildcard.

- Use pseudo-code to install matching rules for forwarding packets the correct controller. In particular, consider which fields you have to match on, and which priority you set. Note: You can (and have to) use `send_to_controller` multiple times.

- How does the priority you choose influence other OpenFlow rules installed by the controllers?

Solution: Both HTTP(s) traffic and emails can be identified by their TCP destination ports. In particular, the ETH mailserver uses ports 993 and 995 for incoming- and port 587 for outgoing mails.[a]

```
send_to_controller({dport=443}, 5, web)
send_to_controller({dport=80}, 4, web)
send_to_controller({dport=993}, 3, email)
send_to_controller({dport=995}, 2, email)
send_to_controller({dport=587}, 1, email)
send_to_controller(*, 0, other)
```

It is important that the matching rule for the *other* controller has a lower priority than the rules for controllers for more specific traffic, otherwise it would receive all packets. Aside from the matching rule for the *other* controller, The rules to not necessarily require distinct priorities – since they cannot match at the same time, they could all use the same priority.

Furthermore, the controllers must be aware of the priority of the `send_to_controller` matching rules and use higher priority for their own rules to work, as the `send_to_controller` would take precedence otherwise.

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[a] `https://www.isg.inf.ethz.ch/Main/HelpMailClientSetup`

11.2 Flexible OpenFlow Switches

An OpenFlow switch can emulate different devices.

With the capabilities to match on-, and modify (some) header fields, and either forwarding or dropping the packet, OpenFlow switches can emulate various hardware. In this exercise, we compare *NAT* and *firewalls*.

First, consider *matching* (for simplicity, only look at TCP and UDP traffic):

- Which header fields does the switch need to match as a NAT, or as a firewall? Are there differences?

Solution: Both applications need to identify *flows*, which can be identified by source- and destination addresse, protocol (udp or tcp), source- and destination port. This is sufficient for both applications.

Next, assume the switch has matched on a packet and sent it to the controller. On the controller, for NAT and firewall respectively:

- Which decisions need to be made?
- Which data needs to be stored?
- Is any external information required or useful?
- Which rules need to be installed on the switch?

Solution: For a NAT, the controller needs to store a lookup table, to avoid assigning the same port twice. For each incoming packet, the controller needs to decide on a port on the OpenFlow Switch and install rules to translate address and port (in both directions).

For a firewall, the controller must take external information into account, such as blacklists, in order to decide which traffic is benign and which malicious. Then, rules need to be installed to either forward or drop the traffic.

Finally, with an OpenFlow switch, we do not need to decide between NAT and firewall, as our switch can be both at the same time. However, this is not without challenges.

- What difficulties arise when combining multiple goals, such as address translation and filtering?

Solution: If both NAT and firewall apply to the same traffic, they overwrite each other. Rules must be carefully combined by hand, such that both actions for NAT *and* firewall are applied, and not just one of them.

11.3 Programmable Dataplanes

P4 offers a programmable processing pipeline.

In OpenFlow, only the controller is programmable. While an OpenFlow switch provides an API such that different controllers can interact with it, the actual matching and actions are fixed hardware functions.

The *Protocol Independent Switch Architecute (PISA)* along with the domain specified programming language *P4* are a natural next step in programmability, as they allow to program the switch itself, i.e. the packet parsing as well as modifications to the packet.

What led to this development? Why are fixed switch functions not enough?

Solution: OpenFlow has a hard time with new protocols, as it does not understand how to parse the header fields. Without this information, matching or modifying anything becomes impossible. each additional protocol requires hardware updates, which is inflexible, in particular to try out new protocols. Furthermore, this lead to a fractured landscape of OpenFlow switches, where each switch supports a different subset of all protocols.

PISA and P4 allow to program how to interpret packets, which make the network hardware re-usable for different protocols. Thus, each switch can be programmed on demand exactly for the protocols it needs to understand. Additonally, operators can also program their 'own' protocols, such as experimental protocols for research.