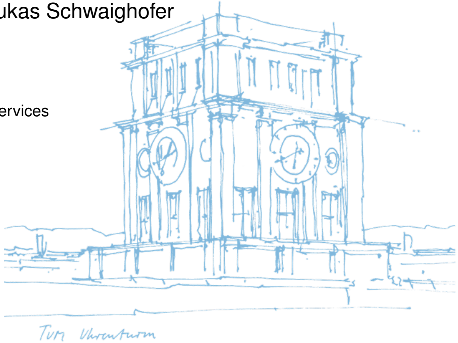
Generation of Secure Network Configuration

Cornelius Diekmann, **Johannes Naab**, Lukas Schwaighofer

December 5, 2016

Chair of Network Architectures and Services
Department of Informatics
Technical University of Munich



Problem Statement

Generation of Secure Network Configurations

Mapping to Security Goals

Security Policy

Security Policy – Manually Edited

Security Policy to Stateful Policy

Stateful Policy to Firewall

Stateful Policy to SDN Rules

From Firewall to Security Policy?

Application within the Sendate Project

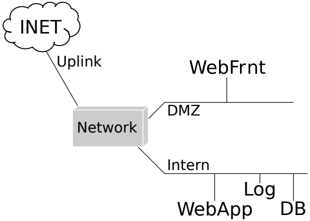
Problem Statement

- Most network components can be configured for their specific purpose.
- Essential to implement a secure network.

Problem Statement

- Most network components can be configured for their specific purpose.
- Essential to implement a secure network.

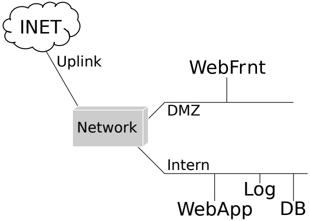
- Goal:



Problem Statement

- Most network components can be configured for their specific purpose.
- Essential to implement a secure network.

- Goal:

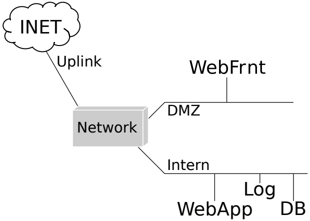


+ Security Requirements

Problem Statement

- Most network components can be configured for their specific purpose.
- Essential to implement a secure network.

- Goal:



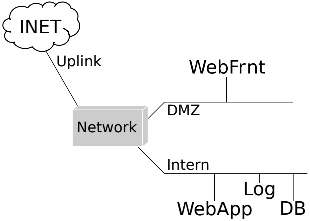
+ Security Requirements ⇒

```
FORWARD DROP
-A FORWARD -i tun0 -s $WebFrnt_ipv4 -o tun0 -d $Log_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebFrnt_ipv4 -o tun0 -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $DB_ipv4 -o tun0 -d $Log_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $DB_ipv4 -o tun0 -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o tun0 -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o tun0 -d $DB_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o tun0 -d $Log_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o eth0 -d $INET_ipv4 -j ACCEPT
-A FORWARD -i eth0 -s $INET_ipv4 -o tun0 -d $WebFrnt_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i eth0 -s $INET_ipv4 -o tun0 -d $WebApp_ipv4
-j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i tun0 -s $WebFrnt_ipv4 -o eth0 -d $INET_ipv4
-j ACCEPT
```

Problem Statement

- Most network components can be configured for their specific purpose.
- Essential to implement a secure network.

- Goal:

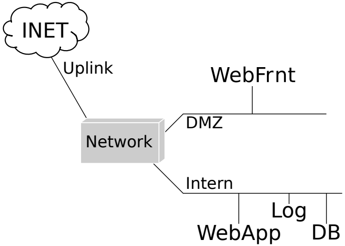


+ Security Requirements ⇒

```
FORWARD DROP
-A FORWARD -i tun0 -s $WebFrnt_ipv4 -o tun0 -d $Log_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebFrnt_ipv4 -o tun0 -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $DB_ipv4 -o tun0 -d $Log_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $DB_ipv4 -o tun0 -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o tun0 -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o tun0 -d $DB_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o tun0 -d $Log_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o eth0 -d $INET_ipv4 -j ACCEPT
-A FORWARD -i eth0 -s $INET_ipv4 -o tun0 -d $WebFrnt_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i eth0 -s $INET_ipv4 -o tun0 -d $WebApp_ipv4
-j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i tun0 -s $WebFrnt_ipv4 -o eth0 -d $INET_ipv4
-j ACCEPT
```

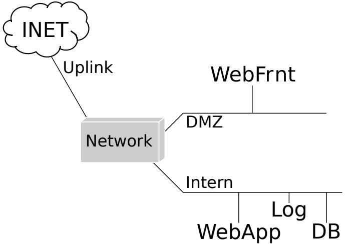
- Manual configuration is error prone
- ⇒ generate configuration automatically to avoid mistakes

Mapping to Security Goals



1. DB, Log and WebApp are internal hosts. WebFrnt must be accessible from outside.
2. Logging data must not leave the log server.
3. DB, Log contain confidential information. WebApp is trusted and allowed to declassify.
4. Only WebApp may access the DB.

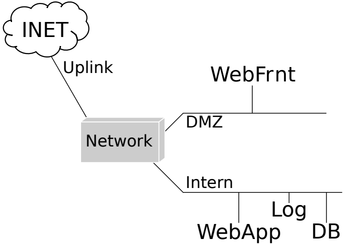
Mapping to Security Goals



1. DB, Log and WebApp are internal hosts. WebFrnt must be accessible from outside.
2. Logging data must not leave the log server.
3. DB, Log contain confidential information. WebApp is trusted and allowed to declassify.
4. Only WebApp may access the DB.

Subnets $\{\text{DB} \mapsto \textit{internal},\ \text{Log} \mapsto \textit{internal},\ \text{WebApp} \mapsto \textit{internal},\ \text{WebFrnt} \mapsto \textit{DMZ}\}$

Mapping to Security Goals

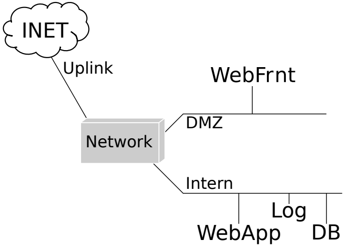


1. DB, Log and WebApp are internal hosts. WebFrnt must be accessible from outside.
2. Logging data must not leave the log server.
3. DB, Log contain confidential information. WebApp is trusted and allowed to declassify.
4. Only WebApp may access the DB.

Subnets $\{$DB $\mapsto$ *internal*, Log $\mapsto$ *internal*, WebApp $\mapsto$ *internal*, WebFrnt $\mapsto$ *DMZ*$\}$

Sink $\{$Log $\mapsto$ *Sink*$\}$

Mapping to Security Goals



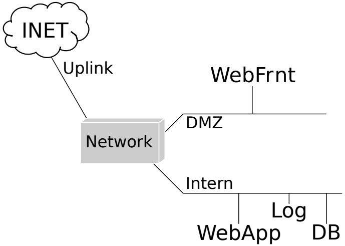
1. DB, Log and WebApp are internal hosts. WebFrnt must be accessible from outside.
2. Logging data must not leave the log server.
3. DB, Log contain confidential information. WebApp is trusted and allowed to declassify.
4. Only WebApp may access the DB.

Subnets $\{$DB $\mapsto$ *internal*, Log $\mapsto$ *internal*, WebApp $\mapsto$ *internal*, WebFrnt $\mapsto$ *DMZ*$\}$

Sink $\{$Log $\mapsto$ *Sink*$\}$

Bell LaPadula $\{$DB $\mapsto$ *confidential*, Log $\mapsto$ *confidential*, WebApp $\mapsto$ *declassify* (*trusted*)$\}$

Mapping to Security Goals



1. DB, Log and WebApp are internal hosts. WebFrnt must be accessible from outside.
2. Logging data must not leave the log server.
3. DB, Log contain confidential information. WebApp is trusted and allowed to declassify.
4. Only WebApp may access the DB.

Subnets {DB ↦ *internal*, Log ↦ *internal*, WebApp ↦ *internal*, WebFrnt ↦ *DMZ*}

Sink {Log ↦ *Sink*}

Bell LaPadula {DB ↦ *confidential*, Log ↦ *confidential*, WebApp ↦ *declassify* (*trusted*)}

Comm. Partners {DB ↦ *Access allowed by* : WebApp}

Security Policy

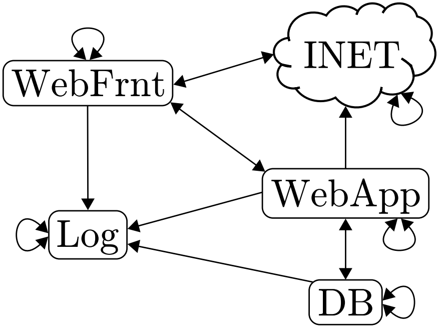
Computing Security Policy

1. Start with allow-all policy:

   $\{\text{Log}, \text{DB}, \text{WebApp}, \text{WebFrnt}, \text{INET}\} \times \{\text{Log}, \text{DB}, \text{WebApp}, \text{WebFrnt}, \text{INET}\}$

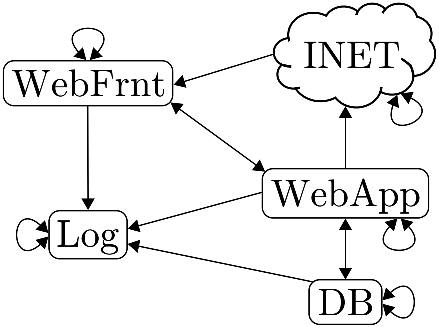
2. Remove all rules which contradict the (completed) Security Goals

- Sound
- Complete: Maximum permissive policy
  (only for certain invariant templates)



Security Policy – Manually Edited

- Security Policy can be edited manually
- Policy is checked against Security Goals
- Changes must not introduce violations of Security Goals

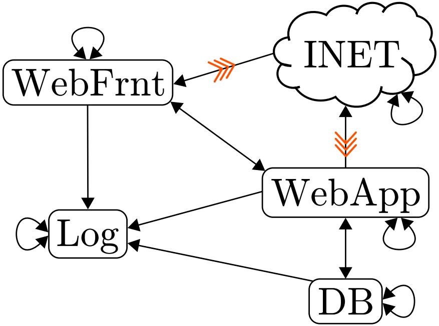


Security Policy to Stateful Policy

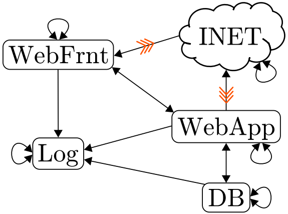
- In order for a TCP connection to work, a bidirectional connection is necessary.
- I.e. client (INET) sends request, response is sent from WebFrnt to client.
- A stateful firewall allows the reverse flow, if such a connection was established by the client.

Consistency:

1. No information flow violation must occur
2. No access control side effects must be introduced



Stateful Policy to Firewall



Term rewriting
⇒

```
FORWARD DROP
-A FORWARD -i tun0 -s $WebFrnt_ipv4 -o tun0 -d $Log_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebFrnt_ipv4 -o tun0 -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $DB_ipv4 -o tun0 -d $Log_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $DB_ipv4 -o tun0 -d $WebApp_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o tun0 -d $WebFrnt_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o tun0 -d $DB_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o tun0 -d $Log_ipv4 -j ACCEPT
-A FORWARD -i tun0 -s $WebApp_ipv4 -o eth0 -d $INET_ipv4 -j ACCEPT
-A FORWARD -i eth0 -s $INET_ipv4 -o tun0 -d $WebFrnt_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i eth0 -s $INET_ipv4 -o tun0 -d $WebApp_ipv4 -j ACCEPT
-I FORWARD -m state --state ESTABLISHED -i tun0 -s $WebFrnt_ipv4 -o eth0 -d $INET_ipv4 -j ACCEPT
```

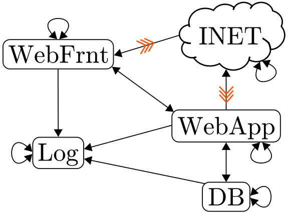
Assumptions

Structure Enforced network connectivity structure = policy.
Links: confidential and integrity protected.

Authenticity Policy's entities must match their network representation (e.g. IP/MAC addresses).

State The stateful connection handling must match the stateful policy's semantics.

Stateful Policy to SDN Rules



Term rewriting
⇒

```
# ARP Request
in_port=$port_src dl_src=$mac_src dl_dst=ff:ff:ff:ff:ff:ff                     ↩
    arp arp_sha=$mac_src arp_spa=$ip4_src arp_tpa=$ip4_dst                      ↩
    priority=40000 action=mod_dl_dst:$mac_dst,output:$port_dst

# ARP Reply
dl_src=$mac_dst dl_dst=$mac_src arp arp_sha=$mac_dst arp_spa=$ip4_dst          ↩
    arp_tpa=$ip4_src priority=40000 action=output:$port_src

# IPv4 one-way
in_port=$port_src dl_src=$mac_src ip nw_src=$ip4_src nw_dst=$ip4_dst           ↩
    priority=40000 action=mod_dl_dst:$mac_dst,output:$port_dst

# if src (resp. dst) is INET, replace $ip4_src (resp. $ip4_dst) with *
# and decrease the priority
```

```
ovs-vsctl set-fail-mode $switch secure && ovs-ofctl add-flows
```

- Only as single network security device is considered
- Stateful firewall handling is not provided by SDN switch
- Could be introduced by `iptables` firewall or Open vSwitch >= 2.5.0

From Firewall to Security Policy?

- Generating a configuration requires an existing security policy
- A lot of firewalls are managed manually and encode implicit knowledge about the security goals

From Firewall to Security Policy?

- Generating a configuration requires an existing security policy
- A lot of firewalls are managed manually and encode implicit knowledge about the security goals

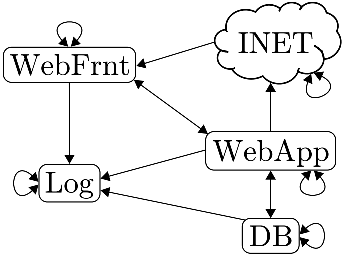
```
-A FORWARD -j DOCKER-ISOLATION
-A FORWARD -d 193.99.144.80/32 -m recent --set --name rateheise --mask 255.255.255.255 --rsource
-A FORWARD -d 193.99.144.80/32 -m recent --update --seconds 60 --hitcount 3 --name rateheise --mask
255.255.255.255 --rsource -j DROP
-A FORWARD -m state --state RELATED,ESTABLISHED -j ACCEPT
-A FORWARD -p tcp -m tcp --dport 22 -j ACCEPT
-A FORWARD -s 10.0.0.2/32 -d 10.0.0.1/32 -p tcp -m tcp --dport 80 -j ACCEPT
-A FORWARD -j MYNET
-A FORWARD -o br-b74b417b331f -j DOCKER
-A FORWARD -o br-b74b417b331f -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
-A FORWARD -i br-b74b417b331f ! -o br-b74b417b331f -j ACCEPT
-A FORWARD -o docker0 -j DOCKER
-A FORWARD -o docker0 -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
-A FORWARD -i docker0 ! -o docker0 -j ACCEPT
-A FORWARD -i docker0 -o docker0 -j ACCEPT
-A FORWARD -i br-b74b417b331f -o br-b74b417b331f -j DROP
-A DOCKER-ISOLATION -i docker0 -o br-b74b417b331f -j DROP
-A DOCKER-ISOLATION -i br-b74b417b331f -o docker0 -j DROP
-A DOCKER-ISOLATION -j RETURN
-A MYNET -d 10.0.0.4/32 ! -i br-b74b417b331f -o br-b74b417b331f -m state --state ESTABLISHED -j ACCEPT
-A MYNET -s 10.0.0.1/32 -i br-b74b417b331f ! -o br-b74b417b331f -m state --state ESTABLISHED -j ACCEPT
-A MYNET -s 10.0.0.1/32 -d 10.0.0.1/32 -i br-b74b417b331f -o br-b74b417b331f -j ACCEPT
-A MYNET -s 10.0.0.1/32 -d 10.0.0.2/32 -i br-b74b417b331f -o br-b74b417b331f -j ACCEPT
<snip>
-A MYNET -s 10.0.0.4/32 -d 10.0.0.4/32 -i br-b74b417b331f -o br-b74b417b331f -j ACCEPT
-A MYNET -s 10.0.0.4/32 ! -d 10.0.0.0/8 -i br-b74b417b331f ! -o br-b74b417b331f -j ACCEPT
-A MYNET ! -s 10.0.0.0/8 -d 10.0.0.1/32 ! -i br-b74b417b331f -o br-b74b417b331f -j ACCEPT
-A MYNET -i br-b74b417b331f -j DROP
-A MYNET -o br-b74b417b331f -j DROP
-A MYNET -s 10.0.0.0/8 -j DROP
-A MYNET -d 10.0.0.0/8 -j DROP
```

From Firewall to Security Policy?

- Generating a configuration requires an existing security policy
- A lot of firewalls are managed manually and encode implicit knowledge about the security goals

```
-A FORWARD -j DOCKER-ISOLATION
-A FORWARD -d 193.99.144.80/32 -m recent --set --name rateheise --mask 255.255.255.255 --rsource
-A  FORWARD  -d  193.99.144.80/32  -m  recent  --update  --seconds  60  --hitcount  3  --name  rateheise  --mask
255.255.255.255 --rsource -j DROP
-A FORWARD -m state --state RELATED,ESTABLISHED -j ACCEPT
-A FORWARD -p tcp -m tcp --dport 22 -j ACCEPT
-A FORWARD -s 10.0.0.2/32 -d 10.0.0.1/32 -p tcp -m tcp --dport 80 -j ACCEPT
-A FORWARD -j MYNET
-A FORWARD -o br-b74b417b331f -j DOCKER
-A FORWARD -o br-b74b417b331f -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
-A FORWARD -i br-b74b417b331f ! -o br-b74b417b331f -j ACCEPT
-A FORWARD -o docker0 -j DOCKER
-A FORWARD -o docker0 -m conntrack --ctstate RELATED,ESTABLISHED -j ACCEPT
-A FORWARD -i docker0 ! -o docker0 -j ACCEPT
-A FORWARD -i docker0 -o docker0 -j ACCEPT
-A FORWARD -i br-b74b417b331f -o br-b74b417b331f -j DROP
-A DOCKER-ISOLATION -i docker0 -o br-b74b417b331f -j DROP
-A DOCKER-ISOLATION -i br-b74b417b331f -o docker0 -j DROP
-A DOCKER-ISOLATION -j RETURN
-A MYNET -d 10.0.0.4/32 ! -i br-b74b417b331f -o br-b74b417b331f -m state --state ESTABLISHED -j ACCEPT
-A MYNET -s 10.0.0.1/32 -i br-b74b417b331f ! -o br-b74b417b331f -m state --state ESTABLISHED -j ACCEPT
-A MYNET -s 10.0.0.1/32 -d 10.0.0.1/32 -i br-b74b417b331f -o br-b74b417b331f -j ACCEPT
-A MYNET -s 10.0.0.1/32 -d 10.0.0.2/32 -i br-b74b417b331f -o br-b74b417b331f -j ACCEPT
<snip>
-A MYNET -s 10.0.0.4/32 -d 10.0.0.4/32 -i br-b74b417b331f -o br-b74b417b331f -j ACCEPT
-A MYNET -s 10.0.0.4/32 ! -d 10.0.0.0/8 -i br-b74b417b331f ! -o br-b74b417b331f -j ACCEPT
-A MYNET ! -s 10.0.0.0/8 -d 10.0.0.1/32 ! -i br-b74b417b331f -o br-b74b417b331f -j ACCEPT
-A MYNET -i br-b74b417b331f -j DROP
-A MYNET -o br-b74b417b331f -j DROP
-A MYNET -s 10.0.0.0/8 -j DROP
-A MYNET -d 10.0.0.0/8 -j DROP
```

$\overset{?}{\Rightarrow}$



From Firewall to Security Policy?

- Validate that security policy matches with our expectations
- Detect hidden bugs hidden within the firewall configuration
- “Visualize” existing firewalls
  - What did the previous administrator configure?
  - Are there security violations embedded within the firewall?

From Firewall to Security Policy?

- Validate that security policy matches with our expectations
- Detect hidden bugs hidden within the firewall configuration
- “Visualize” existing firewalls
  - What did the previous administrator configure?
  - Are there security violations embedded within the firewall?

Automated checking of the firewall configuration before the deployment can help to avoid problems:

From Firewall to Security Policy?

- Validate that security policy matches with our expectations
- Detect hidden bugs hidden within the firewall configuration
- “Visualize” existing firewalls
  - What did the previous administrator configure?
  - Are there security violations embedded within the firewall?

Automated checking of the firewall configuration before the deployment can help to avoid problems:

- Are the security devices and switches only reachable from the controller or management network?
  - I.e. no unauthorized access is possible

From Firewall to Security Policy?

- Validate that security policy matches with our expectations
- Detect hidden bugs hidden within the firewall configuration
- “Visualize” existing firewalls
    - What did the previous administrator configure?
    - Are there security violations embedded within the firewall?

Automated checking of the firewall configuration before the deployment can help to avoid problems:

- Are the security devices and switches only reachable from the controller or management network?
    - I.e. no unauthorized access is possible
- Are the devices accessible by the controller or management network?
    - Even if there is an error, are the devices still reachable to change the configuration
    - ⇒ Allow in-band management of devices
    - ⇒ Protect from (obvious) configuration mistake

Application within the Sendate Project

- Goals to be checked in Data Center Networks
  - Separation of tenants/slices
  - Even if the slices provide their own configuration
  - Accessibility (both positive and negative) of management interfaces

Application within the Sendate Project

- Goals to be checked in Data Center Networks
  - Separation of tenants/slices
  - Even if the slices provide their own configuration
  - Accessibility (both positive and negative) of management interfaces
- Validation of configuration must be integrated within the management
  - Each and every validation must be checked, for maximum benefit before deploying to the devices
- Configuration must be centralized
  - No manual configuration/change to the firewall
- Integration with configuration and change management tools
  - Ansible, Puppet, Salt
- Performance Measurements
  - Impact of rule sets on performance of network devices

Bibliography

[1] C. Diekmann, L. Hupel, and G. Carle.
Semantics-Preserving Simplification of Real-World Firewall Rule Sets.
In *20th International Symposium on Formal Methods*, pages 195–212. Springer, jun 2015.

[2] C. Diekmann, A. Korsten, and G. Carle.
Demonstrating topoS: Theorem-Prover-Based Synthesis of Secure Network Configurations.
In *2nd International Workshop on Management of SDN and NFV Systems, manSDN/NFV*, Barcelona, Spain, nov 2015.