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<yasuhito@gmail.com>

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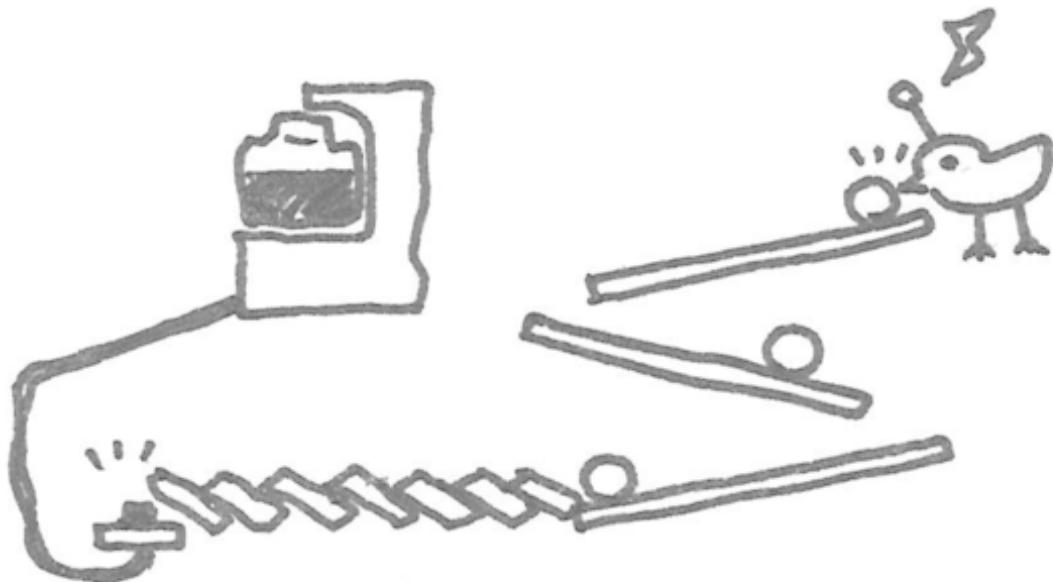
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Perl#(#####)

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#####16 #####17 #
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1.2.

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#####?#####
#####!#####
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1 ##### # xpizza ##### #####://#####.###.###/###/#####/#####/#####/###/#####/#####/#####/#####/#####

2 #####://#### # # # # # # # /#####/

3 ### 2324: #####://### ##### ####/####/####2324 ####

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##### #####
##### ####?#####
##### #####
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##### 1 #####
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1.3. ##### ##### #####

(#####) ##### 3 #####
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1.3.1. ##### 1:

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#####

2 #### (#1#1)

1. #####
 2. #####

#####

サポートセンター

友太郎君



青井さん



マニュアル



1.1.

#####

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(# 1#1)##### 3

1.1. # 1#1:

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|-------|-------|-------|
| ##### | ### | ##### |
| ##### | ##### | 8 # |
| ##### | ##### | 6 # |
| ##### | ##### | 4 # |
| ##### | ### | 2 # |

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8 ### 9 ##### (# 1#2)

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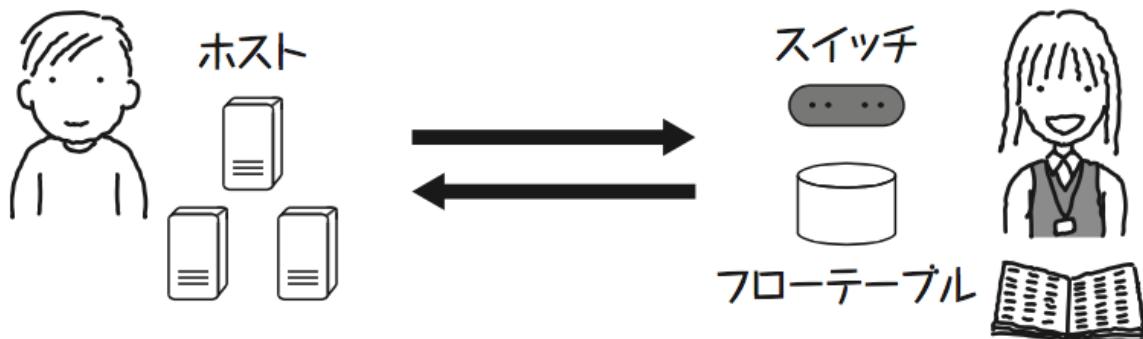
1.2. # 1#2:

| | | |
|-------|-------|-------|
| ##### | ### | ##### |
| ##### | ##### | 9 # |
| ##### | ##### | 6 # |
| ##### | ##### | 4 # |
| ##### | ### | 2 # |

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1.3.2. #####

(# 1#2)#####
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1.2.

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1.3.3. #####

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4 ##### 2#####

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1#3 #####
3 ##### ⁴

1.3. # 1#3:

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|------------------------------------|------------------------|---------|
| ##### | ##### | ### |
| ## ## #### = 192.168.1.0 | ## 8 #### | 80 #### |
| #### ## = 10 | ## 10 #### | 64 #### |
| ## ## ## ## = 00:50:56:#0:00:08 | ## ## = 2 ##### 8 #### | 24 #### |
| ## ## #### = 203.0.113.0/16 | ##### | 10 #### |

####

```
#####
##### = 192.168.1.0#####
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##### 8 #####
#####
```

####

```
#####
##### 9 #####
#####
##### 80 #####
```

1.3.4. ##### 2:

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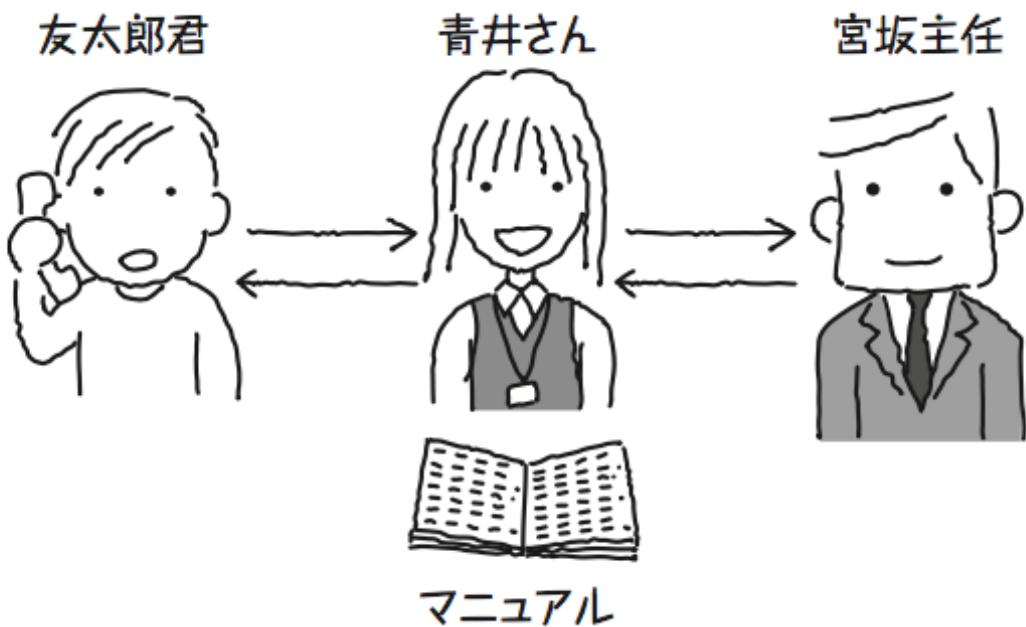
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#####

サポートセンター



1.3.

(#1#3)

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(# 1#4)

1.4. # 1#4:

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| ##### | ### | ##### |
| ##### | ##### | 9 # |
| ##### | ##### | 6 # |
| ##### | ##### | 4 # |
| ##### | ### | 2 # |

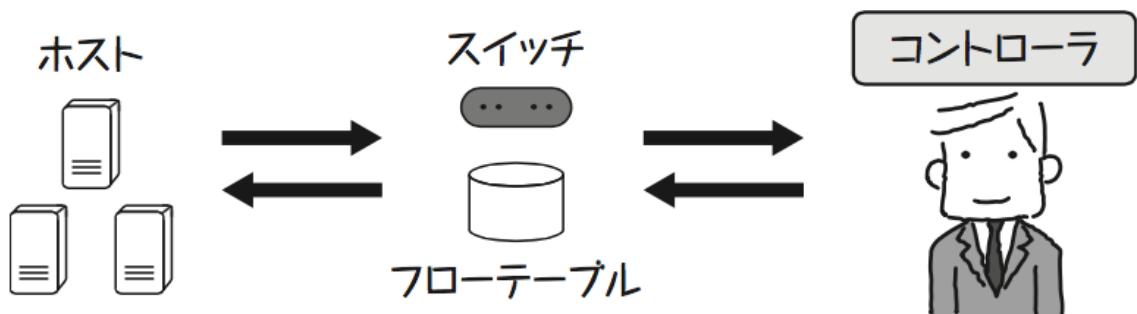
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| ##### | ##### | 1 # |

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(# 1#4) ##### ##### ##### ##### #####

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1.4.

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1.4.

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1.4.1.

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1.4.2.

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(#####)

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#####4 #####15 #####
#####16 #####

1.4.3.

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#####9 #####
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1.4.4.

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6 ##### ##### ##### 7 #####
8 ##### ##### 1.3 ##### ##### 11 ##### ##### 12 #
(##)## 13 ##### (##)## 14 ##### (#####)##### #####



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100 ##### ##### ##### 10 ##### ##### 100 ##### ##### #####

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1.5. ##### ##### #####

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1.6.

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- ##### ##### ##### #####
- ##### ##### ##### #####
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2.

1.3 #####
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2.1.

2

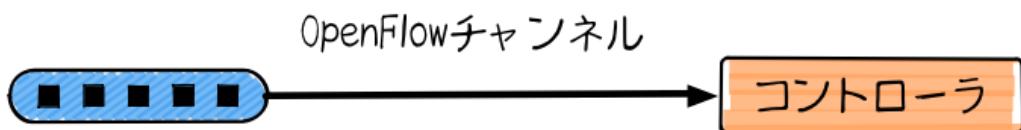
1. #####
 2. #####

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##### 2 ##### 1.3 ##### 1.0 ##### 1.3 ##### 1.0 #####
#####
```

2.2.

```
#####
##### 1 #####
#####
```

2.2.1.

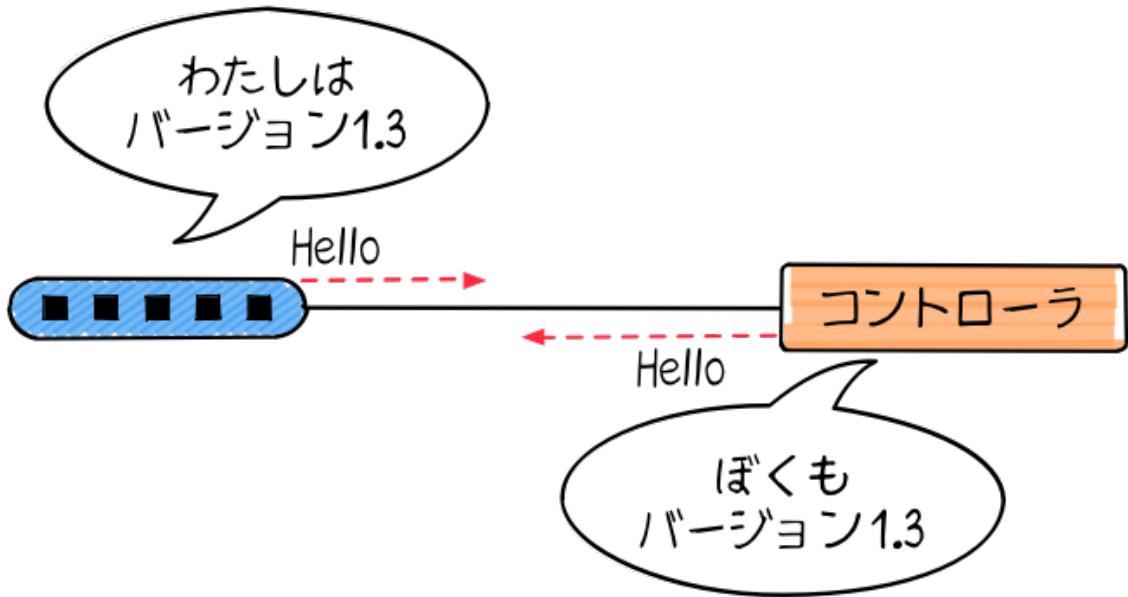


2.1. ##### ##### ##### ##### ##### ##### #####

#####

2.2.2.

(# 2#2)

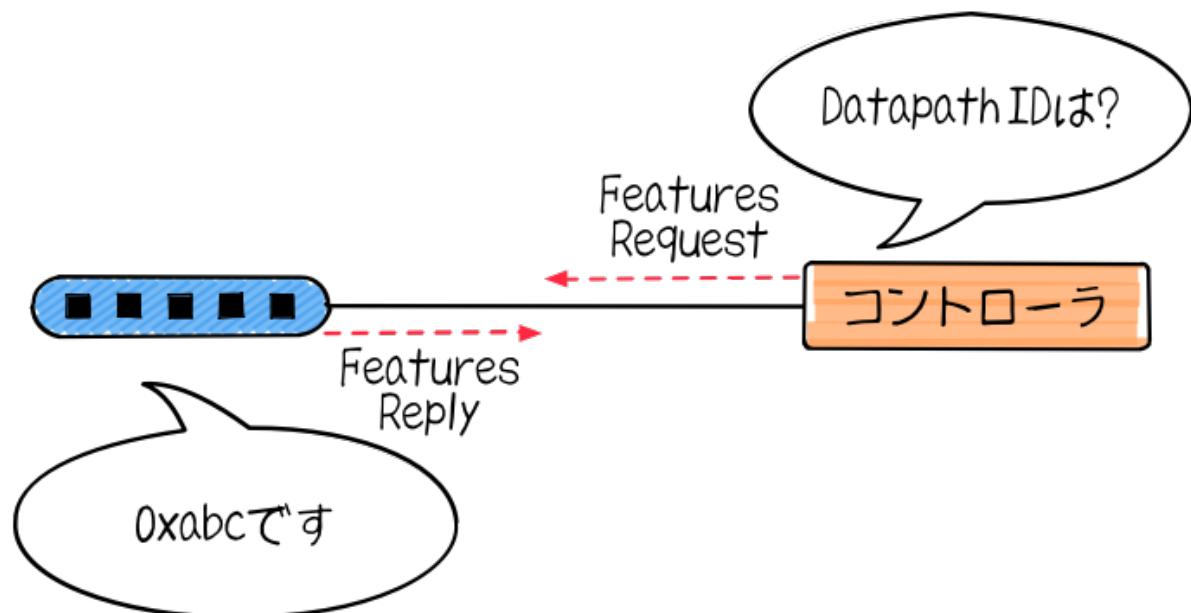


2.2.

#####

2.2.3.

#####

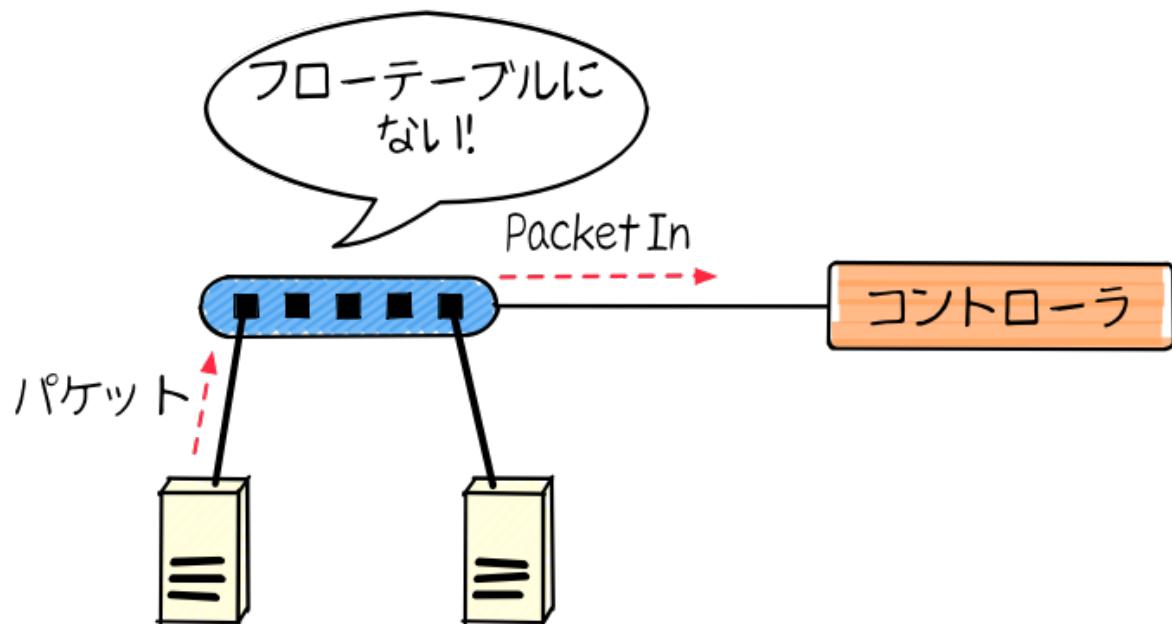


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2.2.4.

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#####
##### (# 2#4)#
#####
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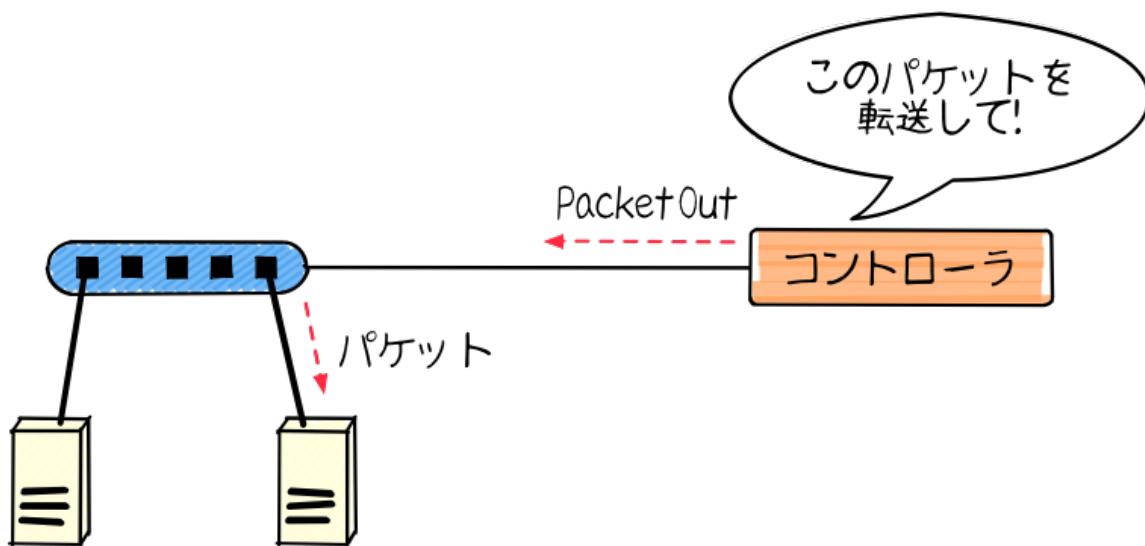
#####



2.4.

2.2.5.

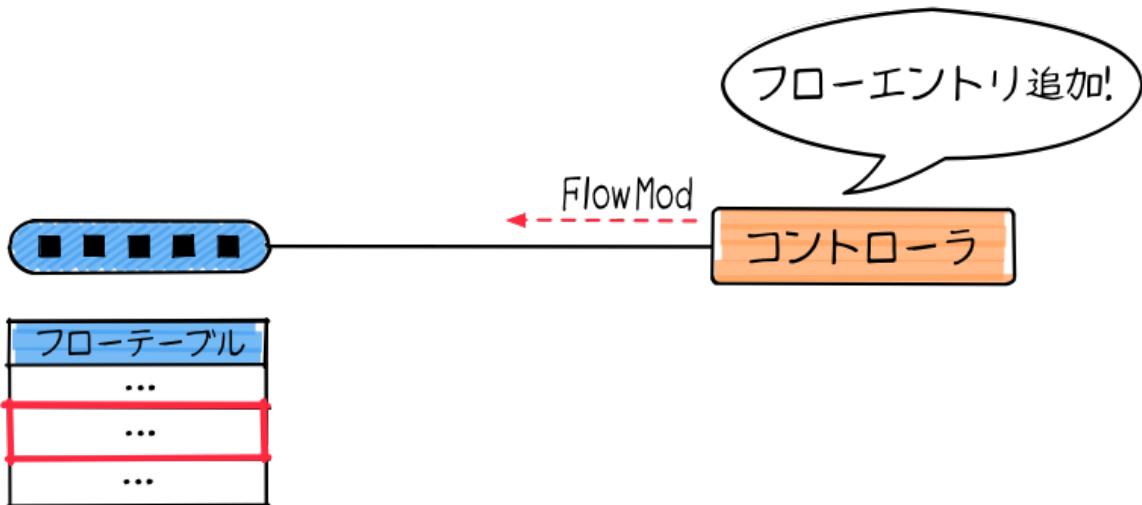
(# 2#5)



2.5.

(# 2#5)

2.2.6.



2.6. ##### ##### ##### ##### ##### ##### #####

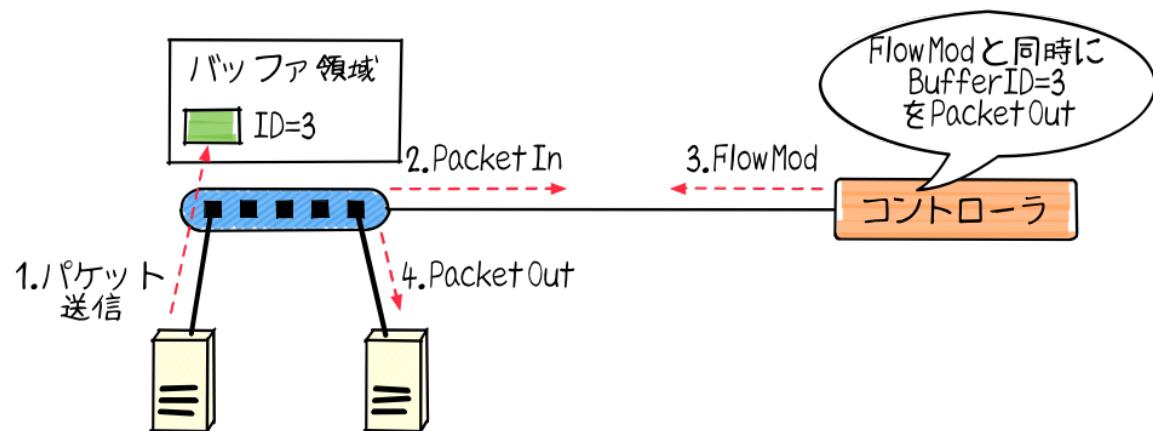


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1## ##### ## ##### ##### ##### ##### ##### ##### #####

& ##### ## ## **2#7** ##### ##### ##### ##### ##### #####

(##### ## ##) ##### ##### ##### #####

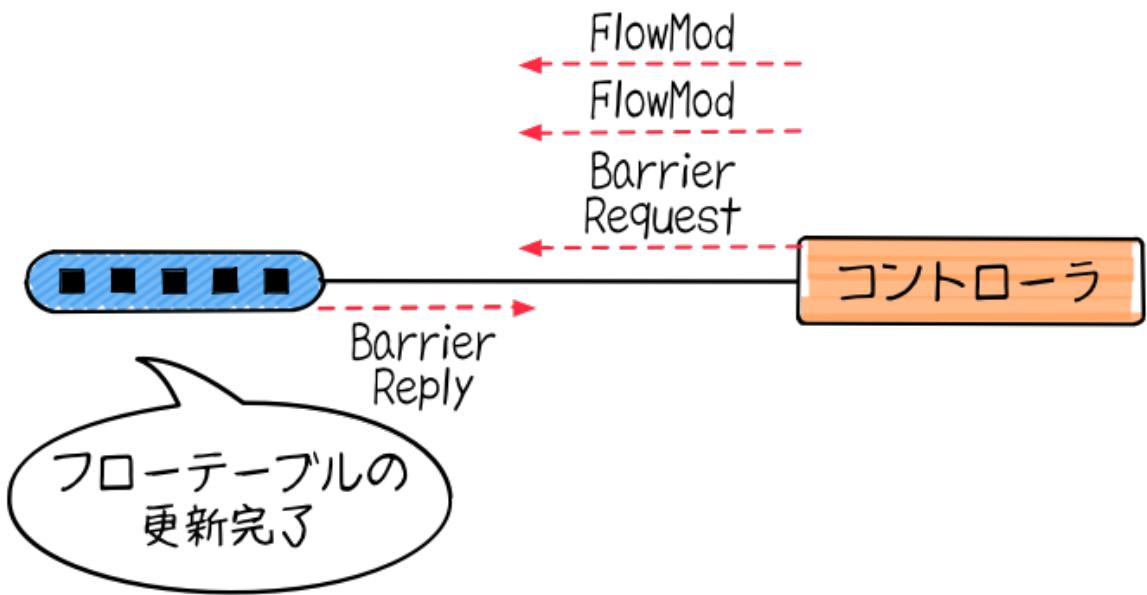
#####



3

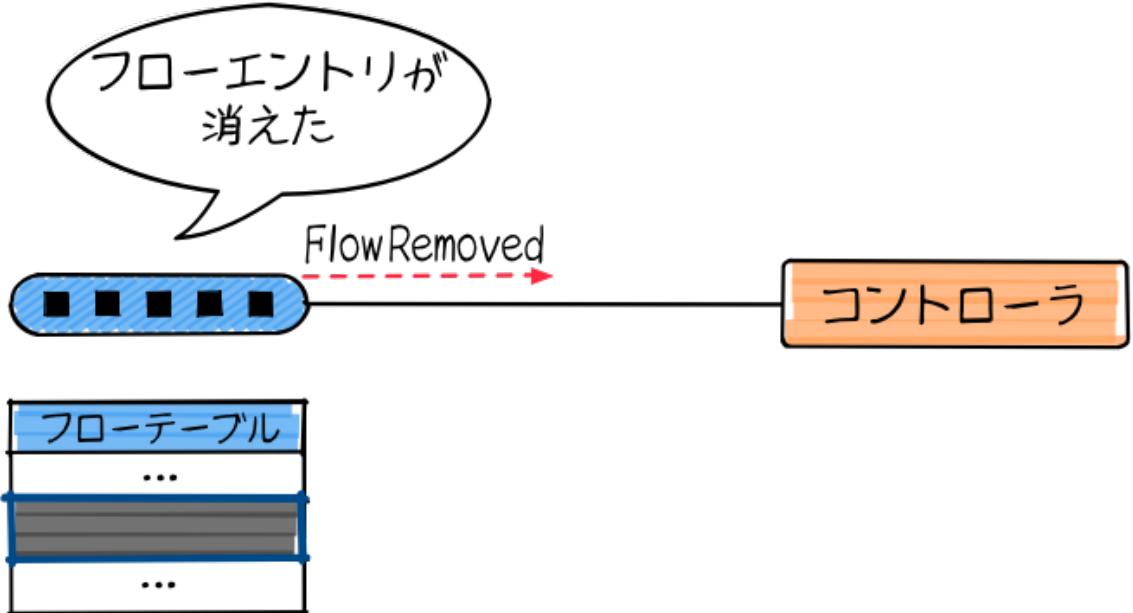
- #####
 - #####
 - #####

2.2.7.



2.8. ##### #####/##### ##### ##### #####

2.2.8.



2.3.

1 ##### 6 #####

- ####
 - ##### (#####)
 - ##### (##)
 - #####
 - #####
 - #####

2.3.1.

(0 # 65535) #####
#####

2.3.2. ##### (#####)

1.3

- #####

- #####
 - ##### (#)
 - ##### (##)

2.3.3. ##### (##)

(##) ##### 2

- #####: ##### O ####
#####
 - #####: #####

0

2.3.4.

#####

2.3.5.



#######

1.3 #####
#####

2.1.

| | |
|----------|-------|
| ## | ## |
| ## ##### | ##### |

| | |
|---------------|-------------------|
| ## | ## |
| ## #### #### | ##### ###### |
| ##### ### | ### #### #### |
| ##### ### | ## #### #### |
| ##### #### | ##### #### |
| #### ## | #### ## |
| #### ##### | #### ## ## (###) |
| ## ##### | ##### #### ###### |
| ## ### | ## ### ### |
| ## ### | ### ## #### |
| ## ### | ## ## #### |
| ## ##### | ## ##### #### |
| ### #### #### | ### ##### ###### |
| ### #### #### | ### ##### #### |
| ### #### #### | ### ##### #### |
| ### #### #### | ### ##### #### |
| ### #### #### | ### ##### #### |
| #####4 #### | #### ## |
| #####4 #### | #### ## |
| ##6 ### | ### ##6 #### |
| ##6 ### | ## ##6 #### |
| ##6 ##### | ##6 ##### |
| #####6 #### | #####6 ## |
| #####6 #### | #####6 ## |
| #### #### | #### ## |
| #### ## | #### ##### #### |
| ## ## | ## ## |

- ##### 1 ##### ## 80 # (= ####) #####
 - ### ##### 02:27:#4:#:#3:5# #### # # ##### 192.168.0.0/24 #####

#####



#####

#####

#####(#####
2##### 3##### ###### ##### ###### #####
#####)#####

```
#####
##### #####
##### ######4 #####
#####
#####
```

2.3.6.

1.3 #####
#####

- #####: #####
 - #####: #####
 - #####: #####
 - #####: #####
 - #####: #####

- #####: #####
 - #####: #####
 - ####: #####

####

#####

[Set-Field, Output]

```
#####
#####
```

```
# #####
```

[Output, Set-Field]

#####

[Set-Field A, Set-Field B, Output A, Output B]

2.3.7. #####

- #####: #########################
 - ## #####: #########################

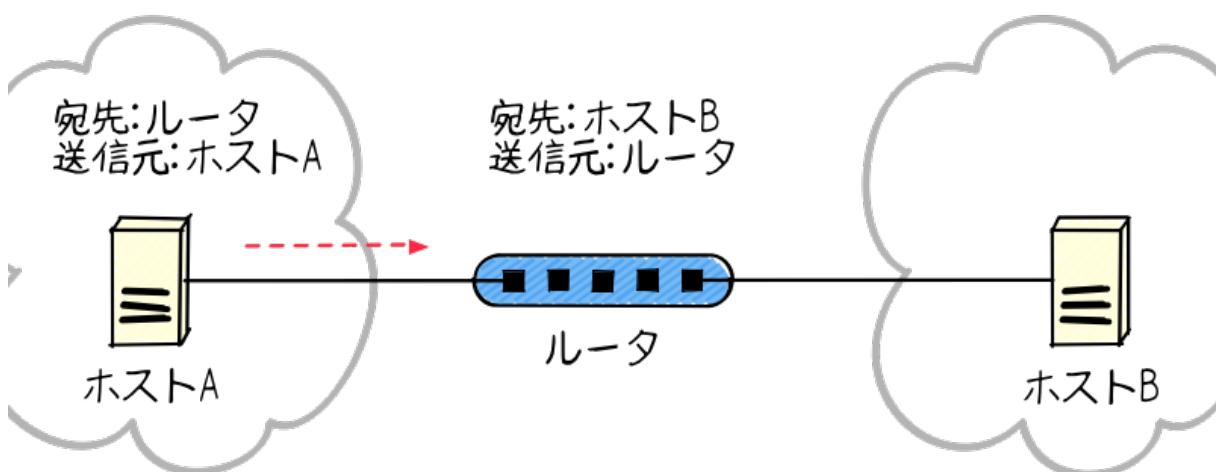
####

2.3.8. ##### ##### #####

(#2#1)#####

- #####/## #### ##### ##### #####
 - #####/## ## ##### ##### #####
 - ##### ##### ##### #####
 - #####/#### #####/##### ##### #####
 - ##### ##/##### ##### #####

#######

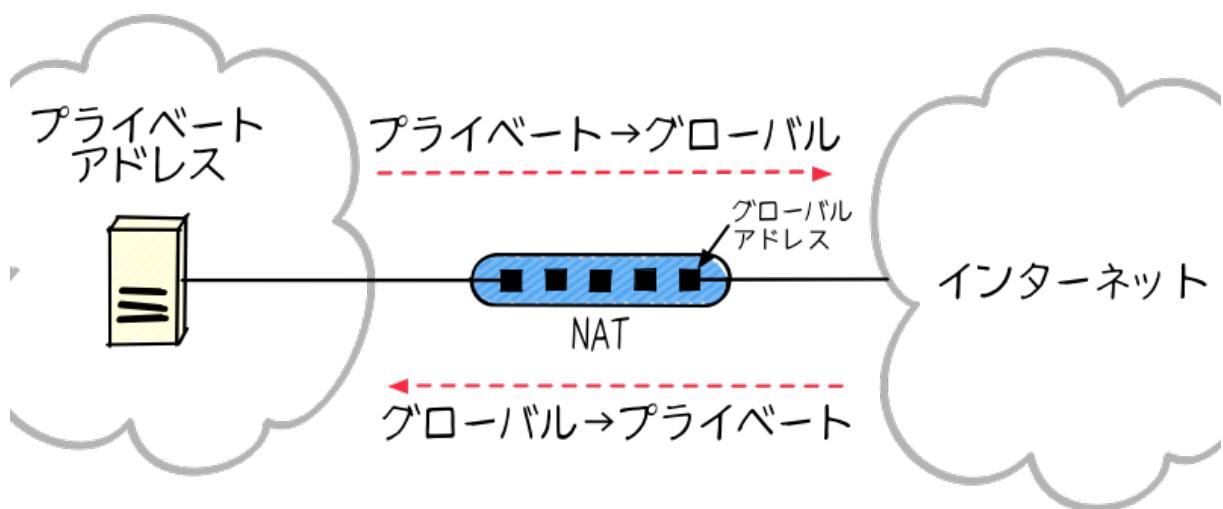


2.10. ##### ##### ##### #####

####

#####

```
## ##### ###### #### (##### ###### #####) ##### #### # #### ##### ####  
#### ## ##### ###### ##### ####
```



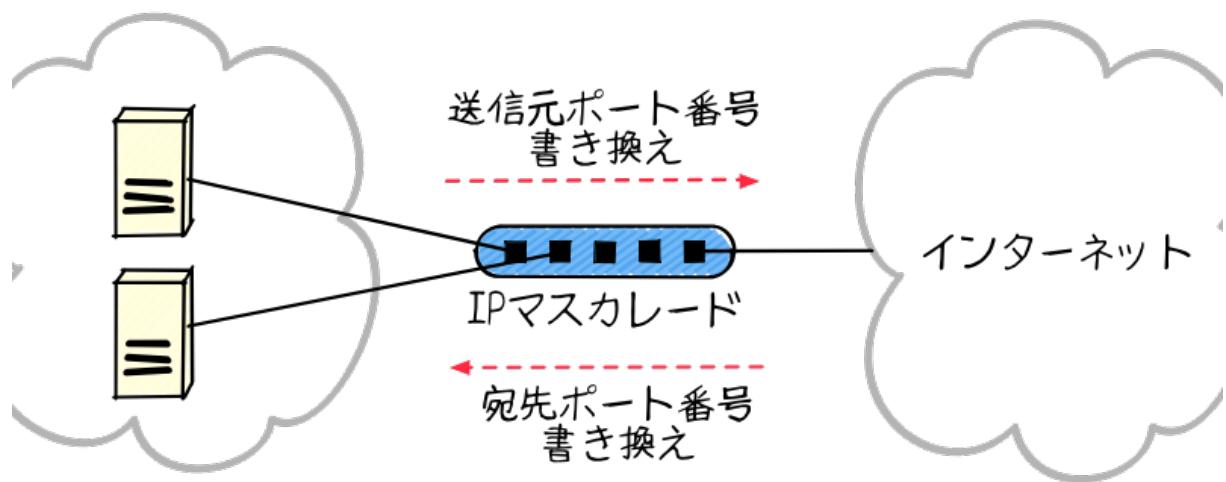
2.11. #### ##### ###### ###### ######

#######

(###)

###/### ###/###/###/###

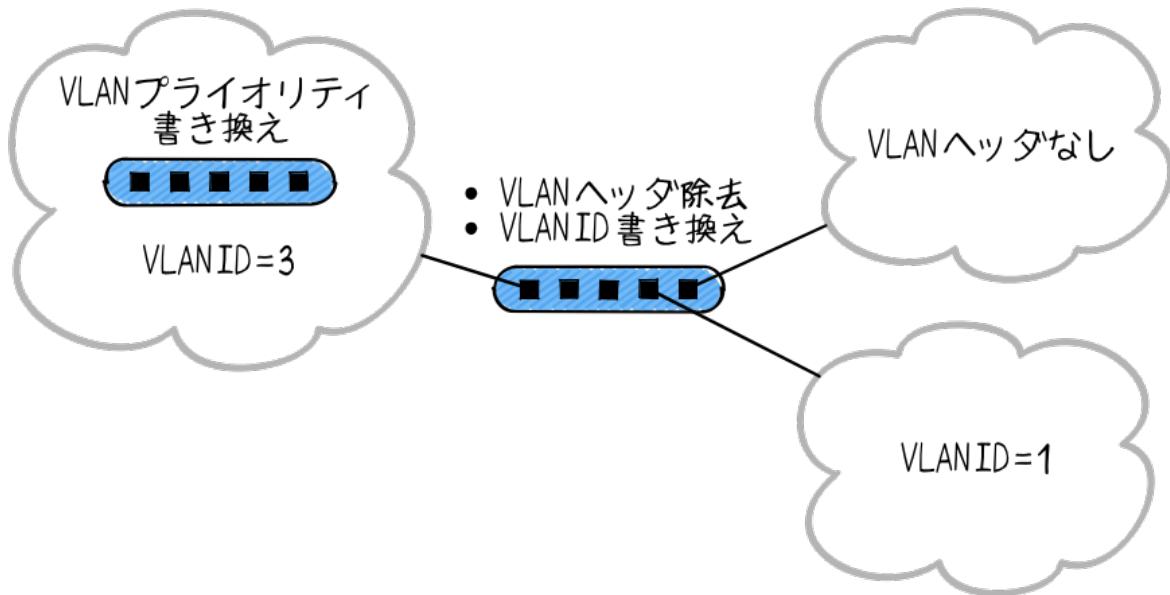
####/### ######/##### ## #####/##### ######/##### # ## #####/##### ######/##### ####/##
#####/##### ######/#####



2.12. ## #####/#####

```
#####
##### 1 #####
#####
#####
###
```

#####



#####

#####

0 (##) ## 7 (##)

2.3.9. ##### #####

```
#####
##### (#####) #####
#####
##### #####
#####
##### O #####
#####
#####
```

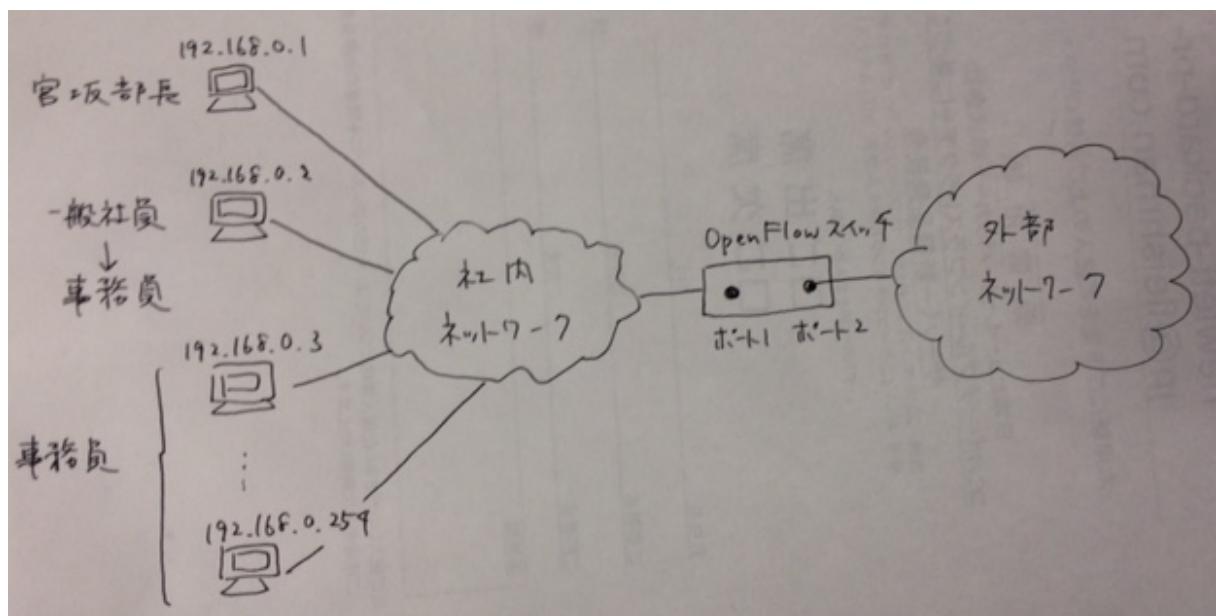
- ##### ##### #### ##### ##### (### ##### ##)
 - ## ##### #### ##### ##### (### ## ##)
 - ##### ##### #### ##### ##### (###### ## ## ##)
 - ## ##### #### ##### ##### (###### ## ## ##)
 - ##### #### ##### ##### ##### ##### (### ## ## ## ## ##)
 - ##### #### ##### ##### ##### ##### ##### (### ## ## ## ## ##)

####

2.4.

1.3 #####
#####

#####(# 2#14)##



2.14.

- ##### (192.168.0.1) ##### 2 #####
 - ##### (192.168.0.2 # 192.168.0.254) ##### 2 #####

#####**#2#2** ##### 5 ##### (192.168.0.1) #####

2.2. ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### 1

| | | | |
|--|--------------------|-------|------|
| ### | ##### | ### | ## |
| ### _## = 192.168.0.1/32, ### _#### = 25 | ##### (##### 2) | 10000 | #### |

| ### | ##### | ## | ## |
|---|--------------------|-------|------|
| ###_## = 192.168.0.1/32, ###_#### = 110 | ##### (##### 2) | 10000 | |
| ###_## = 192.168.0.1/32, ###_#### = 80 | ##### (##### 2) | 10000 | |
| ###_## = 192.168.0.1/32, ###_#### = 443 | ##### (##### 2) | 10000 | |
| ###_## = 192.168.0.1/32 | ##### (####) | 5000 | #### |
| ###_## = 192.168.0.0/24 | ##### (##### 2) | 1000 | |

(192.168.0.2) ##### #2#3 #####

2.3. #####2

| ### | ##### | ## | ## |
|---|--------------------|-------|------|
| ###_## = 192.168.0.1/32, ###_#### = 25 | ##### (##### 2) | 10000 | #### |
| ###_## = 192.168.0.1/32, ###_#### = 110 | ##### (##### 2) | 10000 | |
| ###_## = 192.168.0.1/32, ###_#### = 80 | ##### (##### 2) | 10000 | |
| ###_## = 192.168.0.1/32, ###_#### = 443 | ##### (##### 2) | 10000 | |
| ###_## = 192.168.0.1/32 | ##### (####) | 5000 | |

| | | | |
|---|--------------------|-------|------|
| ### | ##### | ## | ## |
| ### _## = 192.168.0.2/32, ### _#### = 25 | ##### (##### 2) | 10000 | #### |
| ### _## = 192.168.0.2/32, ### _#### = 110 | ##### (##### 2) | 10000 | |
| ### _## = 192.168.0.2/32, ### _#### = 80 | ##### (##### 2) | 10000 | |
| ### _## = 192.168.0.2/32, ### _#### = 443 | ##### (##### 2) | 10000 | |
| ### _## = 192.168.0.2/32 | ##### (####) | 5000 | |
| ### _## = 192.168.0.0/24 | ##### (##### 2) | 1000 | #### |
| ##### | ##### (####) | 0 | |

#2#2 # #2#3 ##### 5 ##### 5 #####
#####

#####1 ##### #2#4 #####
#####2 #####

2.4. ##### 1 (#####1)

| | | | |
|-----------------------------|--------------------|-------|-------|
| ### | ##### | ### | ## |
| ### _## = 192.168.0.1/32 | ##### 2 | 10000 | ##### |
| ### _## = 192.168.0.2/32 | ##### 2 | 10000 | #### |
| ### _## = 192.168.0.0/24 | ##### (##### 2) | 1000 | ##### |

####

| | | | |
|-------|-------|----|--|
| ### | ##### | ## | |
| ##### | ##### | 0 | |

2.5. ##### 2 (#####2)

| | | | |
|------------------|--------------------|-------|-------|
| ### | ##### | ## | ## |
| ### _ #### = 25 | ##### (##### 2) | 10000 | ##### |
| ### _ #### = 110 | ##### (##### 2) | 10000 | |
| ### _ #### = 80 | ##### (##### 2) | 10000 | |
| ### _ #### = 443 | ##### (##### 2) | 10000 | |
| ##### | ##### (####) | 5000 | |

######2#3 #####1 #####
#####

2.4.1. ##### # ##### # ##### # ##### # ##### # #####

2.6. ##### 1 (#####1)

| | | |
|----------------|---------------------------------|-------|
| ### | ##### | ### |
| ### _ ### = 25 | ##### (##### #, #), ##### 2 | 10000 |

| | | |
|----------------|--------------------------|-------|
| ### | ##### | ## |
| ### _### = 110 | ##### (##### #), ##### 2 | 10000 |

2.7. ##### 2 (#####2)

| | | |
|-------|----------------|-------|
| ### | ##### | ## |
| ##### | ##### (#### 2) | 10000 |


```
#####
#####
```

2.4.2.

####

```
##### ## ##### 192.168.1.101, 102 ##### 25, 110 ##### 2 #####
## ##### 192.168.1.103, 104 ##### 80, 443 ##### 2 #####
##### #2#8 # #2#9 #####
```

2.8. ##### 1 (#####1)

| | | |
|------------------------|---------------------------|-------|
| ### | ##### | ### |
| ##_ ## = 192.168.1.101 | ##### 1, ##### ##### 2 | 10000 |
| ##_ ## = 192.168.1.102 | ##### 1, ##### ##### 2 | 10000 |
| ##_ ## = 192.168.1.103 | ##### 2, ##### ##### 2 | 10000 |
| ##_ ## = 192.168.1.104 | ##### 2, ##### ##### 2 | 10000 |

2.9. ##### 2 (#####2)

| | | |
|-------------------------|----------------|-------|
| ### | ##### | ## |
| ##### = 1, ##_### = 25 | ##### (#### 2) | 10000 |
| ##### = 1, ##_### = 110 | ##### (#### 2) | 10000 |
| ##### = 2, ##_### = 80 | ##### (#### 2) | 10000 |
| ##### = 2, ##_### = 443 | ##### (#### 2) | 10000 |

```
##### 64### ##### 8### ##### 11111111 ##  
##### ##### 00001010##### 00001111 ##### 4###  
# 1 ##### 4### ##### 11111010 #####
```

2.5.

```
#####
##### (###) #####
####
```

3. #####!

#####(##)#####!#####!#####!#####!#####!#####!#####!#####!#####!



3.1.

#####?#####
#####

#####

(##)
#####

(4#)
#####

#####, #####!

#####

#####://#####.#####.###/#####/##########/

#####

#####://#####.###/##### #####

#####90#####
#####

```
###2000#####
#####1#####
#####
```

```
#####
##1#####
#####
#####
```

#####



#####?#

```
#####
#####(####://##.#####.###/#####
#####)/##########
#####
```


#####

```
#####
#####
```

1 #####://##### #####/



3.1.

3 #####.....#####
! #####.....#####
#####

3.3.

#####

- ##### #####
- ##### #####
- ##### 6 #, 7 #

#####4####

###

sudo ##### ##### ##### ##### #####
#####

###

2.0 ##### ##### ##### ##### ##### #####

² #####://#####.##/

#####, #####!

```
#####2  
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####  
#####3  
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####
```

3.3.1.

```
$ sudo apt-get update  
$ sudo apt-get install ruby2.0 ruby2.0-dev build-essential
```

#####

```
$ sudo yum update  
$ sudo yum install ruby ruby-devel gcc gcc-c++
```

3.3.2. ##### #### #####

#####

```
$ gem install bundler
```

```
## gem # ##### ##### ##### .### ##### ##### ##### ##### ##### ##### ##### # .### ##### #####  
##### ##### #####
```

3.3.3. ##### ##### ##### ##### #####

3 #####://#####.###/

#####, #####!

#####/# ##### ##### ##### ##### #####

```
##### apt-get #####
```

```
$ sudo apt-get install openvswitch-switch
```

#####

```
yum #####(#####)#####4#####  
#####
```

```
$ sudo yum update
```

```
$ sudo yum install https://rdoproject.org/repos/rdo-release.rpm
```

```
$ sudo yum install openvswitch
```

```
$ sudo systemctl start openvswitch.service
```

#####, #####

3.4. #####, #####!

3.4.1. #####

```
#####!#####
hello_trema/ ##### hello_trema/lib/ # mkdir -p #####

```

```
$ mkdir -p hello_trema/lib
```

```
$ cd hello_trema
```

#####

```
#####
#####.#####
#####
```

4 #####://####.##########.###/#### ####

#####, #####!

```
##### # trema/hello_trema ##### (####://#####.###/####/####/  
##### ####) ##### ##### ##### ##### ##### ##### ##### ##### #####
```

README.md

#####

LICENSE

#####

CHANGELOG.md

####

Gemfile

#####

Rakefile

1

lib/

#####

features/

####

spec/

####

tasks/

#####



```
##### features/ #####9 ##### ##### ##### ##### ##### #####  
####
```

####

###/#####.##

Hello World!

```
class HelloTrema < Trema::Controller
```

```
def start(_args)
```

logger.info 'Trema started.'

end

#####, #####!

```
def switch_ready(datapath_id)
    logger.info "Hello #{datapath_id.to_hex}!"
end
end
```

#####

```
##### #####! ##### ##### ##### 1 ##### ##### ##### ##### ##### ##### #####  
##### ##### ##### ##### ##### ##### trema.conf ##### hello_trema/ ##### #####
```

#####.#####

```
vswitch { datapath_id 0xabc }
```

```
#####1##### vswitch #####1#####( { } )#####
#### datapath_id ( 0xabc ) #####16#####
```

```
## ##### ## ##### ## ##### ## ##### ## ##### ## ##### ## ##### ## ##### ##  
#64##### ## ##### ## ##### ## ##### ## ##### ## ##### ## ##### ## ##### ##  
##### ## #####
```



#####

```
##### = #####  
#####  
#####
```

- ##### = #####
 - ##### = #####

#####

```
#####
#####
```

#####

```
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### # hello_trema/  
##### Gemfile ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####
```

####

#####, #####!

source '<https://rubygems.org/>' ①

gem ‘trema’ ❷

```
$ bundle install --binstubs
```

```
$ ./bin/trema --version
```

trema version 0.9.0

#####

#####(#### ###)

```
##### trem run #####
```

```
$ ./bin/trema run ./lib/hello trema.rb -c trema.conf
```

Trema started.

Hello, 0xabc! ①

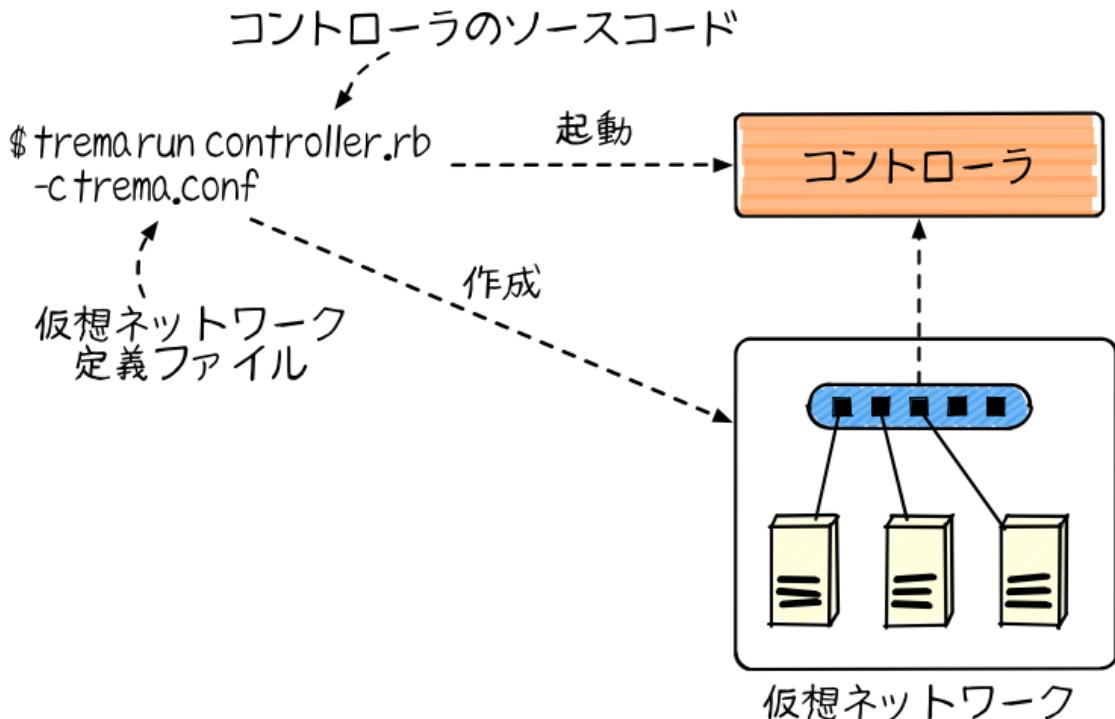
\$

① #####:[#####+#] ##########

Trema started. Hello, 0xabc!

```
##### tremal ###### tremal #####  
#####
```

3.5. #####



3.2. ##### ##### ##### #####

```
trema ##### git # svn ##### tremarun ##### tremarun #####
#####
##### tremahelp ##### tremahelp ##### tremahelp #####
#### ##### tremahelp ##### #####
#####
##### tremarun
#####
##### (#####) #####
##### tremakillall
#####
##### tremastop
#####
##### tremastart
#####
##### tremasend_packets
#####
##### tremashow_stats
#####
##### tremareset_stats
#####
```

trema port_down
#####

trema port_up
#####

trema delete_link

trema netns

```
trema dump_flows
```

3.6.

```
#####
#####(##)#####
#####
```

| | | |
|-------|-----------------------------------|--------|
| ## | # | ##### |
| ## | HelloTrema , Trema::Controller | ##### |
| ##### | @switches , @name | @ #### |
| #### | :match , :actions | : #### |



#####4 #####

```
#####
#####
```

3.6.1.

```
HelloTrema # Trema::Controller #####  
#####
```

###/##### # ##### ##

Hello World!

```
class HelloTrema < Trema::Controller ❶
  def start(_args)
    logger.info 'Trema started.'
  end

  def switch_ready(datapath_id)
    logger.info "Hello #{datapath_id.to_hex}!"
  end
```

❶ HelloTrema # Trema::Controller ###
#####(#####)#####(#####)#####(#####)
#####(#####)#####(#####)#####(#####)
#####(#####)#####(#####)#####(#####)

```
$ irb
> TokyoTower = "#####4##2-8"
> TokyoTower = "#####"
(irb):2: warning: already initialized constant TokyoTower
(irb):1: warning: previous definition of TokyoTower was here
=> "#####4##2-8"
```



irb (##### #####) # ##### ##### ##### #####
#####

```
class #####, #####!#### HelloTrema ##### class +#####
##### ##### end #####  

###/#####_#####.##
```

```
class HelloTrema < Trema::Controller ❶
  def start(_args)
    logger.info 'Trema started.'
  end

  def switch_ready(datapath_id)
    logger.info "Hello #{datapath_id.to_hex}!"
  end
end ❷
```

❶ #####
❷ #####

#####, #####!

#####

```
##### Trema::Controller #####
#### class < ##### ####.
```

###/#####.##

```
class HelloTrema < Tremax::Controller ①  
  ...  
end
```

```
1 Trema::Controller ##### HelloTrema #####
Trema::Controller ##### HelloTrema #####
#####
#####
```

3.6.2.

```
##### HelloTrema ##### main() #####
###
```

```
##### def ##### end ##### HelloTrema #### start #####
switch_ready ##### (_args # datapath_id) #####
#####
```

###/##### # #####.##

```
class HelloTrema < Trema::Controller
  def start(_args) ①
    logger.info "Trema started."
  end
```

```
def switch_ready(datapath_id) ❷
    logger.info "Hello #{datapath_id.to_hex}!"
end
end
```

① start #####

② switch_ready #####

#####

```
##### trem run #####
```



```
#####: ##### ( _ ) #####
##### _args #####
```

args

```
def start(_args)
    logger.info "Trema started."
end
```

```
# ##### args #####
```

```
def start(args)
    logger.info "Arguments = #{args.join ','}"
end
```

#####

#####

#####

(5 #####)

#####



#####

#####?#####

#####

```
#####
#####(#####
#####)#####
##### #####
#### packet_in #####
#####
```

Trema::Controller

3.6.3.

```
##### (#####) #####  
#####
```

alias and BEGIN begin break case class def defined do else elsif END end ensure false for if in module next nil not or redo rescue retry return self super then true undef unless until when while yield

```
#####, #####!## class # def # end # 3 ##### class #####
##### def #####
```

3.6.4.

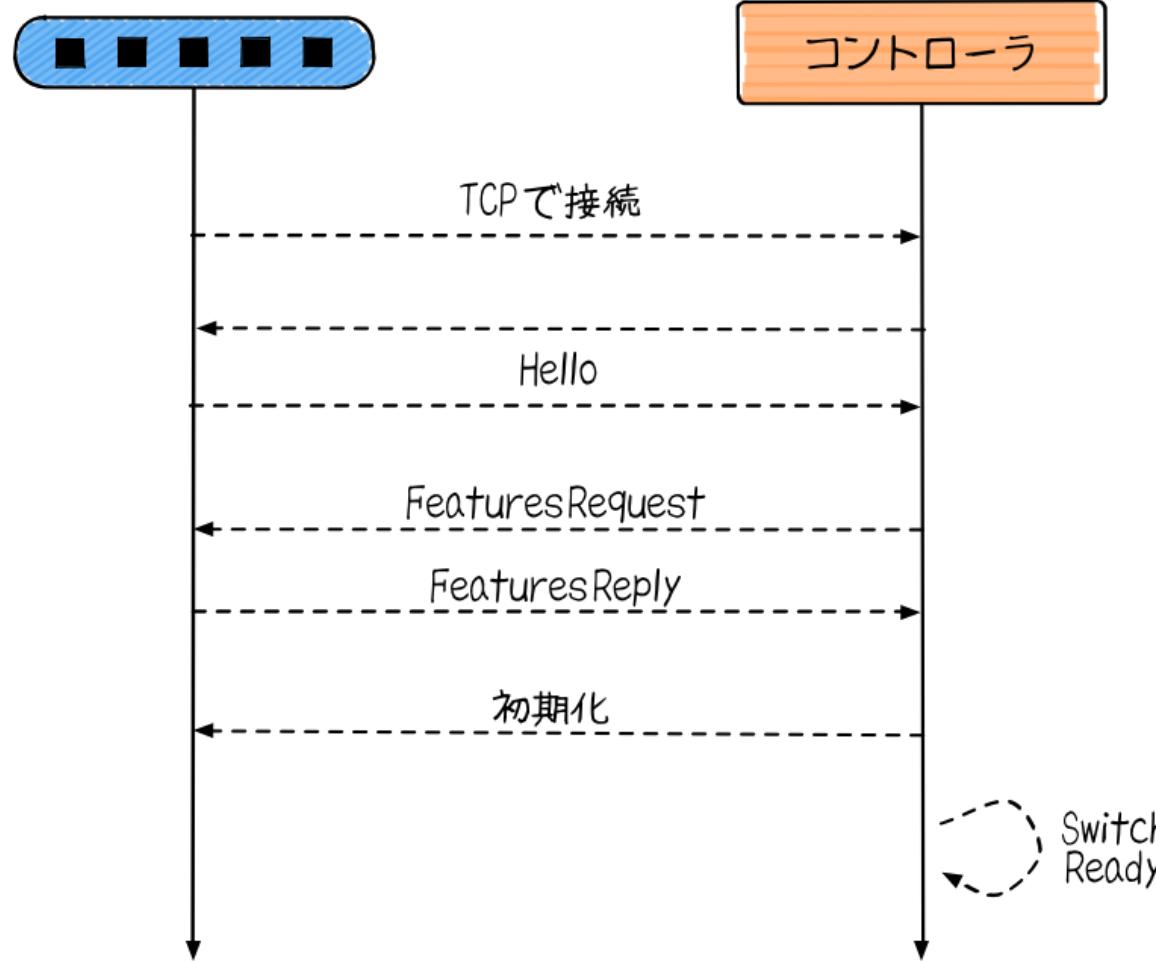
```
##### switch_ready ##### switch_ready ##### switch_ready #####
16##(0#####)#####
```

(###/##### #####.##)

```
def switch_ready(dpid)
    logger.info "Hello #{dpid.to_hex}!"
end
```



```
#####_#####
## ##### ###### switch_ready #####
##### ##### ###### switch_ready ##### 3#####
##### ##### #####
##### _#####
```



3.3. ##### ##### ##### ##### #####

#####16#####

```
to_hex ####16##### switch_ready ##### dpid ####64#####  
##### 0xffffb ####16##### to_hex #16####  
#####
```

#####

```
##### logger #####
```

```
##### (##/#### _ ####.##)
```

```
def start(_args)  
    logger.info 'Trema started.'  
end
```

```
logger ##### unknown (## ##) #  
# debug (## ##) ####6#####
```

#####

```
#####
```

#####

```
#####
```

#####

```
##
```

#####

```
#####
```

#####

```
#####
```

#####

```
#####
```

```
trema run #####
```

```
##### (## _ ####.##)
```

```
class TryLogging < Trema::Controller  
def start(_args)  
    logger.unknown 'UNKNOWN'  
    logger.fatal 'FATAL'  
    logger.error 'ERROR'  
    logger.warn 'WARN'
```

#####, #####!

37 ####

#####
#####, #####!#####
#####

- ##### Trema::Controller #####
- #####
- ##### trema run #####
- #####

#####

3.8.

#####

2.2.0 #####(####://####.#####.###/#/2.2.0/###)

#####

#2##(##### ##### ##### #### ##### #####)

#####

(#####) ##### ## #####(####://####.#####.###/#/#####) ⁵

_ ##### _ ##### _ ##### _ ##### _ ##### _ ##### _

⁵ ##### ####://##.##.##/#####/_#####_#####_#####_##_#####/

4.

#####



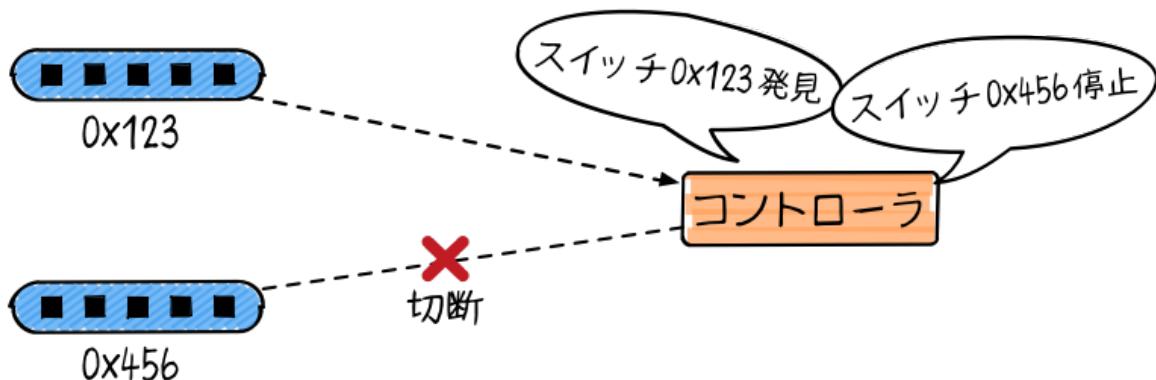
4.1. #####

#####1#####1#####
#####1 ##### #####

###

#####

```
##### 4#####
```



```
##### 4.1. #####
```

4.2.

```
##### ##### ##### ##### #####
```

```
$ git clone https://github.com/trema/switch_monitor.git
```

```
##### bundle install --binstubs ##### ./bin/trema #####
```

```
$ cd switch_monitor  
$ bundle install --binstubs
```

```
##### ##### ##### ##### #####
```

4.3.

```
#####3##### switch_monitor.conf #####  
##### datapath_id ##### 0x1 , 0x2 , 0x3 #####
```

```
##### _ #####.#####
```

```
vswitch { datapath_id 0x1 }  
vswitch { datapath_id 0x2 }  
vswitch { datapath_id 0x3 }
```

```
##### trema run # -c #####
#####
```

```
$ ./bin/trema run ./lib/switch_monitor.rb -c switch_monitor.conf
SwitchMonitor started.
All =
0x3 is up (All = 0x3) ❶
0x3 manufacturer = Nicira, Inc. ❷
0x3 hardware info = ❸
0x3 software info = ❹
0x3 serial number = ❺
0x3 description = ❻
0x1 is up (All = 0x1, 0x3)
0x1 manufacturer = Nicira, Inc.
0x1 hardware info =
0x1 software info =
0x1 serial number =
0x1 description =
0x2 is up (All = 0x1, 0x2, 0x3)
0x2 manufacturer = Nicira, Inc.
0x2 hardware info =
0x2 software info =
0x2 serial number =
0x2 description =
All = 0x1, 0x2, 0x3
All = 0x1, 0x2, 0x3
```

- ❶ ##### 0#3 #####
- ❷ #####
- ❸ ##### (#)
- ❹ ##### (#)
- ❺ ##### (#)
- ❻ ##### (#)

```
0x1 is up #####3#####3#####
##### ( All = 0x1, 0x2, 0x3 ##) #####
#####
vswitch { ... } #####5##10##...#####
```

4.3.1. #####/#####

```
##### trema stop ### trema run #####
##### 0x3 #####
-----
```

```
$ ./bin/trema stop 0x3
-----
```

```
### trema run ##### 0x3 is down #####
-----
```

```
$ ./bin/trema run ./switch_monitor.rb -c ./switch_monitor.conf
```

```
SwitchMonitor started.
```

```
All =
```

```
0x3 is up (All = 0x3)
```

```
0x3 manufacturer = Nicira, Inc.
```

```
0x3 hardware info =
```

```
0x3 software info =
```

```
0x3 serial number =
```

```
0x3 description =
```

```
....
```

```
All = 0x1, 0x2, 0x3
```

```
All = 0x1, 0x2, 0x3
```

```
All = 0x1, 0x2, 0x3
```

```
0x3 is down (All = 0x1, 0x2) ①
-----
```

```
① #### 0#3 #####
-----
```

```
#####! ##### trema start ###
-----
```

```
$ ./bin/trema start 0x3
-----
```

```
0x3 is up #####
-----
```

```
$ ./bin/trema run ./switch_monitor.rb -c ./switch_monitor.conf
```

```
SwitchMonitor started.
```

```
All =
```

```
0x3 is up (All = 0x3)
```

```
0x3 manufacturer = Nicira, Inc.
```

```
0x3 hardware info =
```

```
0x3 software info =
```

```
0x3 serial number =
```

```
0x3 description =
```

```
....
```

#####

All = 0x1, 0x2, 0x3
All = 0x1, 0x2, 0x3
0x3 is down (All = 0x1, 0x2)
All = 0x1, 0x2
.....
All = 0x1, 0x2
All = 0x1, 0x2
0x3 is up (All = 0x1, 0x2, 0x3) ①

4.4.

#####(##/##### _ #####.##)#####

###/#####.## #####.##

```
# Switch liveness monitor.

class SwitchMonitor < Trema::Controller
    timer_event :show_all_switches, interval: 10.sec

    def start(_args)
        @switches = []
        logger.info "#{name} started."
    end

    def switch_ready(dpid)
        @switches << dpid
        logger.info "#{dpid.to_hex} is up (All = #{all_s...}"
        send_message dpid, DescriptionStats::Request...
    end

    def switch_disconnected(dpid)
```

```

#####



@switches -= [dpid]
logger.info "#{dpid.to_hex} is down (All = #{all_switches_in_string})"
end

def description_stats_reply(dpid, packet_in)
  logger.info "Switch #{dpid.to_hex} manufacturer = #{packet_in.manufacturer}"
  logger.info "Switch #{dpid.to_hex} hardware info = #{packet_in.hardware}"
  logger.info "Switch #{dpid.to_hex} software info = #{packet_in.software}"
  logger.info "Switch #{dpid.to_hex} serial number = #{packet_in.serial_number}"
  logger.info "Switch #{dpid.to_hex} description = #{packet_in.datapath}"
end

private

def show_all_switches
  logger.info "All = #{all_switches_in_string}"
end

def all_switches_in_string
  @switches.sort.map(&:to_hex).join(',')
end
end

```

```

#####
## SwitchMonitor #####
#####

```

4.4.1.

```

switch_ready ##### @switches #####
#####

#####_##### (###/#####_#####.##)

def switch_ready(dpid)
  @switches << dpid
  logger.info "#{dpid.to_hex} is up (All = #{all_switches_in_string})"
  send_message dpid, DescriptionStats::Request.new
end

#####

@switches # start #####
#####

#####_##### (###/#####_#####.##)

def start(_args)

```

```
#####
```

```
@switches = []
logger.info "#{name} started."
end
```

4.4.2.

```
#####( @)#####
#####(##) #####
```

```
##### Human #####
```

```
class Human
  def initialize
    @age = 0 1
  end
```

```
  def birthday 2
    @age += 1
  end
end
```

```
1 ##### 0 #
```

```
2 #####
```

```
Human ##### Human ##### @age #0###0##
## birthday ##### @age # 1 ##### @age # initialize ### birthday #####
#####
```

```
##
```

```
#####
```

- [] #####
- [1, 2, 3] #####
- ["###", "###", "###"] #####

```
##### << #####

```

```
fruits = ["###", "###", "###"]
fruits << "#####"
#=> ["###", "###", "###", "#####"]
```

-=

```
fruits = ["###", "###", "###", "###", "###"]
fruits -= ["###", "###"]
#=> ["###", "###", "###"]
```

#####3 #####,
#####!

4.4.3.

(###/#####.##)

```
def switch_disconnected(dpid)
    @switches -= [dpid]
    logger.info "#{dpid.to_hex} is down (All = #{all_switches_in_string})"
end
```

```
#### switch_ready ##### ( -= ) ##### @switches #####
#####
```

4.4.4.

```
##### timer_event #####
```

```
# 1 #####
class Human < Tremor::Controller
  timer.event :birthday, interval: 1.year, 1
```

private ②

```
def birthday ③  
  @age += 1  
end
```

- 1** 1 ##### birthday #####
2 #####

3 ##### birthday #####
Human ##### Human
#####
private
#####
#####

```
class SwitchMonitor < Trema::Controller
  timer_event :show_all_switches, interval: 10.sec
  ...
  private

  def show_all_switches
    logger.info "All = #{all_switches_in_string}"
  end
```

#####10##### show_all_switches #####
#####
#

```
#####
:a # :number # :show_all_switches #####
#####
## (6 #####) #####
#####
switch_monitor.rb #####

```

```
timer_event :show_all_switches, interval: 10.sec
```

```
## :show_all_switches # SwitchMonitor #####
#####
# ####!
timer_event show_all_switches, interval: 10.sec
```

```
#####
show_all_switches #####
##### timer_event #####

```

#####

#####

4.4.5.

```
#####
##### send_message #####
##### DescriptionStats::Request #####
# description_stats_reply #####
#####
##### _ #####, ##### _ ##### _ ##### (###)
##### _ #####.##)

def switch_ready(dpid)
    @switches << dpid
    logger.info "#{dpid.to_hex} is up (All = #{all_switches_in_string})"
    send_message dpid, DescriptionStats::Request.new
end

def description_stats_reply(dpid, packet_in)
    logger.info "Switch #{dpid.to_hex} manufacturer = #{packet_in.manufacturer}"
    logger.info "Switch #{dpid.to_hex} hardware info = #{packet_in.hardware}"
    logger.info "Switch #{dpid.to_hex} software info = #{packet_in.software}"
    logger.info "Switch #{dpid.to_hex} serial number = #{packet_in.serial_number}"
    logger.info "Switch #{dpid.to_hex} description = #{packet_in.datapath}"
end
```

1.0

| | | |
|-------|---------------------------|-------------------------|
| ##### | ##### | #### |
| ##### | DescriptionStats::Request | description_stats_reply |
| ##### | FlowStats::Request | flow_stats_reply |
| ##### | AggregateStats::Request | aggregate_stats_reply |
| ##### | TableStats::Request | table_stats_reply |
| ##### | PortStats::Request | port_stats_reply |
| ##### | QueueStats::Request | queue_stats_reply |

4.5.

#####

- ##### switch ready # switch disconnected #####

- ##### DescriptionStats::Request #####
description_stats_reply #####
- #### (timer_event) #####
- trema start # trema stop #####/#####

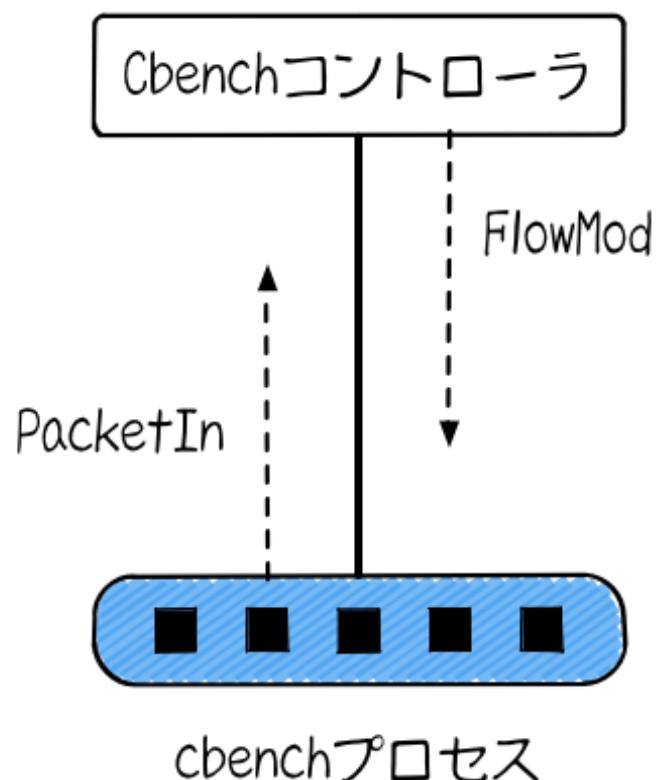
#####

5.

5.1.

```
#####1.0#####1##### ##### #####
#####
##### #####
#####
```

5#1#####



5.1.

5.2.

```
#####
1 #####
#####
$ git clone https://github.com/trema/cbench.git
#####
##### bundle install --binstubs #####
##### ./bin/trema #####
##### ./bin/cbench #####
#####
$ cd cbench
$ bundle install --binstubs
#####

```

5.3.

```
#####
$ ./bin/trema run ./lib/cbench.rb
#####
2 #
#####
$ ./bin/cbench --port 6653 --switches 1 --loops 10 --ms-per-test 10000 --delay 1000 --throughput
cbench: controller benchmarking tool
running in mode 'latency'
connecting to controller at localhost:6653
faking 1 switches :: 10 tests each; 10000 ms per test
with 100000 unique source MACs per switch
starting test with 1000 ms delay after features_reply
ignoring first 1 "warmup" and last 0 "cooldown" loops
debugging info is off
1 switches: fmods/sec: 807 total = 0.080652 per ms
1 switches: fmods/sec: 797 total = 0.079694 per ms
1 switches: fmods/sec: 799 total = 0.079730 per ms
1 switches: fmods/sec: 797 total = 0.079698 per ms
1 switches: fmods/sec: 801 total = 0.080003 per ms
1 switches: fmods/sec: 800 total = 0.079965 per ms
1 switches: fmods/sec: 802 total = 0.080159 per ms

```

¹ #####

² #####

#####

```
1 switches: fmods/sec: 802 total = 0.080182 per ms
1 switches: fmods/sec: 806 total = 0.080549 per ms
1 switches: fmods/sec: 801 total = 0.080082 per ms
RESULT: 1 switches 9 tests min/max/avg/stdev = 79.69/80.55/80.01/0.26 responses/s
```

#####10#####10##### fmods/sec ##### 1 ##### #### #
#####

5.4.

```
#####
## ####/#####.## ##
#####
###/#####.##
```

A simple openflow controller for benchmarking.

```
class Cbench < Trema::Controller
  def start(_args)
    logger.info "#{name} started."
  end
```

```
def packet_in(datapath_id, packet_in)
    send_flow_mod_add(
        datapath_id,
        match: ExactMatch.new(packet_in),
        buffer_id: packet_in.buffer_id,
        actions: SendOutPort.new(packet_in.in_port + 1)
    )
end
end
```

5.4.1.

- logger.info(...) (3 #####, #####!#####)
 - ExactMatch.new(...)
 - packet_in.buffer_id
 - SendOutPort.new(...)
 - packet_in.in_port

```
#####
#
#door.open
#####
##### open #####
#####
#redrum'.reverse
#=> "murder"
#####
##### ( join ) #####
[ 'M', 'A', 'S', 'H' ].join('#')
#
```

5.4.2.

(###/#####.##)

```
def start(_args)
    logger.info "#{name} started."
end
```

```
##### start ##### _args #####
###
```

5.4.3. #####

```
def packet_in(datapath_id, packet_in)  
    ...  
end
```

```
packet_in #####(#####)(#####)##### ###### ## ##### ###### #####
#####
```

####


```
PacketIn #####  
######5#1#####
```

5.1. ##### (##)

| | |
|-------------|---------------|
| #### | ## |
| :####? | ##### true ## |
| :####_### | ##### |
| :####_##### | ##### |
| :####_### | ##### |

```
#####3 #####, #####!##### #####
#####
```

5.4.4. #### ###

```
#####
```

- #####: ##### ## ##### (##)
- #####: ##### ## #####_#####+1#####
- #####: ##### ## #####

```
#####
```

(##### 1.0)

```
##### send_flow_mod_add ##### match: #####
( Match.new(...) ## ExactMatch.new(...) ) #####
```

```
send_flow_mod_add(
    datapath_id,
    match: Match.new(...), ❶
    ...
)
```

```
❶ ##### match: #####
##### Match.new ##### ##### ##### #####
00:50:56:#0:00:08 # #### ## # 3 ##### ##### ##### #####
##### ##### ##### ##### ##### ##### ##### ##### #####
```

```
send_flow_mod_add(
    datapath_id,
    match: Match.new(
        source_mac_address: '00:50:56:c0:00:08'
        vlan_vid: 3
    )
)
```

#####

...

1.0 ##### 12 ##### Match.new #####12#####(#
5#2#)

5.2. ##### ####.###

| | |
|---------------------------|-----------|
| ##### | ## |
| :## _### | ##### |
| :##### _### _##### | ##### |
| :##### _### _### _##### | ##### |
| :##### _### | ##### |
| :##### _## _##### | ##### |
| :##### _## _### _##### | ##### |
| :## _##### | ##### |
| :## | ##### |
| :##### _##### _### | ###/##### |
| :##### _##### _##### _### | ###/##### |
| :### _## | ### ## |
| :### _##### | ##### |



2##### ##### ##### ##### 1.3 ##### 40 #####
1.3 ##### ##### ##### ##### 1.0 #####
1.3 ##### 8#####1.3#####14##### (#
#####)#####

(##### 1.0)

#####12##### ##### ##### ##### #####

Match.new #####12##### ##### #####

```
def packet_in(datapath_id, packet_in)
...
send_flow_mod_add(
    datapath_id,
    match: Match.new(
        in_port: packet_in.in_port,
```

```
#####
```

```
source_mac_address: packet_in.source_mac_address,  
destination_mac_address: packet_in.destination_mac_address,  
...  
#####
```

```
#####1#####12##### ##### ##### ##### ##### ##### #####  
##### ##### ##### ##### #####  
#####
```

```
def packet_out(datapath_id, packet_in)  
    send_flow_mod_add(  
        datapath_id,  
        match: ExactMatch.new(packet_in),  
        ...  
    )  
#####
```



```
##### ##### ##### 1.0 ##### 1.3 #####  
##### ##### #####  
#####
```

(#####1.0)

```
##### send_flow_mod_add ##### actions: #####  
#3#  
#####
```

```
send_flow_mod_add(  
    datapath_id,  
    ...  
    actions: ##### ①  
)  
###
```

```
send_flow_mod_add(  
    datapath_id,  
    ...  
    actions: [#####0, #####1, #####2, ...] ②  
)  
#####
```

① actions: ##### 1 #
② actions: #####
#####

```
#####2##### ##### ##### ##### ##### ##### #####  
##### ##### ##### ##### ##### ##### #####  
#####
```

③ #####1.0 ##### ##### ##### ##### ##### #####

#####

#####

```
send_flow_mod_add(  
    datapath_id,  
    ...  
    actions: [StripVlanHeader.new, SendOutPort.new(2)] ❶  
)
```

① ##### 2 ####

######5#3#13#####

5.3.

#####

####

```
##### buffer_id: ##### send_flow_mod_add ##### #####
# ##### ##### ##### ##### ##### ##### ##### #####
```

```
send_flow_mod_add(  
    datapath_id,  
    match: ...,
```

#####

actions: ...,

buffer_id: packet_in.buffer_id **①**
)

```
① ##### #### ##### ###### #### ## ####  
send_flow_mod_add ################5#4#####
```

#####



```
#####1.0 ##2##### ###### ##### ###### ##### ###### #####  
##### ##### ##### ##### ##### ##### ##### ##### 1.3 #####  
##8#####1.3##### ##### ##### #####
```

5.5.

```
#####
##### packet_in #####
### 1 #####
#####
multi_threaded_packet_in #####
#####

def start(_args)
  @db = DB.new ①
end

# ##### packet_in #####
def multi_threaded_packet_in(datapath_id, packet_in) ②
  # !!! ### @db #### !!!
  return if @db.lookup(packet_in.in_port)
  @db.add packet_in.source_mac_address, packet_in.in_port
end

① #####
② #####
#####
```

5.5.1.

```
#####
##### #####
#####
#####

def start(_args)
  @db = DB.new
  @mutex = Mutex.new ①
end

def multi_threaded_packet_in(datapath_id, packet_in)
  @mutex.synchronize do ②
    # #####@db#####
    return if @db.lookup(packet_in.in_port)
    @db.add packet_in.source_mac_address, packet_in.in_port
  end
end
```

#####

end

```
① ##### #####
② do...end ##### 1 #####
#####
##### packet_in #####
##### #####
```

```
def start(_args)
  @db = DB.new
  @mutex = Mutex.new
end
```

```
def packet_in(datapath_id, packet_in)
    Thread.start do ❶
        @mutex.synchronize do
            return if @db.lookup(packet_in.in_port)
            @db.add packet_in.source_mac_address, packet_in.in_port
        end
    end
end
```

```
① packet_in #####  
##### Thread.start ##### ## #####  
Tread.new #####
```

```
##### packet_in #####  
##### packet_in #####
```

```
def start(_args)
  @db = DB.new
  @mutex = Mutex.new
  @work_queue = Queue.new ❶
  10.times { start_worker_thread } ❷
end
```

```
def packet_in(datapath_id, packet_in)
    @work_queue.push [datapath_id, packet_in] ③
end
```

private

#####

def start worker thread ④

```
#####
```

```
Thread.new do
  loop do
    datapath_id, packet_in = @work_queue.pop ⑤
    @mutex.synchronize do
      next if @db.lookup(packet_in.in_port)
      @db.add packet_in.source_mac_address, packet_in.in_port
    end
  end
end
```

```
① #####
② ##### 10 #####
③ ##### # # ##### ##### _ ## # ##### # # #####
④ #####
⑤ ##### ##### _ ##### _ ## # ##### # # ##### ##### _ #####
## @mutex.synchronize do ... end #####
##### ##### ##### ##### ##### ##### #####
##### ##### _ ##### _ ##### .##
```

```
# A simple openflow controller for benchmarking (multi-threaded version).
```

```
class MultiThreadedCbench < Trema::Controller
```

```
  def start(_args)
    @work_queue = Queue.new
    10.times { start_worker_thread }
    logger.info 'Cbench started.'
  end
```

```
  def packet_in(datapath_id, packet_in)
    @work_queue.push [datapath_id, packet_in]
  end
```

```
  private
```

```
  def start_worker_thread
    Thread.new do
      loop do
        datapath_id, packet_in = @work_queue.pop
        send_flow_mod_add(datapath_id,
          match: ExactMatch.new(packet_in),
          buffer_id: packet_in.buffer_id,
          actions: SendOutPort.new(packet_in.in_port + 1))
      end
    end
```

#####

end

#####

```
$ ./bin/trema run lib/multi_threaded_cbench.rb
```

#####

```
$ ./bin/cbench --port 6653 --switches 1 --loops 10 --ms-per-test 10000 --delay 1000 --throughput  
cbench: controller benchmarking tool
```

running in mode 'throughput'

connecting to controller at localhost:6653

faking 1 switches :: 10 tests each; 10000 ms per test

with 100000 unique source MACs per switch

starting test with 1000 ms delay after features_reply

ignoring first 1 "warmup" and last 0 "cooldown" loops

debugging info is off

1 switches: fmods/sec: 748 total = 0.074746 per ms

1 switches: fmods/sec: 714 total = 0.071319 per ms

1 switches: fmods/sec: 705 total = 0.070448 per ms

1 switches: fmods/sec: 704 total = 0.070376 per ms

1 switches: fmods/sec: 718 total = 0.071747 per ms

1 switches: fmods/sec: 734 total = 0.073346 per ms

1 switches: fmods/sec: 739 total = 0.073763 per ms

1 switches: fmods/sec: 736 total = 0.073487 per ms

1 switches: fmods/sec: 732 total = 0.073146 per ms

1 switches: fmods/sec: 730 total = 0.072917 per ms

RESULT: 1 switches 9 tests min/max/avg/stdev = 70.3

```
#####
#####
```

5.6.

```
#####
##### send_flow_mod_add #
#####2 #
##### send_message #####
#####
##
```

```
####/#_ ####.##  
  
# A simple openflow controller for benchmarking (fast version).  
class FastCbench < Trema::Controller  
  def start(_args)  
    logger.info "#{name} started."  
  end  
  
  def packet_in(dpid, packet_in)  
    @flow_mod ||= create_flow_mod_binary(packet_in) ❶  
    send_message dpid, @flow_mod ❷  
  end  
  
  private  
  
  def create_flow_mod_binary(packet_in)  
    options = {  
      command: :add,  
      priority: 0,  
      transaction_id: 0,  
      idle_timeout: 0,  
      hard_timeout: 0,  
      buffer_id: packet_in.buffer_id,  
      match: ExactMatch.new(packet_in),  
      actions: SendOutPort.new(packet_in.in_port + 1)  
    }  
    FlowMod.new(options).to_binary.tap do |flow_mod| ❸  
      def flow_mod.to_binary  
        self  
      end  
    end  
  end  

```

- ❶ ### @flow_mod # nil ##### create_flow_mod_binary # #### ## #####!
 - #####
 - ❷ ##### ## ##### ##### ##### #####
 - ❸ send_message ##### ##### ##### FlowMod#to_binary #####
 - #####
-

cbench: controller benchmarking tool
running in mode 'throughput'
connecting to controller at localhost:6653

#####

faking 1 switches :: 10 tests each; 10000 ms per test
with 100000 unique source MACs per switch
starting test with 1000 ms delay after features_reply
ignoring first 1 "warmup" and last 0 "cooldown" loops
debugging info is off

```
1 switches: fmods/sec: 6741 total = 0.674018 per ms
1 switches: fmods/sec: 6400 total = 0.639859 per ms
1 switches: fmods/sec: 6508 total = 0.650710 per ms
1 switches: fmods/sec: 6334 total = 0.633349 per ms
1 switches: fmods/sec: 6325 total = 0.632465 per ms
1 switches: fmods/sec: 6293 total = 0.629207 per ms
1 switches: fmods/sec: 6276 total = 0.627579 per ms
1 switches: fmods/sec: 6332 total = 0.633133 per ms
1 switches: fmods/sec: 6219 total = 0.621860 per ms
1 switches: fmods/sec: 6293 total = 0.629266 per ms
RESULT: 1 switches 9 tests min/max/avg/stdev = 621.86/650.71/633.05/7.77 responses/s
```



#####

5.7. ####

- ##### send flow mod add #####

#####

- #####
- #####
- #####

#####

#####

6.

#####



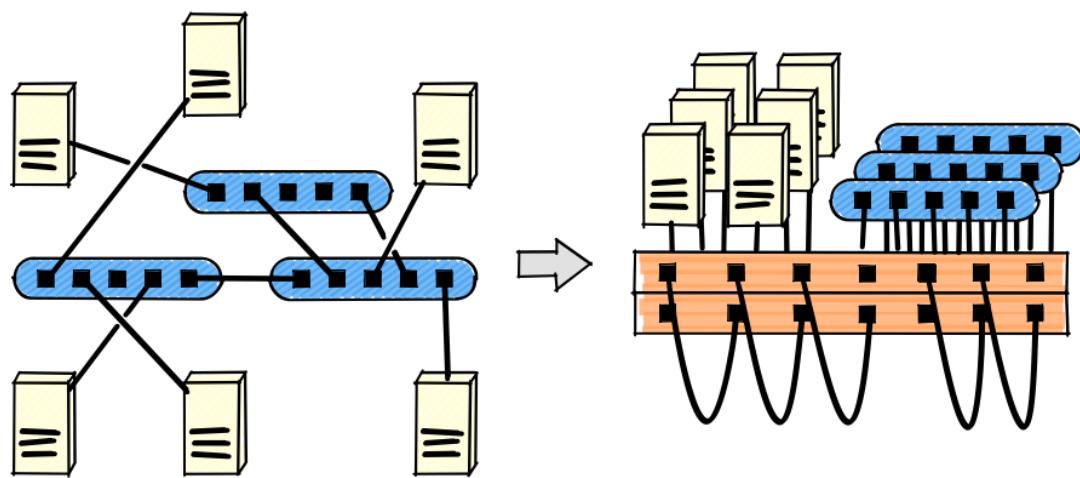
6.1.

#####

(# 6#1)#####

#####

#####



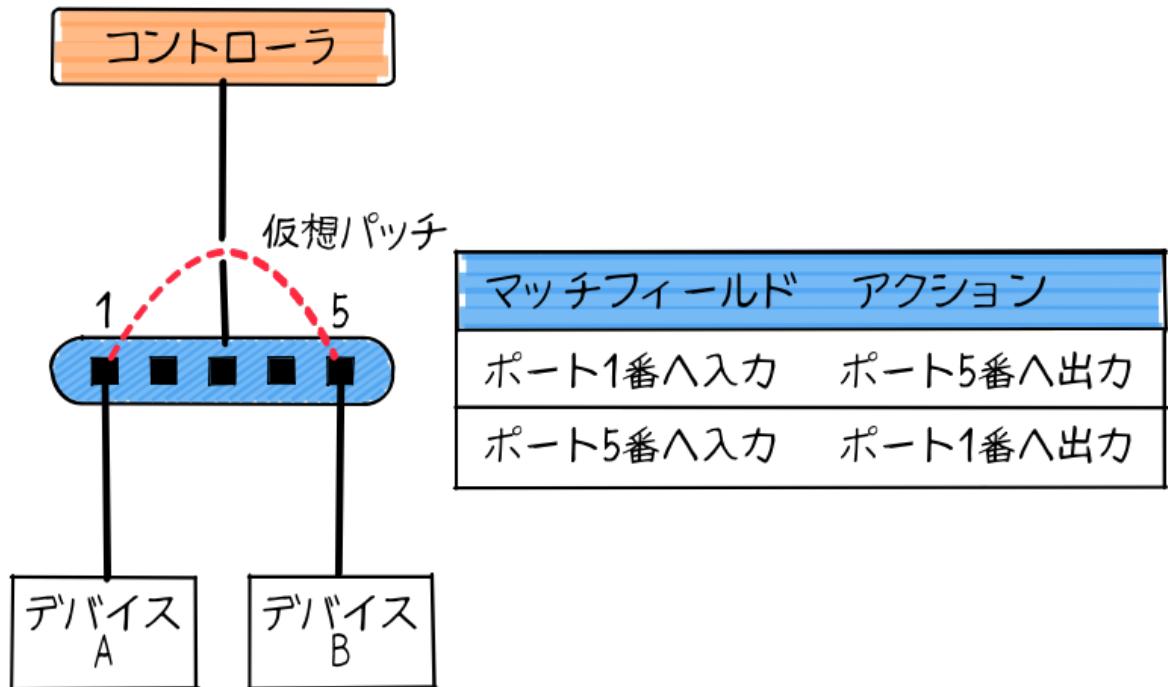
6.1.

#####

6.2. #####

#####

6#2 #####(#####
#####)#####(#####
##



6.2.

6#2 #####1##5#####2#####

- #####1#####5#####
- #####5#####1#####

#####

#####

#####

#####

#####

6.3.

#####/##### _ ##### (#####://#####.###/#####/
_ #####)

\$ git clone https://github.com/trema/patch_panel.git

bundle install --binstubs

\$ cd patch_panel

```
#####
```

```
$ bundle install --binstubs
```

```
.....
```

```
#####
```

```
##### 3 ####
```

- lib/patch_panel.rb : #####
- patch_panel.conf : #####
- bin/patch_panel : #####

6.3.1.

```
##### patch_panel.conf #####
```

```
## vhost ##### link #####
```

```
#####_#####.#####
```

```
.....
```

```
vswitch('patch_panel') { datapath_id 0xabc }
```

```
vhost ('host1') { ip '192.168.0.1' }
vhost ('host2') { ip '192.168.0.2' }
vhost ('host3') { ip '192.168.0.3' }
```

```
link 'patch_panel', 'host1'
link 'patch_panel', 'host2'
link 'patch_panel', 'host3'
```

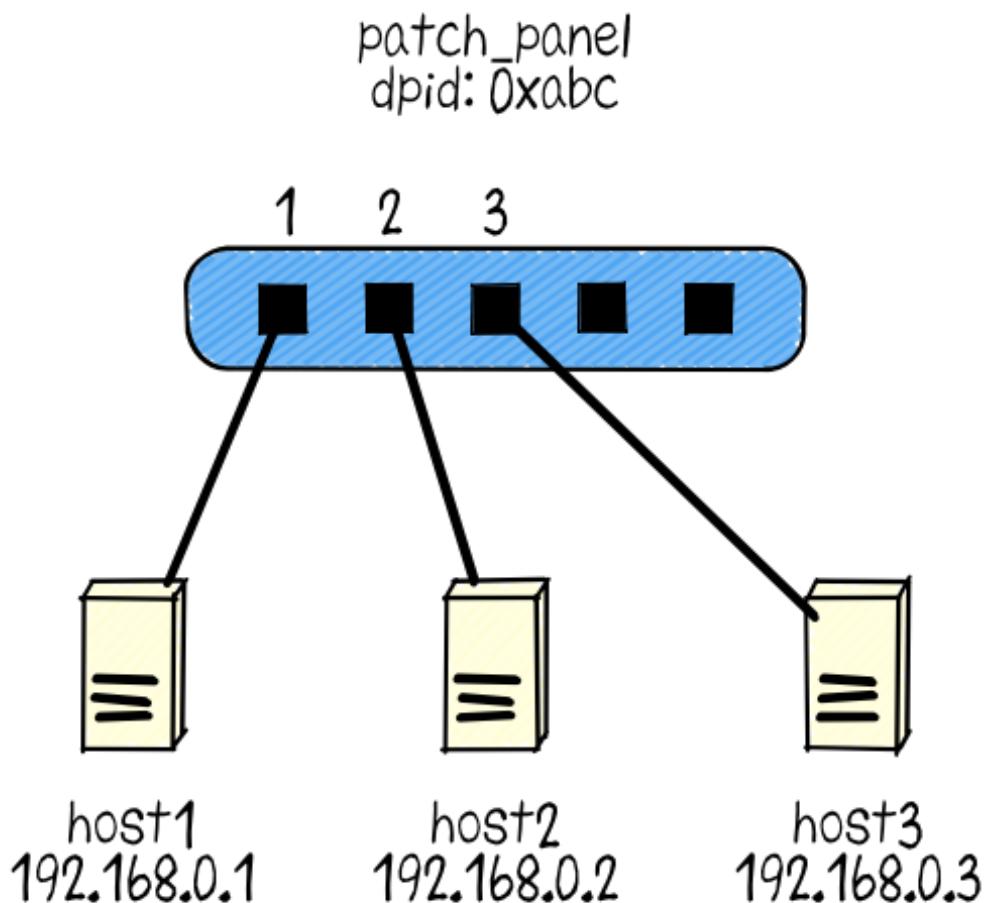
```
.....
```

```
##### 0xabc # 3 ##### host1 , host2 , host3 ##### (# 6#3)#####
```

```
##### ( link #####) ##### link ##### 1 ##### 2 ##
```

```
## 3 ##... #####
```

#####



6.3. ##### ##### ##### #####.##### ##### ##### #####

```
##### trema run # -c #####
trema run #####
```

```
$ ./bin/trema run ./lib/patch_panel.rb -c patch_panel.conf
```

```
##### trema send_packets  
#####1#####2#####
```

```
$ ./bin/trema send_packets --source host1 --dest host2  
$ ./bin/trema send_packets --source host2 --dest host1
```

```
#####O##### trema show stats #####
```

```
$ ./bin/trema show_stats host1  
Packets sent:
```

```
#####
```

```
192.168.0.1 -> 192.168.0.2 = 1 packet
```

```
$ ./bin/trema show_stats host2
```

```
Packets sent:
```

```
192.168.0.2 -> 192.168.0.1 = 1 packet
```

```
trema show_stats #####1 # ####2 #####1 ##  
#####
```

```
##### ./bin/patch_panel ##### 0#### 1 #### 2 #####  
#####
```

```
$ ./bin/patch_panel create 0xabc 1 2
```

```
#####1 # ####2 #####
```

```
$ ./bin/trema send_packets --source host1 --dest host2
```

```
$ ./bin/trema send_packets --source host2 --dest host1
```

```
$ ./bin/trema show_stats host1
```

```
Packets sent:
```

```
192.168.0.1 -> 192.168.0.2 = 2 packets
```

```
Packets received:
```

```
192.168.0.2 -> 192.168.0.1 = 1 packet
```

```
$ ./bin/trema show_stats host2
```

```
Packets sent:
```

```
192.168.0.2 -> 192.168.0.1 = 2 packets
```

```
Packets received:
```

```
192.168.0.1 -> 192.168.0.2 = 1 packet
```

```
#####
```

6.4.

```
##### ####_ #####.#####
```

```
####_ #####.##
```

```
# Software patch-panel.
```

```
class PatchPanel < Trema::Controller
```

```
def start(_args)
```

```
  @patch = Hash.new{}.freeze
```

```
  logger.info "#{name} started."
```

```
end
```

```
#####
```

```
def switch_ready(dpid)
    @patch[dpid].each do |port_a, port_b|
        delete_flow_entries dpid, port_a, port_b
        add_flow_entries dpid, port_a, port_b
    end
end

def create_patch(dpid, port_a, port_b)
    add_flow_entries dpid, port_a, port_b
    @patch[dpid] += [port_a, port_b].sort
end

def delete_patch(dpid, port_a, port_b)
    delete_flow_entries dpid, port_a, port_b
    @patch[dpid] -= [port_a, port_b].sort
end

private

def add_flow_entries(dpid, port_a, port_b)
    send_flow_mod_add(dpid,
        match: Match.new(in_port: port_a),
        actions: SendOutPort.new(port_b))
    send_flow_mod_add(dpid,
        match: Match.new(in_port: port_b),
        actions: SendOutPort.new(port_a))
end

def delete_flow_entries(dpid, port_a, port_b)
    send_flow_mod_delete(dpid, match: Match.new(in_port: port_a))
    send_flow_mod_delete(dpid, match: Match.new(in_port: port_b))
end
```

```
#####
```

- #####
- #####3 #####, #####!##### switch_ready ##### delete_flow_entries
add_flow_entries
- create_patch # delete_patch #####
- add_flow_entries ##### send_flow_mod_add #2#####1#####2#####
#####2#####

```
#####
```

```
#####
#####
```

6.4.1.

```
#####
#####
```

```
##### (##/#### _ ####.##)
```

```
def start(_args)
  @patch = Hash.new([]).freeze
  logger.info "#{name} started."
end
```

```
@patch ##### (##) ##### 0#1 #### 1 ## 4 ##### 0#2 #### 1 ## 2 #### 3 ## 4
##### @patch #####
```

| | |
|---------------|------------------|
| ##### ## (##) | ##### (####) |
| 0#1 | [[1, 4]] |
| 0#2 | [[1, 2], [3, 4]] |



```
##### Hash.new([]).freeze
```

```
Hash.new ### (#####) ### [].freeze #####
## #### ##### .freeze ##### [] #### << #####
##### ##### ##### #####
```

```
hash = Hash.new([])
```

```
p hash[1]    #=> []
p hash[1] << "bar" #=> ["bar"]
p hash[1]    #=> ["bar"]
```

```
p hash[2]    #=> ["bar"] ##### ["bar"] #####
#####
```

```
##### .freeze #####
```

```
hash = Hash.new([]).freeze
hash[0] += [0] #####OK
hash[1] << 1
# ### `<<` can't modify frozen array (TypeError)
```

```
#####
```

6.4.2.

```
##### ( {} ) ##### : #####
#####
animals = { armadillo: '#####', boar: '#####' }

#####
##### #####? #####
#####
animals[:boar] #=> "####"

#####
##### (#### :boar) ##### (#####) #####
#####
animals[:cow] = '##'

#####
##### @patch[0x1] = [[1, 2], [3, 4]]

#####
##### send_flow_mod_add      #####
( :) #####
#####
# def flow_mod(message, port_no)
#   send_flow_mod_add(
#     message.datapath_id,
#     match: ExactMatch.new(message),
#     actions: SendOutPort.new(port_no)
#   )
# end

# #####
# def flow_mod(message, port_no)
#   send_flow_mod_add(
#     message.datapath_id,
#     { match: ExactMatch.new(message),
```

```
actions: SendOutPort.new(port_no) }  
)  
end
```

6.4.3. ##### _

```
switch_ready ##### @patch #####  
#####(#####)#####  
#####_##### (###/#####_#####.##)
```

```
def switch_ready(dpid)  
  @patch[dpid].each do |port_a, port_b| ①  
    delete_flow_entries dpid, port_a, port_b ②  
    add_flow_entries dpid, port_a, port_b ③  
  end  
end
```

- ① @patch[dpid].each ##### 1 ##### (##)##### port_a # port_b #2#####
1
- ② ##### delete_flow_entries #####
- ③ ##### add_flow_entries ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####2#####

6.4.4.

```
#####
```

```
#####
```

```
fruits = ["##", "##", "##"]
```

```
fruits.each do |each|  
  puts each  
end
```

```
####:  
##  
##  
##
```

```
##### fruits # each ##### fruits ##### do ##### each # #####  
##### each ##### (do...end) #####
```

```

#####
#####
#####
```

#####

```

for (int i = 0; i < 3; i++) {
    puts fruits[i];
}
```

```

##### #### ##### #### i ##### i < 3 #####
#####
#####
```

##5 #####

```

# start_worker_thread ##### 10 #####
10.times { start_worker_thread }

#####
# n ## 1#10 ##### n #####
10.times { |n| start_worker_thread }
```

```

## times ##### 10 ##### ## #####
# 10.times { start_worker_thread } (10 # #####_#####_##### ##)#####
#####
#####
```

6.4.5. ###_###_#####

```

1#####(2#####)##### add_flow_entries #####
#####
#####_####_(###/####_.##)

def add_flow_entries(dpid, port_a, port_b)
    send_flow_mod_add(dpid,
        match: Match.new(in_port: port_a),
        actions: SendOutPort.new(port_b))
    send_flow_mod_add(dpid,
        match: Match.new(in_port: port_b),
        actions: SendOutPort.new(port_a))
end

add_flow_entries ###2##### send_flow_mod_add #####
#####
#####_####_(###/####_.##)
```

```
#####
```

```
send_flow_mod_add(dpid,  
    match: Match.new(in_port: port_a),  
    actions: SendOutPort.new(port_b))
```

```
##### port_a ##### port_b #####2#####  
#####
```

- match : #####(:in_port) # port_a ##### Match #####
- actions : ##### port_b ##### SendOutPort #####

6.4.6. ##### _ ##### _ #####

```
delete_flow_entries ##### add_flow_entries #####  
delete_flow_entries #####
```

```
##### _ ##### (###/##### _ #####.##)
```

```
def delete_flow_entries(dpid, port_a, port_b)  
    send_flow_mod_delete(dpid, match: Match.new(in_port: port_a))  
    send_flow_mod_delete(dpid, match: Match.new(in_port: port_b))  
end
```

```
##### send_flow_mod_delete # send_flow_mod_add ##### match: #####  
#####
```

6.4.7. ##### _ #####, ##### _ #####

```
create_patch # delete_patch ##### bin/patch_panel #####
```

```
create_patch ##### add_flow_entries ##### @patch #####
```

```
##### _ ##### (###/##### _ #####.##)
```

```
def create_patch(dpid, port_a, port_b)  
    add_flow_entries dpid, port_a, port_b  
    @patch[dpid] += [port_a, port_b].sort  
end
```

```
## delete_patch #####
```

```
##### _ ##### (###/##### _ #####.##)
```

```
def delete_patch(dpid, port_a, port_b)
```

```
#####
```

```
delete_flow_entries dpid, port_a, port_b  
@patch[dpid] -= [port_a, port_b].sort  
end
```

6.4.8. #####_##### #####

```
PatchPanel ##### bin/patch_panel #### PatchPanel ##### create_patch #  
delete_patch ##### patch_panel create # patch_panel delete ### 2 #####  
####  
##### ##### (#####://#####.###/#####5000/##) ##### ##### ##### #####  
## patch_panel create # patch_panel delete ##### ##### ##### #####  
### ##### ##### ##### ##### ##### ##### #####  
#####_#####  
#!/usr/bin/env ruby  
  
require 'rubygems'  
require 'bundler'  
Bundler.setup :default  
  
require 'gli'  
require 'trema'  
  
# patch_panel command  
module PatchPanelApp  
extend GLI::App  
  
desc 'Creates a new patch' ①  
arg_name 'dpid port#1 port#2'  
command :create do |c|  
  c.desc 'Location to find socket files'  
  c.flag [:S, :socket_dir], default_value: Trema::DEFAULT_SOCKET_DIR  
  
  c.action do |_global_options, options, args|  
    dpid = args[0].hex  
    port1 = args[1].to_i  
    port2 = args[2].to_i  
    Trema.trema_process('PatchPanel', options[:socket_dir]).controller.  
      create_patch(dpid, port1, port2)  
end  
end  
  
desc 'Deletes a patch' ②
```

```

#####
arg_name 'dpid port#1 port#2'
command :delete do |c|
  c.desc 'Location to find socket files'
  c.flag [:S, :socket_dir], default_value: Trema::DEFAULT_SOCKET_DIR

  c.action do |_global_options, options, args|
    dpid = args[0].hex
    port1 = args[1].to_i
    port2 = args[2].to_i
    Trema.trema_process('PatchPanel', options[:socket_dir]).controller.
      delete_patch(dpid, port1, port2)
  end
end

exit run(ARGV)
end

```

① create #####
 ② delete #####
command ##### do ... end #####

#####

desc 'Creates a new patch' ①
arg_name 'dpid port#1 port#2' ②
command :create do |c|
 c.desc 'Location to find socket files' ③
 c.flag [:S, :socket_dir], default_value: Trema::DEFAULT_SOCKET_DIR ④

c.action do |_global_options, options, args|
 dpid = args[0].hex ⑤
 port1 = args[1].to_i ⑥
 port2 = args[2].to_i ⑦
 Trema.trema_process('PatchPanel', options[:socket_dir]).controller.
 create_patch(dpid, port1, port2) ⑧
end
end

① create #####
② #####
③ -S (--socket_dir) #####
④ -S (--socket_dir) ##### ##### #####

```
#####
```

⑤⑥⑦#####

⑧ PatchPanel ##### create_patch #####
PatchPanel

```
Trema.trema_process('PatchPanel', options[:socket_dir]).controller.create_patch(dpid, port1, port2)
```

```
## Trema.trema_process.controller #####( PatchPanel #####)  
##### create_patch #####
```

6.5.

```
#####
```

- #####
- #####
- #####

```
#####  
#####  
#####
```

```
##### 3 ##### ##### ##### #### #, ##### ##, ##### ### ##### ####
```

7.

##



7.1.

#####

- #####
- #####

##

#####

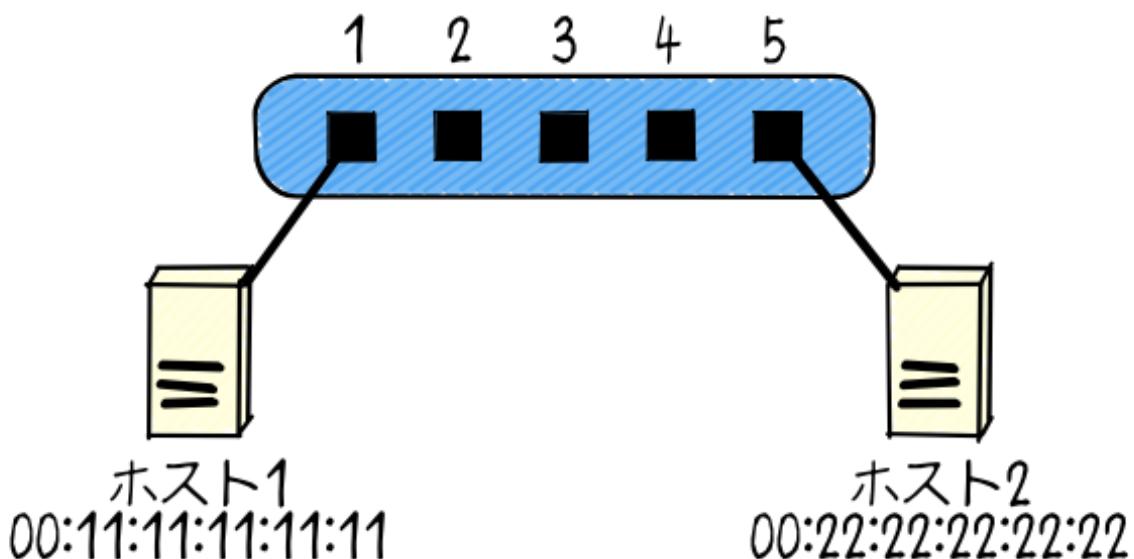
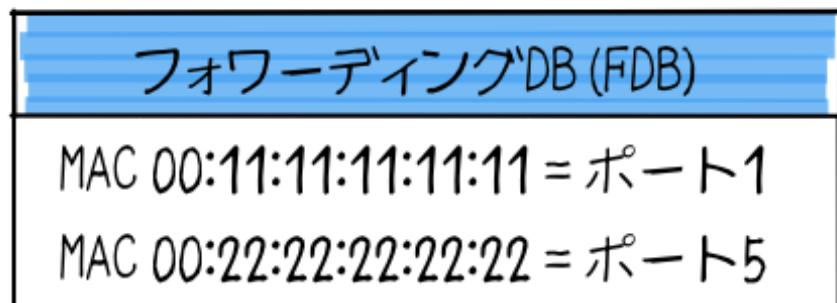
- ### ([12#](#), [13#](#), [14#](#))
- ##### ([16#](#))
- ##### ([17#](#))

#####
#####

#####
#####

7.2.

#####(# 7#1)#
#####



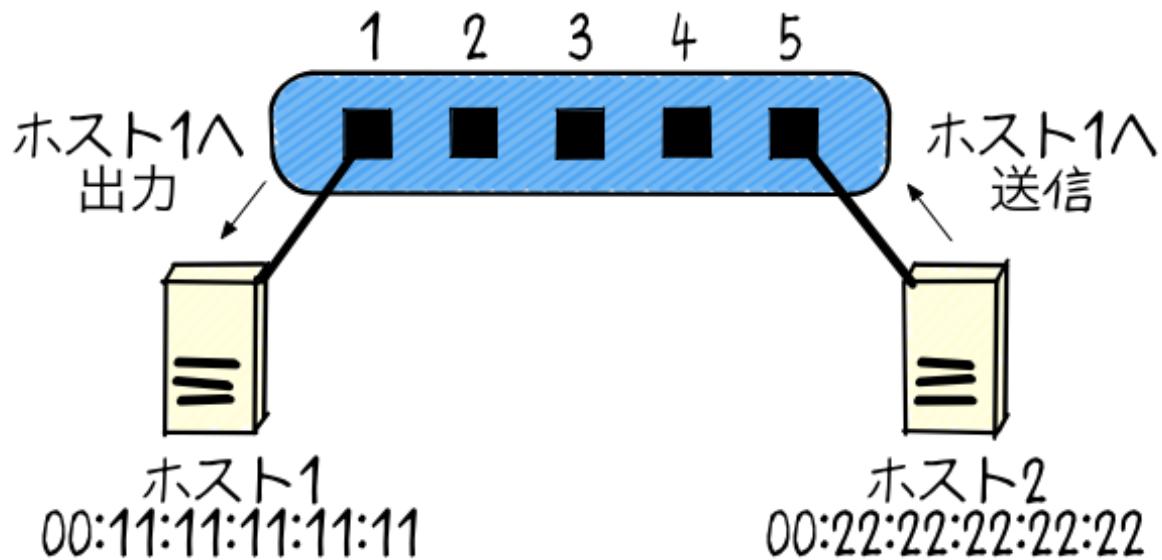
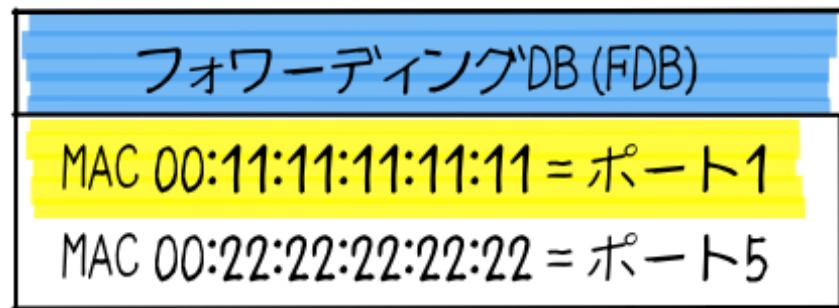
7.1. #####1#####2#####3#####4#####5#####

#####1#####5#####1#####2#####3#####4#####5#####

#####
#####(##)#####+#####
#####

#####2#####1#####3#####4#####5##### 7#2#####1#####

1. #####(00:11:11:11:11:11)#####
2. #####00:11:11:11:11:11=#####1#####1#####1#####



7.2. #####1#####

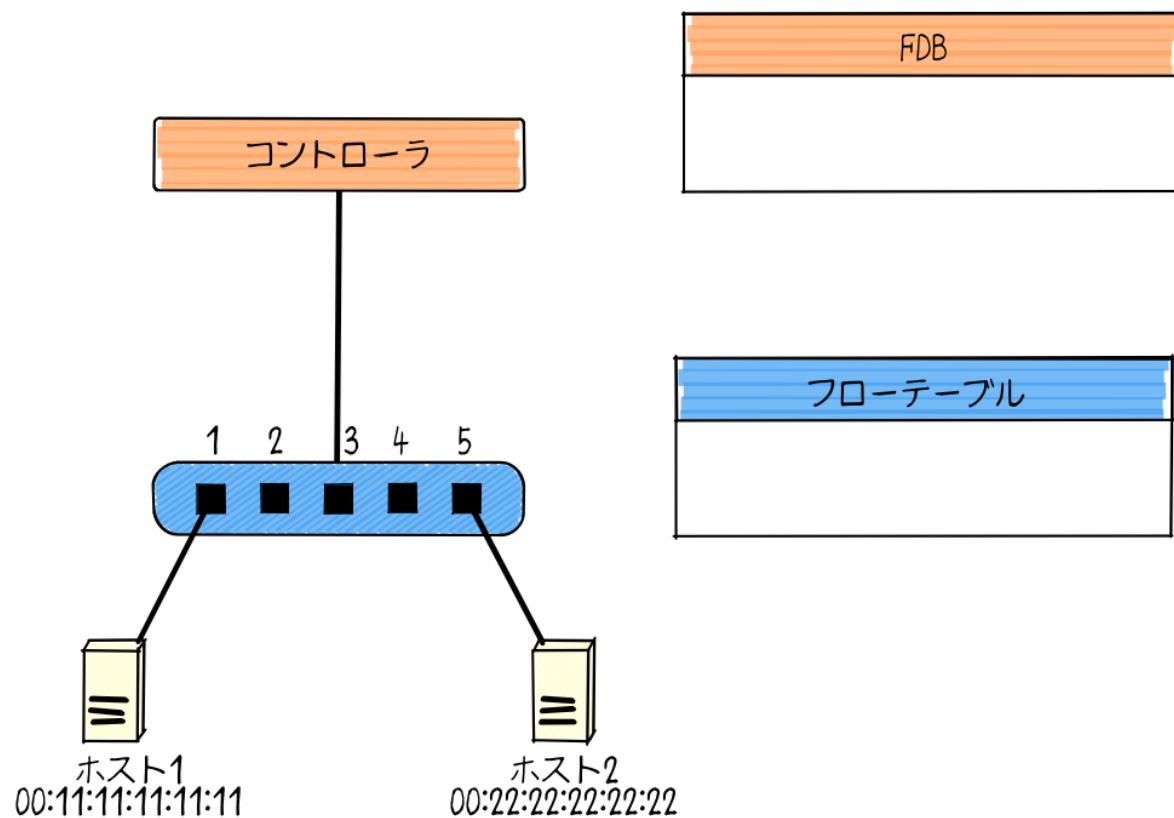
(#####)

7.3. #####(#####)#####

7#3#####2#####

- #####
- #####

#####



7.3. #####(#####)###

#####

7.3.1.

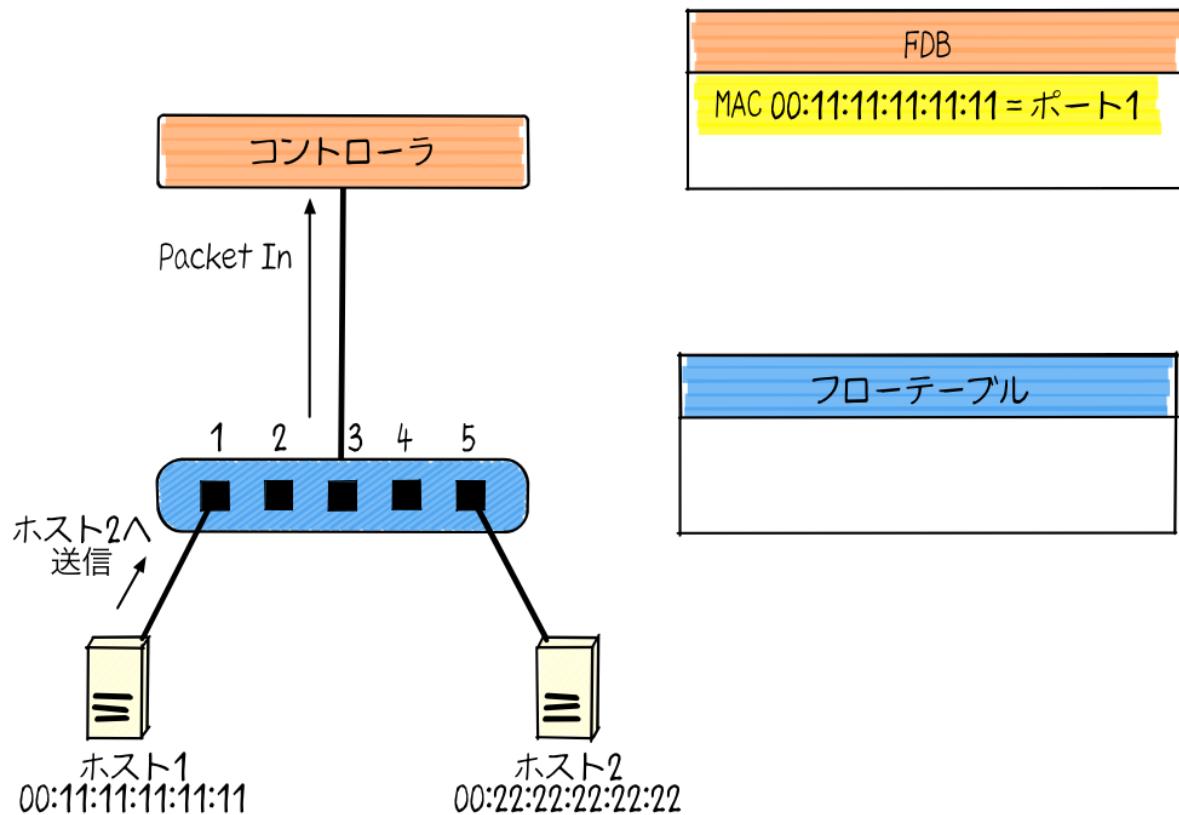
#####1#####2#####1#####(# 7#4) #

1. #####

2. #####1#####1#####

#00:11:11:11:11:11#####

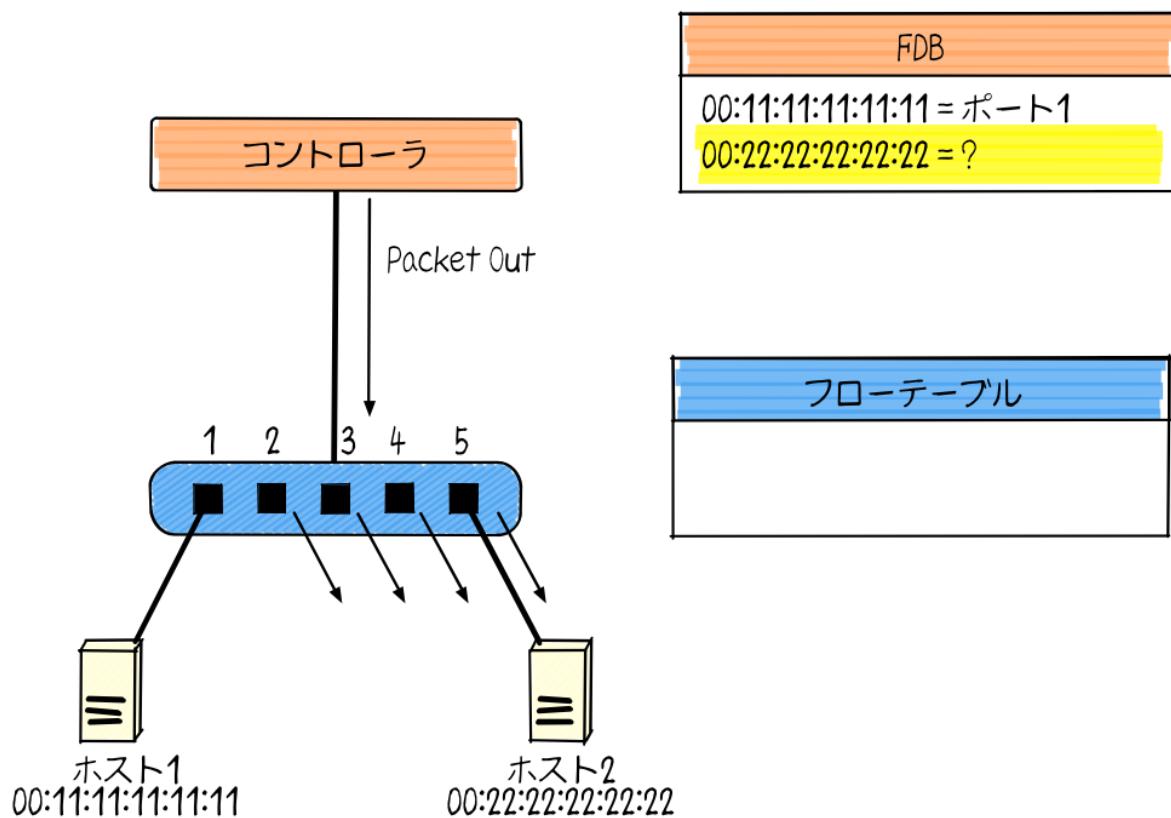
#####



7.3.2. #####(#####)

#####(# 7#5)##

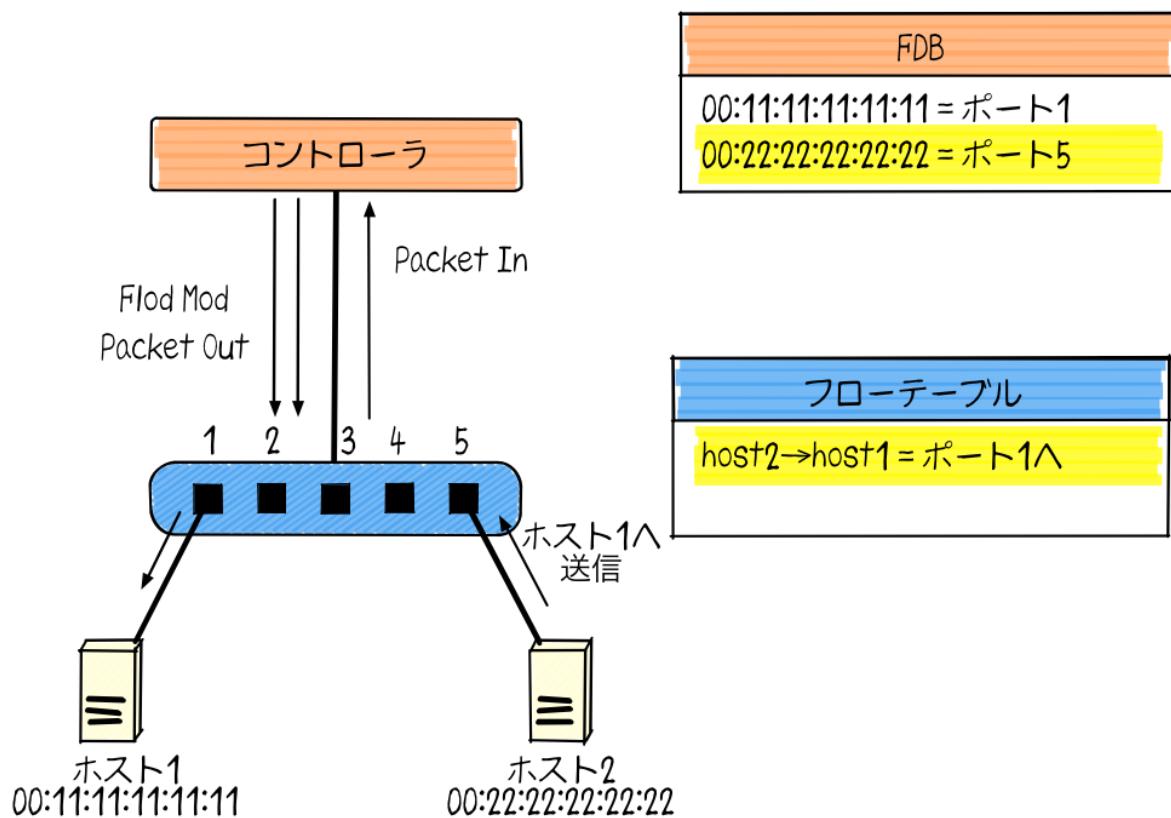
1. #####2#####
 2. #####5#2#####



7.3.3. #####(#### ###### ####)

#####2#####1#####(# 7#6)##

1. #####
 2. #####5#####00:22:22:22:22#####
####
 3. ##### #1=#####
00:11:11:11:11#####1#####
 4. #####1#####1#####
#####(#### = 1)#####1#####



7.6. #####1#
###

#####2#####1#####1#####2#####
#1#####

#####1#####2#####3#####4#####5#####6#####7#####8#####9#####
1#####2#####3#####4###### 7#6#####5#####
#####

7.4.

```
#####
##### _ ##### ( #####:#####.###/#####/#####_ ####) #####
```

```
$ git clone https://github.com/trema/learning_switch.git
```

```
##### bundle install --binstubs #####
```

```
$ cd learning_switch  
$ bundle install --binstub
```

```
#####
```

```
#####1#####2##### trema.conf #####
####
```

```
#####.####
```

```
vswitch('lsw') {
    datapath_id 0xabc
}
```

```
vhost ('host1') {
    ip '192.168.0.1'
}
```

```
vhost ('host2') {
    ip '192.168.0.2'
}
```

```
link 'lsw', 'host1'
link 'lsw', 'host2'
```

```
##### trema run # -c #####
```

```
$ ./bin/trema run ./lib/learning_switch.rb -c trema.conf
```

```
##### trema send_packets #####1#####2#####
```

```
$ ./bin/trema send_packets --source host1 --dest host2
$ ./bin/trema send_packets --source host2 --dest host1
```

```
trema show_stats #####1#####2#####
```

```
$ ./bin/trema show_stats host1
```

```
Packets sent:
```

```
192.168.0.1 -> 192.168.0.2 = 1 packet
```

```
Packets received:
```

```
192.168.0.2 -> 192.168.0.1 = 1 packet
```

```
$ ./bin/trema show_stats host2
```

```
Packets sent:
```

```
192.168.0.2 -> 192.168.0.1 = 1 packet
```

```
Packets received:
```

```
192.168.0.1 -> 192.168.0.2 = 1 packet
```

```
#####
```

7.5.

```
#####
#####_#####_#####.## # #####/##.## # 2 #####
(#####/#####_#####.##) #####_##### #### private #####
#####/#####_#####.##

require 'fdb'

# An OpenFlow controller that emulates an ethernet switch.
class LearningSwitch < Trema::Controller
  timer_event :age_fdb, interval: 5.sec

  def start(_argv)
    @fdb = FDB.new
    logger.info "#{name} started."
  end

  def switch_ready(datapath_id)
    # Drop BPDU frames
    send_flow_mod_add(
      datapath_id,
      priority: 100,
      match: Match.new(destination_mac_address: '01:80:C2:00:00:00')
    )
  end

  def packet_in(_datapath_id, packet_in)
    @fdb.learn packet_in.source_mac, packet_in.in_port
    flow_mod_and_packet_out packet_in
  end

  def age_fdb
    @fdb.age
  end

  private

  def flow_mod_and_packet_out(packet_in)
    port_no = @fdb.lookup(packet_in.destination_mac)
    flow_mod(packet_in, port_no) if port_no
    packet_out(packet_in, port_no || :flood)
  end

  def flow_mod(packet_in, port_no)
    send_flow_mod_add(

```

```
packet_in.datapath_id,
match: ExactMatch.new(packet_in),
actions: SendOutPort.new(port_no)
)
end

def packet_out(packet_in, port_no)
send_packet_out(
  packet_in.datapath_id,
  packet_in: packet_in,
  actions: SendOutPort.new(port_no)
)
end
end
```

#####

- ##### LearningSwitch #####
 - ##### start ##### lib/fdb.rb #####
 - ##### swtich_ready ##### 01:80:C2:00:00:00 #####
#####
 - packet_in ##### flow_mod_and_packet_out ##### @fdb #####
flow_mod # packet_out ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####
#####(#####)##### :flood #####

```
##### packet_in ##### 3 #####
##### #####
```


7.5.1. #####(##### ##)###

1. ##### (@fdb) #####
 2. ##### (@fdb.lookup #####)

#####

#####_####_#####_##, #####_###_##_#####_## (##/
#####_#####.##)

```
def packet_in(_datapath_id, packet_in)
    @fdb.learn packet_in.source_mac, packet_in.in_port
    flow_mod_and_packet_out packet_in
end
```

```
def flow_mod_and_packet_out(packet_in)
    port_no = @fdb.lookup(packet_in.destination_mac)
    flow_mod(packet_in, port_no) if port_no
    packet_out(packet_in, port_no || :flood)
end
```

#####(##### #####)

```
##### ( flow_mod ####)##  
##### ( packet_out ####)#
```

#####(####/######)#####(####/######)#####(####/######)#####(####/######)

```
def flow_mod_and_packet_out(packet_in)
    port_no = @fdb.lookup(packet_in.destination_mac)
    flow_mod(packet_in, port_no) if port_no
    packet_out(packet_in, port_no || :flood)
end
```

```
## flow_mod ##### packet_out ##### send_flow_mod_add (5 #####
#####) ### send packet out (##### #####) ##### ##### #####
```

```
def flow_mod(packet_in, port_no)
    send_flow_mod_add(
        packet_in.datapath_id,
        match: ExactMatch.new(packet_in),
        actions: SendOutPort.new(port_no)
    )
end
```

```
def packet_out(packet_in, port_no)
    send_packet_out(
        packet_in.datapath_id,
        packet_in: packet_in,
        actions: SendOutPort.new(port_no))
```

)
end

7.5.2. #####

```
#####      #####1#####
##### send_packet_out #####

```

```
send_packet_out(datapath_id, options)
```

#####

datapath_id

options

```
##### buffer_id #####  
##### #####
```

```
send_packet_out(  
    datapath_id,  
    buffer_id: packet_in.buffer_id,  
    raw_data: packet_in.raw_data,  
    actions: SendOutPort.new(port_number)  
)
```

#####
#####**2** #####
#####
#####

#####

```
##### raw_data #####
```

```
send_packet_out(  
    datapath_id,  
    raw_data: packet_in.raw_data,  
    actions: SendOutPort.new(port_number)  
)  
  
##### packet_in ##### (.raw_data #####)##
```

```
send_packet_out(  
    datapath_id,  
    packet_in: packet_in,  
    actions: SendOutPort.new(port_number)  
)
```

7.5.3.

options #####

buffer_id

```
##### (#####)
```

raw_data

```
##### ##### ##### ##### ##### ##### buffer_id ##### ##### ##### ##### ##### ##### ##### #####  
##### ##### ##### #####
```

packet_in

actions

1 ##### ##### #####

(#####)

```
#####
##### flow_mod_and_packet_out :flood packet_out #####
## :flood #####
#####
##### #####
#### (###/##### ####.##)
```

```
def flow_mod_and_packet_out(packet_in)
    port_no = @fdb.lookup(packet_in.destination_mac)
    flow_mod(packet_in, port_no) if port_no
```

```

packet_out(packet_in, port_no || :flood)
end
.....
```

7.5.4. ###

```

#####
#####_#####.## ##### require 'fdb' ###### ##### ## ##### require #####
# #include # ##### import ##### ##### ##### ##### ##### ##### ##### #####
##### .## ##### require 'fdb' ##### ##### ##### ##### ##### ##### ##### #####
#####_#####/##### #####.## ##### ##### ##### require 'learning_switch/extensions' #####
#####
##### ##### ##### ##### ##### FDB #####
#####
###/###.##
# A database that keeps pairs of a MAC address and a port number
class FDB
  # Forwarding database (FDB) entry.
  class Entry
    DEFAULT_AGE_MAX = 300

    attr_reader :mac
    attr_reader :port_no

    def initialize(mac, port_no, age_max = DEFAULT_AGE_MAX)
      @mac = mac
      @port_no = port_no
      @age_max = age_max
      @last_update = Time.now
    end

    def update(port_no)
      @port_no = port_no
      @last_update = Time.now
    end

    def aged_out?
      Time.now - @last_update > @age_max
    end
  end

  def initialize
    @db = {}
  end

  def lookup(mac)
```

```

entry = @db[mac]
entry && entry.port_no
end

def learn(mac, port_no)
entry = @db[mac]
if entry
entry.update port_no
else
@db[mac] = Entry.new(mac, port_no)
end
end

def age
@db.delete_if { |_mac, entry| entry.aged_out? }
end
end

```

```

FDB #####3##### lookup # learn # age ##### lookup ##### #### #####
##### learn ##### #### ##### #### ##### #### ##### #####
##### ##### ( FDB::Entry#aged_out? ###) #####

```

7.5.5.

```

switch_ready ##### #### 01:80:C2:00:00:00 #####
#####_#####

```

```

def switch_ready(datapath_id)
# Drop BPDU frames
send_flow_mod_add(
datapath_id,
priority: 100,
match: Match.new(destination_mac_address: '01:80:C2:00:00:00')
)
end

```

```

#####
##16 #####

```

7.6.

```

#####

```

- #####
- #####
- #####

1.3

8. #####1.3#####

#####1.3 #####1.0#####

8.1. #####1.0#####

7 #####

#####

#####1.0##### 1 #####

#####

```
#####1.0##### switch_ready #####
##### packet_in #####
#####
```

8.2.

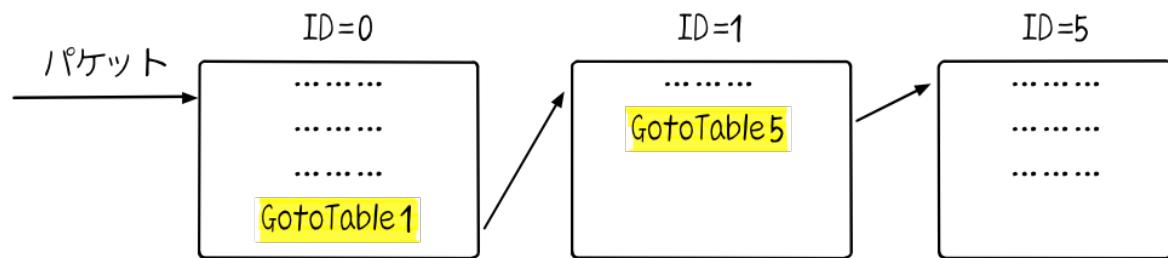
```
##### 1 ###### #####1.0 #####1.3 #####1.3 ##  
1 #####→#####→...→#####→#####  
#####
```



8.1. #####1.3#####

8.2.1.

```
#####
##### # O #####
#####
##### # O #####
#####
##### #####
#####
##### #####
#####
#####
```



8.2.2. #####1.3

#####1.3 #####

```
#####1#####
#####1.0#####
#####6##### (#8#1)#
#####
```

8.1. ##### 1.3 ##### (#####)

| | |
|------------------|---------------------|
| ##### | ## |
| SetField | ##### |
| CopyTtlOut | 2##### |
| CopyTtlIn | #####1##### |
| SetMplsTtl | ##### |
| DecrementMplsTtl | #####1#### |
| PushVlanHeader | ##### |
| PopVlanHeader | ##### |
| PushMpls | ##### |
| PopMpls | ##### |
| Group | ##### |
| SetIpTtl | ##4#####6#### |
| DecrementIpTtl | ##4#####6####1#### |
| PushPbb | ##### (####) ###### |
| PopPbb | ##### (####) ###### |

##1 ##### (#8#2)##

8.2. ##### 1.3 ##### (######)

| | |
|-------------|-------------------------|
| ##### | ## |
| SendOutPort | ##### (##) ##### |
| SetQueue | SendOutPort ##### ## |

8.2.3.

#####

```
# ##### 0 #### 1 ## GotoTable
send_flow_mod_add(
    datapath_id,
    table_id: 0,
    ...
instructions: GotoTable.new(
)
```

#####1##### 2 #####

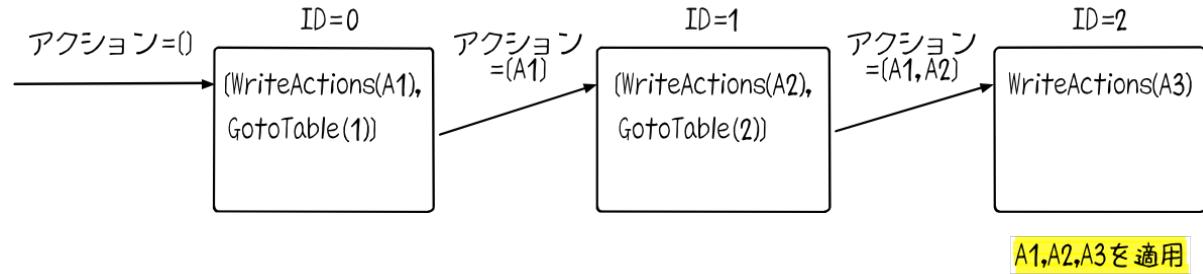
- Apply #####
 - WriteActions #####

Apply #####1.0 # ###### actions ####
#####

#####

```
# #### 1 #####
send_flow_mod_add(
    datapath_id,
    ...
instructions: Apply.new(SendOutPort.new(1))
)
```

```
WriteActions ##### ##### #####  
WriteActions ##### ##### #####  
##### ##### ##### ##### #####
```



8.3. ##### #####

```
##### ##### ##### ##### #####  
## WriteActions ##### Clear ##### ##### #####  
##### ##### #####
```

8.3. ##### 1.3 ##### #####

| | |
|-------------------|-------------------------------|
| ##### ##### ##### | ## |
| GotoTable | ##### ##### ##### ##### ##### |
| Apply | ##### ##### ##### |
| WriteActions | ##### ##### ##### ##### ##### |
| Clear | ##### ##### ##### |
| WriteMetadata | ##### ##### 64### ##### ##### |
| Meter | ##### ##### ##### ##### ##### |

8.3. #####1.3 ## ##### ##

```
#####1.3##### ##### ##### ##### ##### ##### ##### #####1.0 ##### ##### #####  
##### ##### ##### ##### ##### ##### #####1.3##### ##### ##### ##### ##### #####  
SendOutPort.new(:controller) (##### ##### ##### ##### ##### ##### ##### #####)  
##
```

8.4. #####1.3##### ##### ##### #####

```
#####1.3##### ##### ##### #####2##### ##### ##### ##### ##### ##### #####  
##### ##### #####  
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####
```

#####

#####

8.5.

#####1.3#####_#####13.#####

#####_#####13.##

require 'fdb'

An OpenFlow controller that emulates an ethernet switch.

class LearningSwitch13 < Trema::Controller

timer_event :age_fdb, interval: 5.sec

INGRESS_FILTERING_TABLE_ID = 0

FORWARDING_TABLE_ID = 1

AGING_TIME = 180

def start(_args)

 @fdb = FDB.new

 logger.info "#{name} started."

end

def switch_ready(datapath_id)

 add_bpdu_drop_flow_entry(datapath_id)

 add_default_broadcast_flow_entry(datapath_id)

 add_default_flooding_flow_entry(datapath_id)

 add_default_forwarding_flow_entry(datapath_id)

end

def packet_in(_datapath_id, packet_in)

 @fdb.learn(packet_in.source_mac, packet_in.in_port)

 add_forwarding_flow_and_packet_out(packet_in)

end

def age_fdb

 @fdb.age

end

private

def add_forwarding_flow_and_packet_out(packet_in)

 port_no = @fdb.lookup(packet_in.destination_mac)

 add_forwarding_flow_entry(packet_in, port_no) **if** port_no

```

packet_out(packet_in, port_no || :flood)
end

def add_forwarding_flow_entry(packet_in, port_no)
  send_flow_mod_add(
    packet_in.datapath_id,
    table_id: FORWARDING_TABLE_ID,
    idle_timeout: AGING_TIME,
    priority: 2,
    match: Match.new(in_port: packet_in.in_port,
      destination_mac_address: packet_in.destination_mac,
      source_mac_address: packet_in.source_mac),
    instructions: Apply.new(SendOutPort.new(port_no))
  )
end

def packet_out(packet_in, port_no)
  send_packet_out(
    packet_in.datapath_id,
    packet_in: packet_in,
    actions: SendOutPort.new(port_no)
  )
end

def add_default_broadcast_flow_entry(datapath_id)
  send_flow_mod_add(
    datapath_id,
    table_id: FORWARDING_TABLE_ID,
    idle_timeout: 0,
    priority: 3,
    match: Match.new(destination_mac_address: 'ff:ff:ff:ff:ff:ff'),
    instructions: Apply.new(SendOutPort.new(:flood))
  )
end

def add_default_flooding_flow_entry(datapath_id)
  send_flow_mod_add(
    datapath_id,
    table_id: FORWARDING_TABLE_ID,
    idle_timeout: 0,
    priority: 1,
    match: Match.new,
    instructions: Apply.new(SendOutPort.new(:controller))
  )
end

```

```

def add_bpdu_drop_flow_entry(datapath_id)
    send_flow_mod_add(
        datapath_id,
        table_id: INGRESS_FILTERING_TABLE_ID,
        idle_timeout: 0,
        priority: 2,
        match: Match.new(destination_mac_address: '01:80:C2:00:00:00')
    )
end

def add_default_forwarding_flow_entry(datapath_id)
    send_flow_mod_add(
        datapath_id,
        table_id: INGRESS_FILTERING_TABLE_ID,
        idle_timeout: 0,
        priority: 1,
        match: Match.new,
        instructions: GotoTable.new(FORWARDING_TABLE_ID)
    )
end
end

```

8.5.1. ##### _ #####

```
switch_ready #####
```

```
#####13##### _ ##### (###/#####_#####13.#)
```

```

def switch_ready(datapath_id)
    add_bpdu_drop_flow_entry(datapath_id)
    add_default_broadcast_flow_entry(datapath_id)
    add_default_flooding_flow_entry(datapath_id)
    add_default_forwarding_flow_entry(datapath_id)
end

```

```
##### add_bpdu_drop_flow_entry ##### #### ##### #####
```

```
#####13##### _ ##### _ ##### _ ##### (###/#####_#####13.#)
```

```

def add_bpdu_drop_flow_entry(datapath_id)
    send_flow_mod_add(
        datapath_id,
        table_id: INGRESS_FILTERING_TABLE_ID,
        idle_timeout: 0,

```

```

priority: 2,
match: Match.new(destination_mac_address: '01:80:C2:00:00:00')
)
end

```

3

```



```

```

def add_default_forwarding_flow_entry(datapath_id)
  send_flow_mod_add(
    datapath_id,
    table_id: INGRESS_FILTERING_TABLE_ID,
    idle_timeout: 0,
    priority: 1,
    match: Match.new,
    instructions: GotoTable.new(FORWARDING_TABLE_ID)
  )
end

```

3

```

priority
#####
1 ##### (## = 2) #####
match
#####
instructions
  GotoTable(FORWARDING_TABLE_ID) #####
  1 #####

```

```
### add_default_flooding_flow_entry ##### #### ##### #####
#####

#####
#####13##### _##### _##### _##### _##### (###/#####_#####13.##)

def add_default_flooding_flow_entry(datapath_id)
    send_flow_mod_add(
        datapath_id,
        table_id: FORWARDING_TABLE_ID,
        idle_timeout: 0,
        priority: 1,
        match: Match.new,
        instructions: Apply.new(SendOutPort.new(:controller))
    )
end


#####
##### INGRESS_FILTERING_TABLE_ID ##
FORWARDING_TABLE_ID ##### table_id ##
FORWARDING_TABLE_ID #####


priority
#####
##### 1 #####
instructions
#####
SendOutPort.new(:flood) #####
SendOutPort.new(:controller) # Apply #####

```

8.5.2. ##### _##

```
packet_in ##### ## ##### ###### #### + ## #### ###### ###### #### #
##### _##### _## ##### ###### ###### ###### #####
#####
#####13##### _##### (###/#####_#####13.##)

def packet_in(_datapath_id, packet_in)
    @fdb.learn(packet_in.source_mac, packet_in.in_port)
    add_forwarding_flow_and_packet_out(packet_in)
end

private

def add_forwarding_flow_and_packet_out(packet_in)
    port_no = @fdb.lookup(packet_in.destination_mac)
    add_forwarding_flow_entry(packet_in, port_no) if port_no
```

```
packet_out(packet_in, port_no || :flood)
end

def add_forwarding_flow_entry(packet_in, port_no)
  send_flow_mod_add(
    packet_in.datapath_id,
    table_id: FORWARDING_TABLE_ID,
    idle_timeout: AGING_TIME,
    priority: 2,
    match: Match.new(in_port: packet_in.in_port,
                     destination_mac_address: packet_in.destination_mac,
                     source_mac_address: packet_in.source_mac),
    instructions: Apply.new(SendOutPort.new(port_no))
  )
end
```

#####

```
priority
#####
# FORWARDING_TABLE_ID #####
#####
idle_timeout
#####
#####
match , instructions
#####
# in_port #####
#####
#####
```

8.6. ####

#####1.3 #####1.0 #####

- #####
 - GotoTable #####1#####
 - #####1.3 ##### ## #####1.0 #####
packet_in #####

```
#####
#####
```

9.

#####



9.1.

#####

##

#####



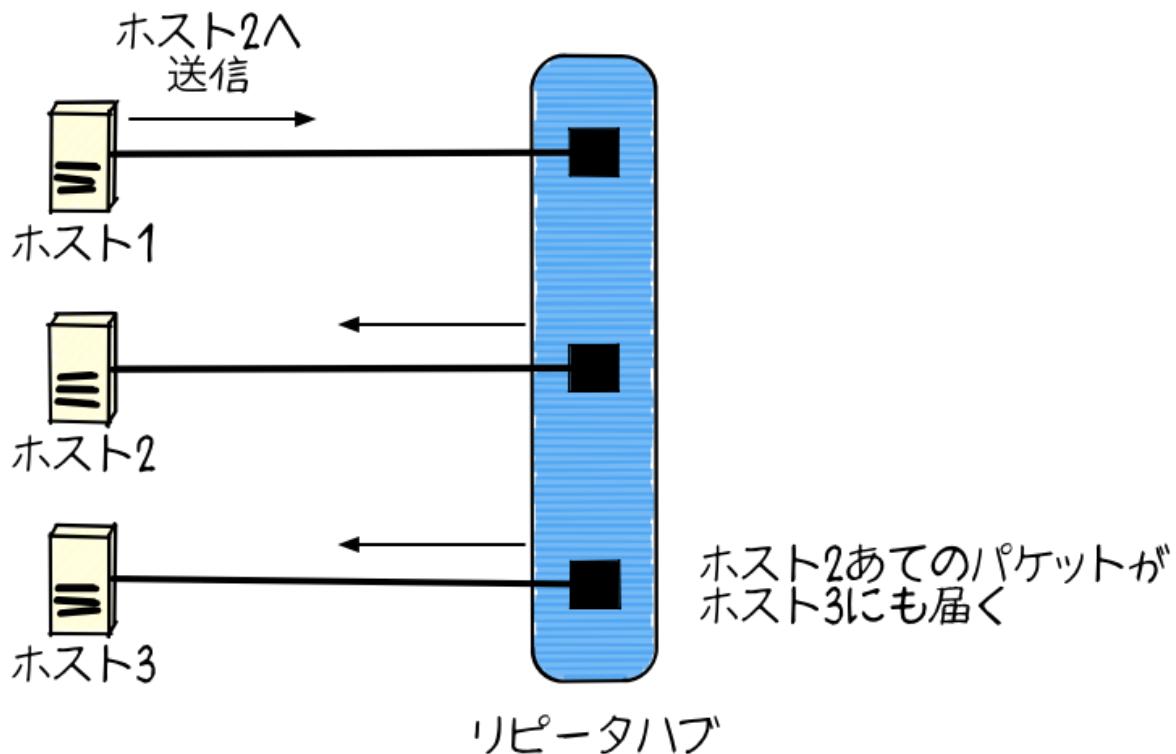
#####

#####2#####

```
#####
##### (#####)#####3#####
#####
#####
```

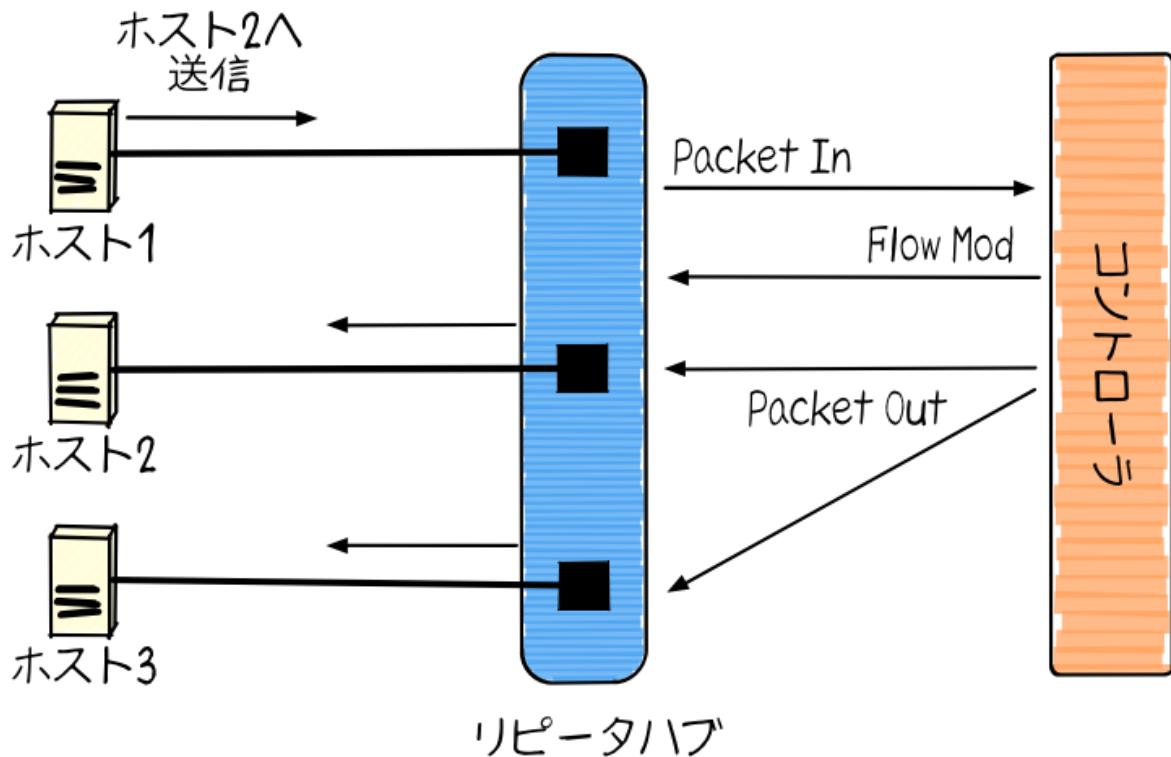
9.2.

```
#####3#####9#1#####1#####
#2#####3#####2#
#####(7#####)#####
#####
```



9.1.

```
#####9#2#####1#####
#####(#####)#####
#####
1#####
```



9.2. ##### #####

9.3.

#####

- #####

#####

1. ### 1##### 2##### 3 #####
 2. #####
 3. ### 1 #### 2 #####
 4. ### 2#### 3 #####

#####

9.4.

3

3

#####

4

#####

#####/# #####/##### 5

#####

9.5. #####

1. ### 1##### 2##### 3 ##### #####
 2. ##### ##### ##### ##### #####
 3. ### 1 ##### 2 ##### #####
 4. ### 2##### 3 ##### #####

3 #####://##### ##

4 #####://#####/#/#####/#/#####/#/#####

5 #####://##### #####/#####/##### ##### ##### #####

#####

- #####: ### 1##### 2##### 3 ##### ##### ##### ##### ##### ##### ##### ##### #####
 - #####: ### 1 ##### 2 ##### ##### #####
 - #####: ### 2##### 3 ##### ##### #####

#####

9.5.1. #####:

```
##### (#####) ##### 3 ##### (# 9#1) #####
##### features/repeater_hub.feature #####:
```

Given a file named "trema.conf" with:

11

```
vswitch('repeater_hub') { datapath_id 0xabc }
```

```
vhost('host1') {  
    ip '192.168.0.1'  
    promisc true  
}  
vhost('host2') {  
    ip '192.168.0.2'  
    promisc true  
}  
vhost('host3') {  
    ip '192.168.0.3'  
    promisc true  
}
```

```
link 'repeater_hub', 'host1'  
link 'repeater_hub', 'host2'  
link 'repeater_hub', 'host3'
```

11

```
#### Given a file named "trema.conf" with: ... ####... ##### trema.conf #####
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####
```

```
##### promisc ##### (#####) #####) # true #####
```

#####

And I trema run "lib/repeater_hub.rb" with the configuration "trema.conf"


```
##### #####
```

```
from /home/yasuhito/.rvm/gems/ruby-2.2.0/gems/gli-2.13.2/lib/gli/app_support.rb:309:in `call_command'  
from /home/yasuhito/.rvm/gems/ruby-2.2.0/gems/gli-2.13.2/lib/gli/app_support.rb:83:in `run'  
from /home/yasuhito/.rvm/gems/ruby-2.2.0/gems/trema-0.7.1/bin/trema:252:in `<module:App>'  
from /home/yasuhito/.rvm/gems/ruby-2.2.0/gems/trema-0.7.1/bin/trema:14:in `<module:Trema>'  
from /home/yasuhito/.rvm/gems/ruby-2.2.0/gems/trema-0.7.1/bin/trema:12:in `<top (required)>'  
from /home/yasuhito/.rvm/gems/ruby-2.2.0/bin/trema:23:in `load'  
from /home/yasuhito/.rvm/gems/ruby-2.2.0/bin/trema:23:in `<main>'  
from /home/yasuhito/.rvm/gems/ruby-2.2.0/bin/ruby_executable_hooks:15:in `eval'  
from /home/yasuhito/.rvm/gems/ruby-2.2.0/bin/ruby_executable_hooks:15:in `<main>'
```

STDERR

```
And I trema run "lib/repeater_hub.rb" with the configuration "trema.conf"  
expected "trema run ../../lib/repeater_hub.rb -c trema.conf -d" to be successfully executed  
(RSpec::Expectations::ExpectationNotMetError)  
.features/step_definitions/trema_steps.rb:41:in `/^I trema run "([^"]*)" ( interactively)? with the  
configuration "([^"]*)$/'  
features/repeater_hub.feature:27:in `And I trema run "lib/repeater_hub.rb" with the configuration  
"trema.conf"'
```

Failing Scenarios:

```
cucumber features/repeater_hub.feature:5 # Scenario: Run as a daemon
```

```
1 scenario (1 failed)  
3 steps (1 failed, 1 skipped, 1 passed)  
0m8.113s
```

```
##### trema run ##### lib/repeater_hub.rb #####  
#####
```

```
$ mkdir lib  
$ touch lib/repeater_hub.rb  
$ ./bin/cucumber features/repeater_hub.feature
```

```
#####
```

```
$ ./bin/cucumber features/repeater_hub.feature  
(#)  
<<-STDERR  
error: No controller class is defined.
```

STDERR

```
And I trema run "lib/repeater_hub.rb" with the configuration "trema.conf" # features/step_definitions/  
trema_steps.rb:30
```

#####

9.5.2. #####:

```
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####1 #####2 ##### #####  
##### _ ##### ##### ##### (#####) ##### ##### ##### I  
run ... #####
```

When I run `trema send_packets --source host1 --dest host2`

#####

```
$ ./bin/cucumber features/repeater_hub.feature  
(#)  
1 scenario (1 passed)  
4 steps (4 passed)
```

#####

0m21.910s

9.5.3. #####:

Then the number of packets received by "host2" should be:

| source | #packets |
|-------------|----------|
| 192.168.0.1 | 1 |

And the number of packets received by "host3" should be:

| source | #packets |
|-------------|----------|
| 192.168.0.1 | 1 |

```
##### 2### 3 ##### ## #### 192.168.0.1 ##### 1 #####  
#####
```

#####

```
$ ./bin/cucumber features/repeater_hub.feature
```

(##)

```
When I run `trema send_packets --source host1 --dest host2`  
=><-STDERR
```

STDERR

Then the number of packets received by "host2" should be:

| source | #packets |
|-------------|----------|
| 192.168.0.1 | 1 |

expected: 1

got: 0

(compared using ==)

(RSpec::Expectations::ExpectationNotMetError)

./features/step_definitions/show_stats_steps.rb:52:in `block (2 levels) in <top (required)>'

./features/step_definitions/show_stats_steps.rb:50:in `each'

./features/step_definitions/show_stats_steps.rb:50:in `^the number of packets received by "(.*?)" should be:

\$/'

features/repeater_hub.feature:30:in `Then the number of packets received by "host2" should be:'

And the number of packets received by "host3" should be:

| source | #packets |
|-------------|----------|
| 192.168.0.1 | 1 |

```
##### #####
```

Failing Scenarios:

```
cucumber features/repeater_hub.feature:5 # Scenario: Run as a daemon
```

1 scenario (1 failed)

6 steps (1 failed, 1 skipped, 4 passed)

0m20.198s

```
.....
```

```
#####2 # 1 ##### RepeaterHub #####
```

```
##### RepeaterHub #####
```

```
.....
```

```
class RepeaterHub < Trema::Controller
  def packet_in(datapath_id, packet_in)
    send_flow_mod_add(
      datapath_id,
      match: ExactMatch.new(packet_in),
      actions: SendOutPort.new(:flood)
    )
  end
end
```

```
.....
```

```
$ ./bin/cucumber features/repeater_hub.feature
```

```
(##)
```

Then the number of packets received by "host2" should be:

| | |
|-------------|----------|
| source | #packets |
| 192.168.0.1 | 1 |

expected: 1

got: 0

```
.....
```

```
#####2 ##### ##### ##### ##### ##### ##### ##### #####
```

```
##### ##### ##### ##### ##### ##### ##### #####
```

```
.....
```

```
class RepeaterHub < Trema::Controller
  def packet_in(datapath_id, packet_in)
    send_flow_mod_add(
      datapath_id,
      match: ExactMatch.new(packet_in),
      actions: SendOutPort.new(:flood)
    )
    send_packet_out(
      datapath_id,
```

```

raw_data: packet_in.raw_data,
actions: SendOutPort.new(:flood)
)
end
end

```

#####

\$ bundle exec cucumber features/repeater_hub.feature

Rack is disabled

Feature: "Repeater Hub" example

@sudo

Scenario: Run as a daemon

Given a file named "trema.conf" with:

"""

vswitch('repeater_hub') { datapath_id 0xabc }

vhost('host1') {

ip '192.168.0.1'

promisc true

}

vhost('host2') {

ip '192.168.0.2'

promisc true

}

vhost('host3') {

ip '192.168.0.3'

promisc true

}

link 'repeater_hub', 'host1'

link 'repeater_hub', 'host2'

link 'repeater_hub', 'host3'

"""

And I trema run "lib/repeater_hub.rb" with the configuration "trema.conf"

When I run `trema send_packets --source host1 --dest host2`

Then the number of packets received by "host2" should be:

| | |
|-----------------|----------|
| source | #packets |
| 192.168.0.1 1 | |

And the number of packets received by "host3" should be:

| | |
|-----------------|----------|
| source | #packets |
| 192.168.0.1 1 | |

1 scenario (1 passed)

#####

6 steps (6 passed)
0m20.976s

.....

#####! #####

9.6.

4

####⁶

#####

####⁷

(#####)

####⁸

#####

#####⁹

#####

RepeaterHub ##### 4 #####

\$./bin/reek lib/repeater_hub.rb

\$./bin/flog lib/repeater_hub.rb
9.0: flog total
4.5: flog/method average

5.6: RepeaterHub#packet_in lib/repeater_hub.rb:7

\$./bin/flay lib/repeater_hub.rb
Total score (lower is better) = 0

\$./bin/rubocop lib/repeater_hub.rb

Inspecting 1 file

⁶ #####://#####.###/#####/####

⁷ #####://#####.###.##/###.###

⁸ #####://#####.###.##/###.###

⁹ #####://#####.###/#####/#####

1 file inspected, no offenses detected

9.7.

#####2#####

(features/ ##)

9.8.

10.

#####!#####



10.1. #####

#####

#####

#####

10.2. #####

#####.....#####.....#####.....#

#####

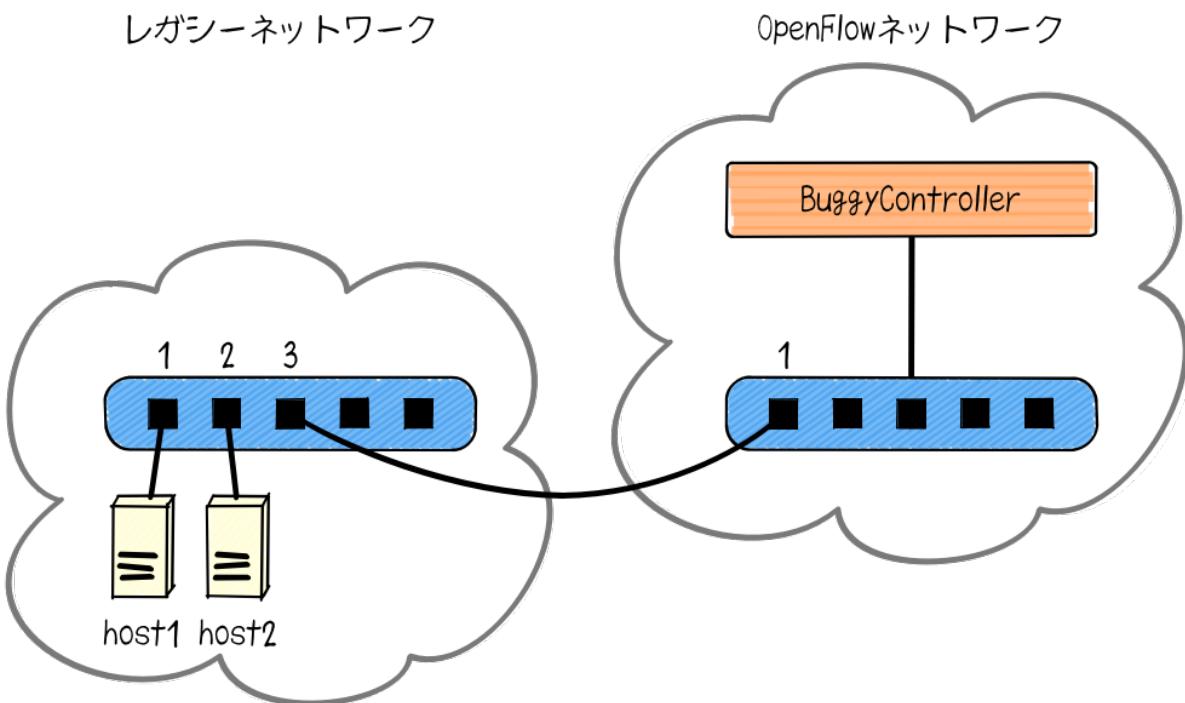
```
#####
#####
```

#####

10.3.

```
#####
##### !#####
#####
```

```
#####
##10#1#####
#####
```



10.1.

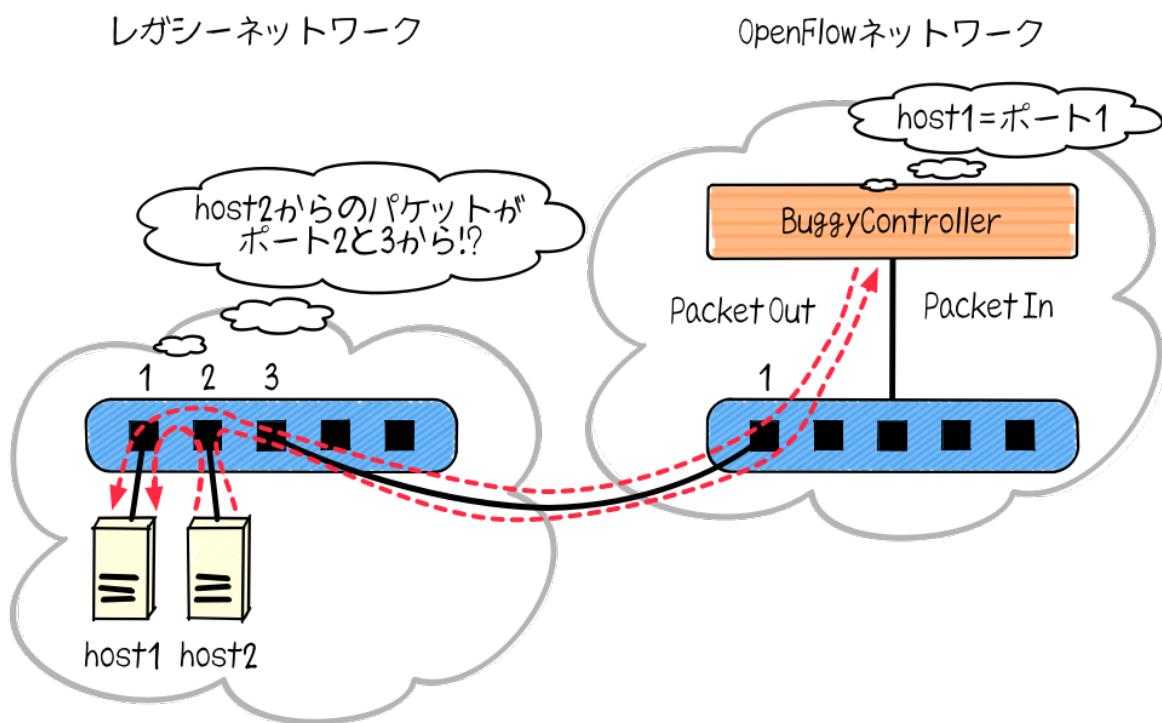
#####2#####3#####1##
#####(######)
#####

10.3.1. ##### ###### ####### ######

#####

```
##### #####1#####
#####
##
```

10.3.2.



10.2.

1 https://www.khanacademy.org/math/algebra/two-variable-equations/parallel_perpendicular_parallel/e/parallel_lines

#####

10.3.3 #####

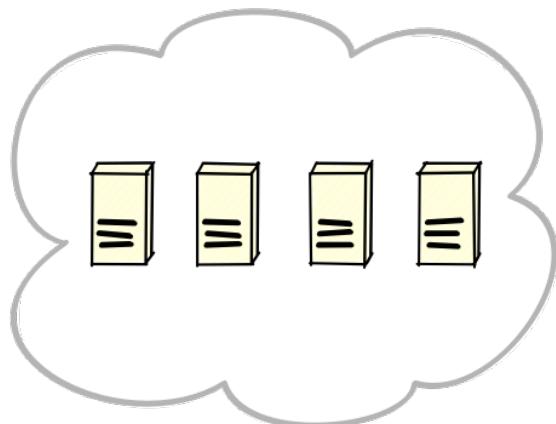
10.4

```
#####
#####3#####
#####
```

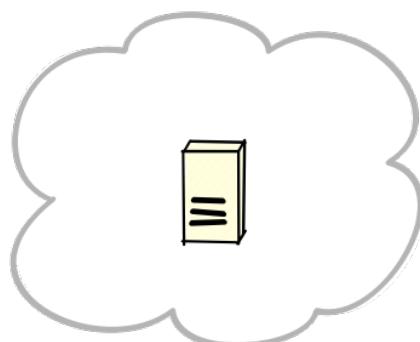
10.4.1.

#####

レガシーネットワーク



OpenFlowネットワーク



10.3.

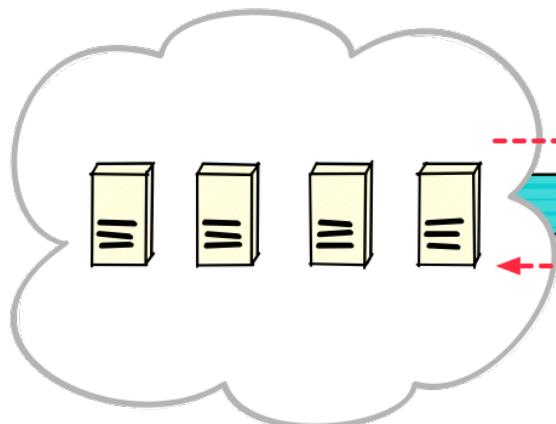
#####

```
#####
#####
```

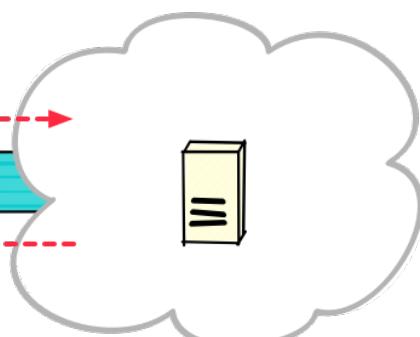
10.4.2.

######10#4##

レガシーネットワーク



OpenFlowネットワーク



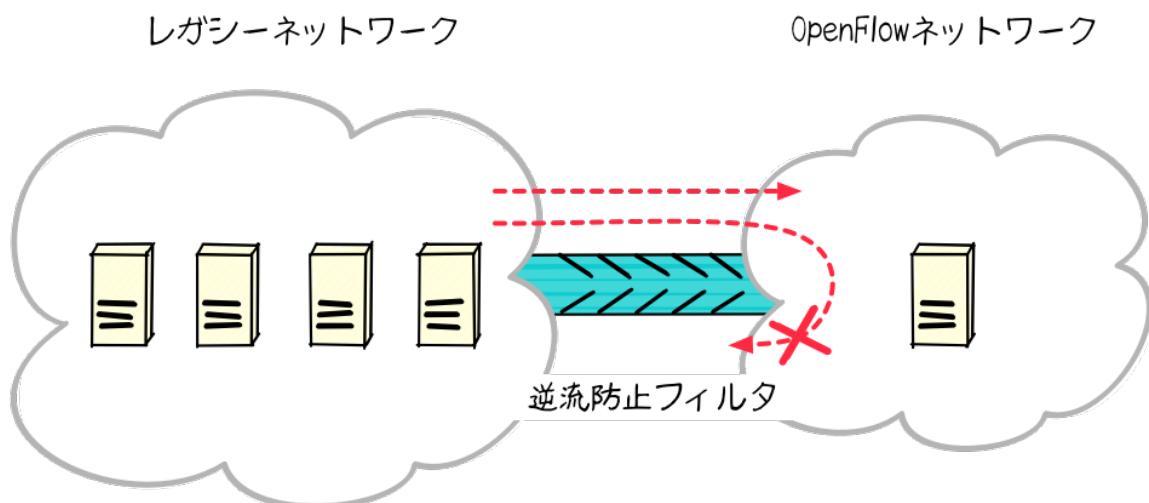
10.4.

#####

#####

```
#####
#####
```

10.4.3.



10.5.

#####→#####
#####

```
#####
#####2#####1#####
###
```

10.5.

#####

```
#####
```

10.5.1.

```
##### ##### ##### ##### ##### ##### ##### ##### #####  
(#####://#####.###/#####/##_##_#####) ##### ##### #####
```

```
$ git clone https://github.com/trema/one_way_bridge.git
```

```
##### bundle install --binstubs ##### ##### ##### #####
```

```
$ cd one_way_bridge  
$ bundle install --binstubs
```

```
##### ##### ##### ##### ##### ##### ##### #####
```

```
######_##_#####.##
```

```
# Safety-net controller bridging legacy and OpenFlow networks.
```

```
class OneWayBridge < Trema::Controller  
  def packet_in(datapath_id, packet_in)  
    out_port = { 1 => 2, 2 => 1 }.fetch(packet_in.in_port)  
    add_flow datapath_id, packet_in.source_mac, packet_in.in_port, out_port  
    send_packet datapath_id, packet_in, out_port  
    add_drop_flow datapath_id, packet_in.source_mac, out_port  
  end
```

```
  def flow_removed(datapath_id, packet_in)  
    delete_flow datapath_id, packet_in.match.source_mac_address  
  end
```

```
  private
```

```
    def add_flow(datapath_id, source_mac, in_port, out_port)  
      send_flow_mod_add(  
        datapath_id,  
        idle_timeout: 10 * 60,  
        match: Match.new(in_port: in_port, source_mac_address: source_mac),  
        actions: SendOutPort.new(out_port)  
      )  
    end
```

```
    def add_drop_flow(datapath_id, source_mac, in_port)  
      send_flow_mod_add(  
        datapath_id,
```

```
idle_timeout: 10 * 60,
match: Match.new(in_port: in_port, source_mac_address: source_mac)
)
end

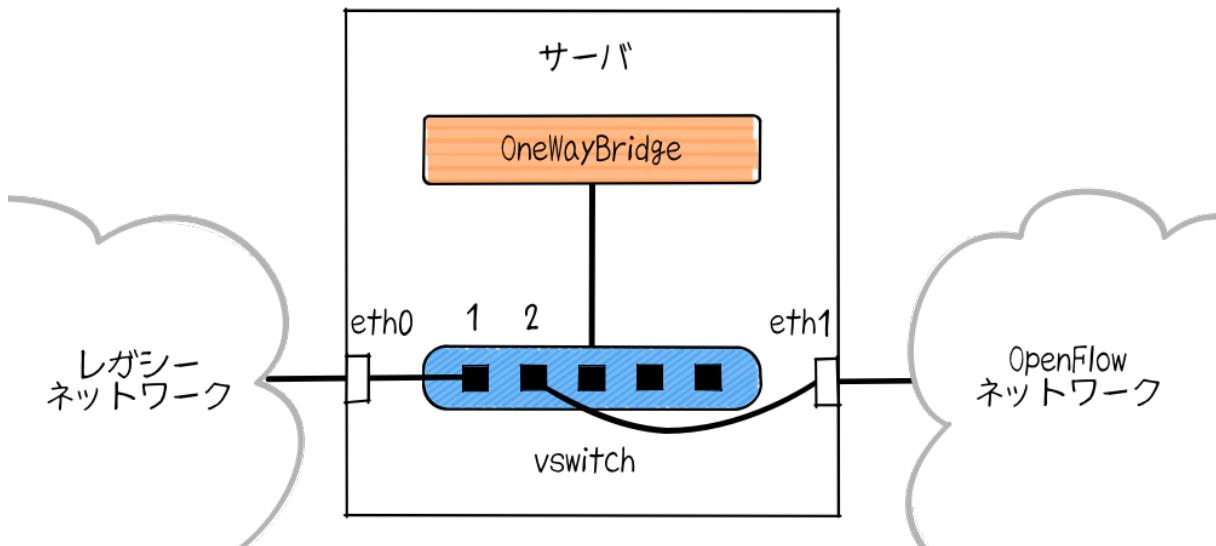
def send_packet(datapath_id, packet_in, out_port)
  send_packet_out(
    datapath_id,
    packet_in: packet_in,
    actions: SendOutPort.new(out_port)
  )
end

def delete_flow(datapath_id, source_mac)
  send_flow_mod_delete(
    datapath_id,
    match: Match.new(source_mac_address: source_mac)
  )
end
end
```

```
packet_in ##### add_flow #####
##### send_packet #####
##### add_drop_flow #####
flow_removed #####
:source_mac_address delete_flow #####
##
```

10.5.2.

```
#####
#####2#####(#####)#####
(#10#6#
```



10.6.

link #####0###1#####
#####

#####

```
vswitch ('bridge') {  
    datapath_id 0xabc  
}
```

```
link 'bridge', 'eth0'  
link 'bridge', 'eth1'
```

```
##### tremu run # -c #####
```

```
$ ./bin/trema run ./lib/one-way-bridge.rb -c ./trema.conf
```

10.5.3.

10.6. ###

#####

#####

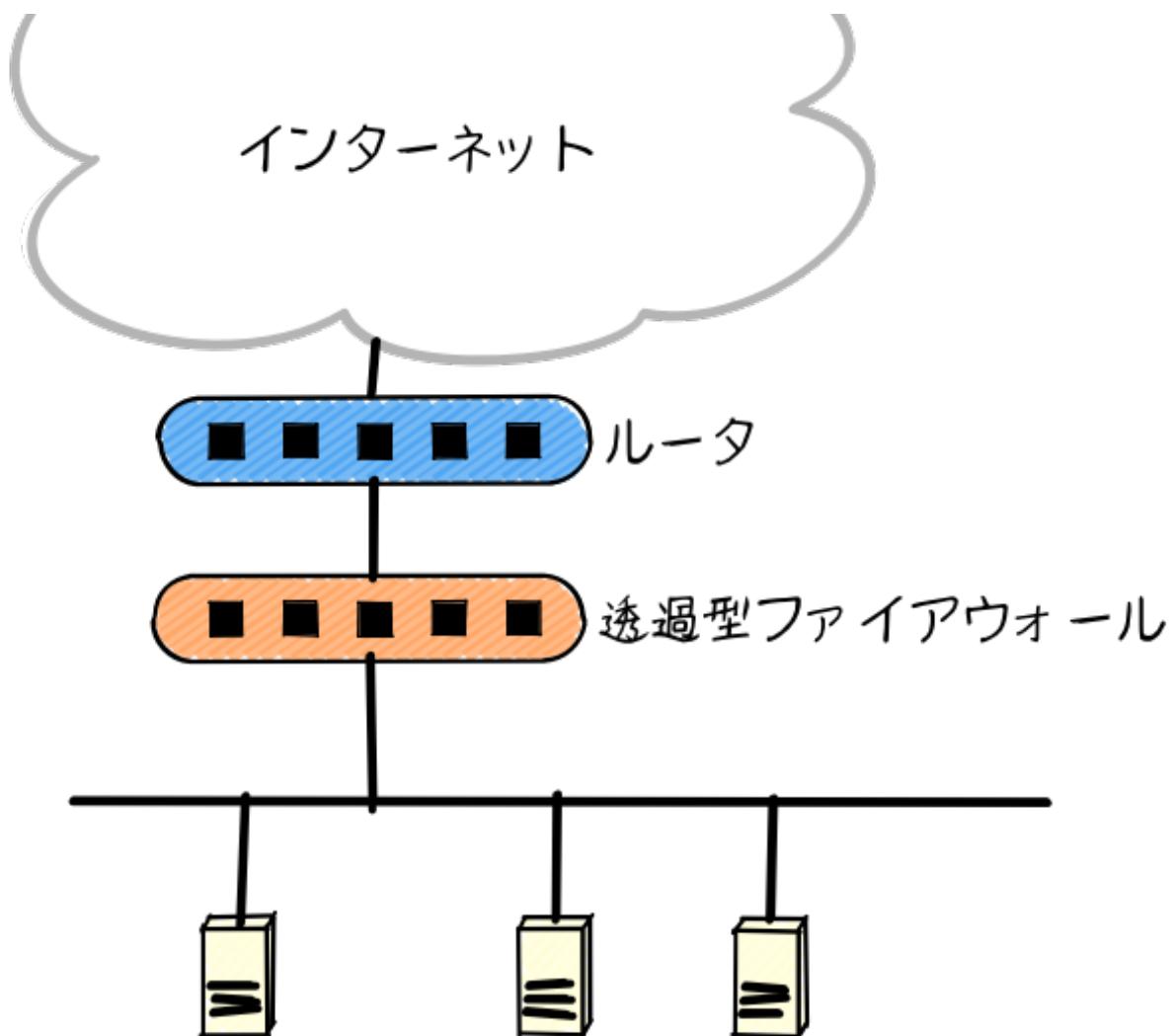
- #####
- #####2#####

11.

```
#####
#####
```

11.1.

```
#####
##### 11#1 #####
#####
```



11.1.

```
#####
##### 4#####
##### 2#####
#####
```

#####1918

###1918#####
###

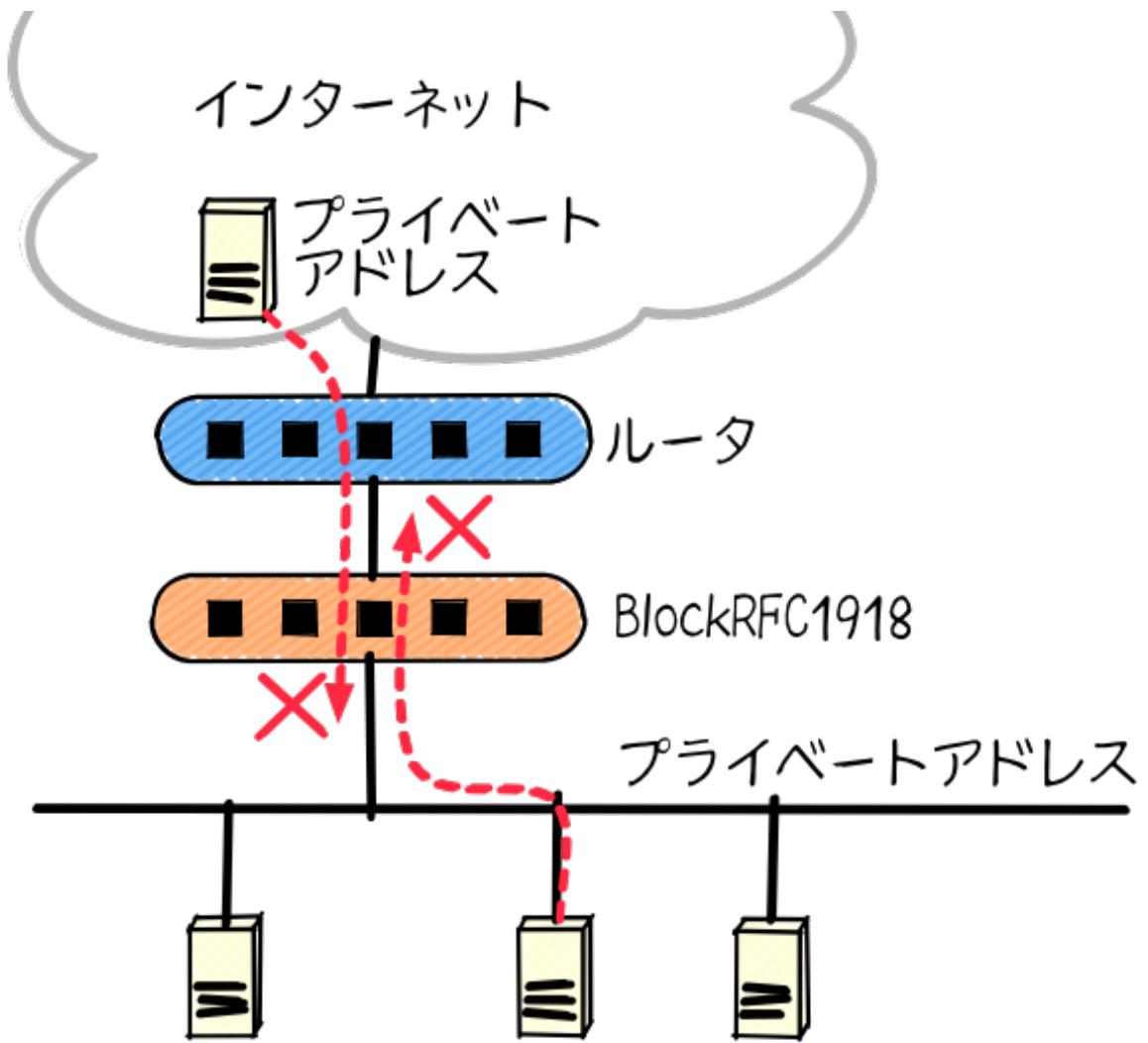
#####

#####→#####

11.2. #####1918#####

#####1918##### ## ##### (# 11#2)#####
##1918 (#####) ##### 3 ## ## #####

- 10.0.0.0/8
- 172.16.0.0/12
- 192.168.0.0/16



11.2. #####1918#####

11.2.1.

```
#####1918 ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####  
trema/transparent_firewall ##### (#:::::#####.###/#####/#####/#####_#####) ####  
#####
```

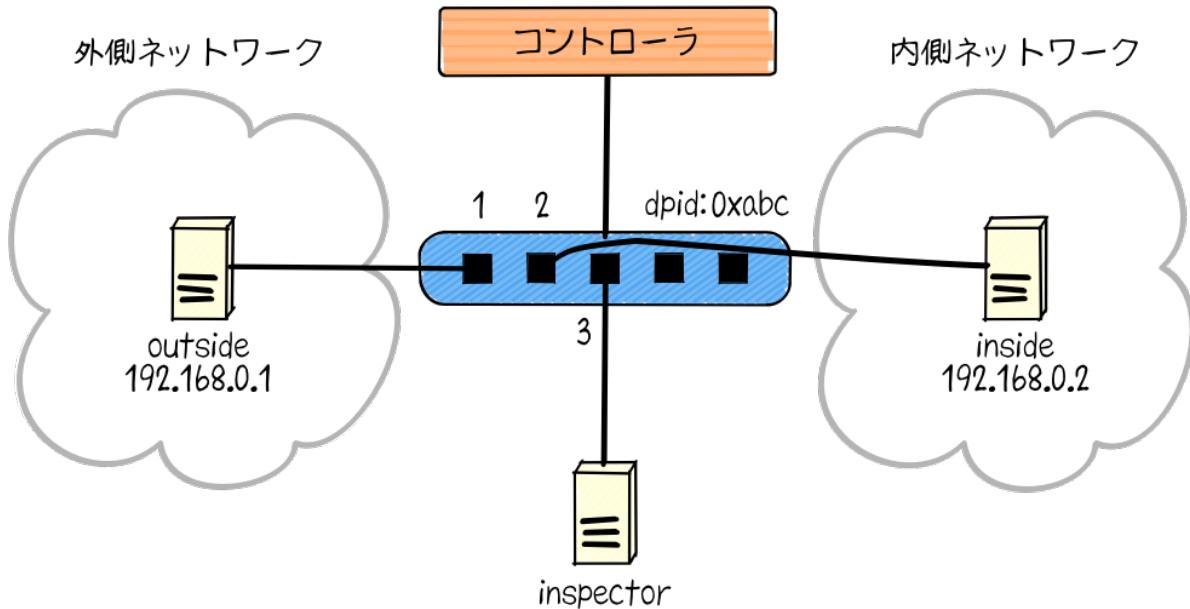
```
$ git clone https://github.com/trema/transparent_firewall.git
```

```
##### bundle install --binstubs #####
```

```
$ cd transparent_firewall  
$ bundle install --binstubs
```

```
##### ######1#####3##### trema.conf ##### (#  
11#3)#

```



11.3. #####1918

#####.#####

```
vswitch('firewall') { datapath_id 0xabc }

vhost('outside') { ip '192.168.0.1' }
vhost('inside') { ip '192.168.0.2' }
vhost('inspector') {
    ip '192.168.0.3'
    promisc true
}

link 'firewall', 'outside'
link 'firewall', 'inside'
link 'firewall', 'inspector'
```

```
##### trema run # -c #####1918 #####
```

#####

```
$ ./bin/trema run ./lib/block_rfc1918.rb -c trema.conf  
0xabc: connected  
0xabc: loading finished
```

```
$ ./bin/trema send_packets --source outside --dest inside  
$ ./bin/trema send_packets --source inside --dest outside
```

```
$ ./bin/trema show_stats outside
```

Packets sent:

192.168.0.1 -> 192.168.0.2 = 1 packet

```
$ ./bin/trema show_stats inside
```

Packets sent:

192.168.0.2 -> 192.168.0.1 = 1 packet

```
$ ./bin/trema show stats inspector
```

Packets received:

192.168.0.1 -> 192.168.0.2 = 1 packet

192.168.0.2 -> 192.168.0.1 = 1 packet

```
##### # show_stats ## Packets received: #####
##### 2 ##### ##### ##### #####
```

11.3. #####1918#####

#####1918#####

###/#####_###1918.##

A sample transparent firewall

```
class BlockRFC1918 < Trema::Controller
  PORT = {
    outside: 1,
    inside: 2,
    inspect: 3
  }
```

```
PREFIX = ['10.0.0.0/8', '172.16.0.0/12', '192.168.0.0/16'].map do |each|
```

```
IPv4Address.new each  
end
```

```
def switch_ready(dpid)  
  if @dpid  
    logger.info "#{dpid.to_hex}: ignored"  
    return  
  end  
  @dpid = dpid  
  logger.info "#{@dpid.to_hex}: connected"  
  start_loading  
end
```

```
def switch_disconnected(dpid)  
  return if @dpid != dpid  
  logger.info "#{@dpid.to_hex}: disconnected"  
  @dpid = nil  
end
```

```
def barrier_reply(dpid, _message)  
  return if dpid != @dpid  
  logger.info "#{@dpid.to_hex}: loading finished"  
end
```

```
private
```

```
def start_loading  
  PREFIX.each do |each|  
    block_prefix_on_port prefix: each, in_port: :inside, priority: 5000  
    block_prefix_on_port prefix: each, in_port: :outside, priority: 4000  
  end  
  install_postamble 1500  
  send_message @dpid, Barrier::Request.new  
end
```

```
def block_prefix_on_port(prefix:, in_port:, priority:)  
  send_flow_mod_add(  
    @dpid,  
    priority: priority + 100,  
    match: Match.new(in_port: PORT[in_port],  
      ether_type: 0x0800,  
      source_ip_address: prefix),  
    actions: SendOutPort.new(PORT[:inspect]))  
  send_flow_mod_add(  
    @dpid,  
    priority: priority,
```

```
#####
```

```
match: Match.new(in_port: PORT[in_port],  
    ether_type: 0x0800,  
    destination_ip_address: prefix),  
actions: SendOutPort.new(PORT[:inspect]))  
end
```

```
def install_postamble(priority)  
    send_flow_mod_add(  
        @dpid,  
        priority: priority + 100,  
        match: Match.new(in_port: PORT[:inside]),  
        actions: SendOutPort.new(PORT[:outside]))  
    send_flow_mod_add(  
        @dpid,  
        priority: priority,  
        match: Match.new(in_port: PORT[:outside]),  
        actions: SendOutPort.new(PORT[:inside]))  
end  
end
```

```
##### switch_ready ##### switch_ready #####  
start_loading #####  
#####1918#####_##### (###/#####_###1918.##)
```

```
def switch_ready(dpid)  
    if @dpid  
        logger.info "#{dpid.to_hex}: ignored"  
        return  
    end  
    @dpid = dpid  
    logger.info "#{@dpid.to_hex}: connected"  
    start_loading ①  
end
```

```
① ##### start_loading #####  
start_loading #####1918 ##### 3 #####  
##### ##### ## ##### inspector #####  
block_prefix_on_port #####  
#####1918#####_#####, #####1918#####_#####_##_##### (###/  
#####_###1918.##)
```

```
def start_loading  
    PREFIX.each do |each|
```

```

block_prefix_on_port prefix: each, in_port: :outside, priority: 4000 ①
block_prefix_on_port prefix: each, in_port: :inside, priority: 5000 ②
end
install_postamble 1500
send_message @dpid, Barrier::Request.new
end

def block_prefix_on_port(prefix:, in_port:, priority:)
  send_flow_mod_add( ③
    @dpid,
    priority: priority + 100,
    match: Match.new(in_port: PORT[in_port],
      ether_type: 0x0800,
      source_ip_address: prefix),
    actions: SendOutPort.new(PORT[:inspect]))
  send_flow_mod_add( ④
    @dpid,
    priority: priority,
    match: Match.new(in_port: PORT[in_port],
      ether_type: 0x0800,
      destination_ip_address: prefix),
    actions: SendOutPort.new(PORT[:inspect]))
end

```

```

① ##### 1 # (#####) #####
② ##### 2 # (#####) #####
③ ##### inspector #####
④ ##### inspector #####
##### install_postamble #####
#####
#####1918##### _ ##### (##/## _ ##1918.##

```

```

def install_postamble(priority)
  send_flow_mod_add( ①
    @dpid,
    priority: priority + 100,
    match: Match.new(in_port: PORT[:inside]),
    actions: SendOutPort.new(PORT[:outside]))
  send_flow_mod_add( ②
    @dpid,
    priority: priority,
    match: Match.new(in_port: PORT[:outside]),
    actions: SendOutPort.new(PORT[:inside]))

```

```
end
```

```
1 ##### 2 # (#####) ##### ## ##### 1 # (#####) ###
2 ##### 1 ##### ## ##### 2 #####
##### Barrier::Request #####
Barrier::Reply ##### barrier_reply #####
#####
#1918##### _ ##### (##/##### _###1918.##)
```

```
def barrier_reply(dpid, _message) ①
  return if dpid != @dpid
  logger.info "#{@dpid.to_hex}: loading finished"
end
```

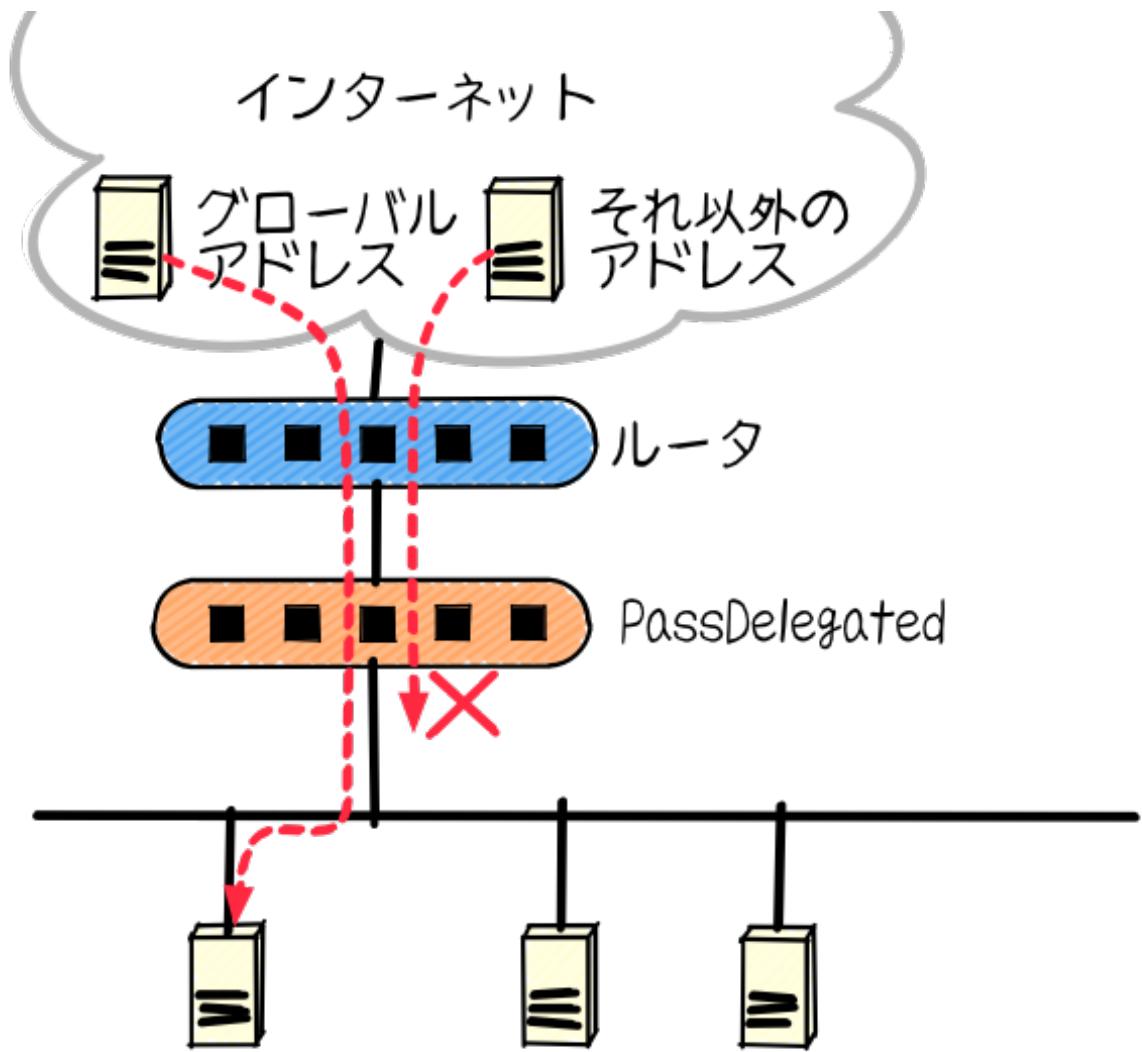
```
private
```

```
def start_loading
  PREFIX.each do |each|
    block_prefix_on_port prefix: each, in_port: :outside, priority: 4000
    block_prefix_on_port prefix: each, in_port: :inside, priority: 5000
  end
  install_postamble 1500
  send_message @dpid, Barrier::Request.new ②
end
```

```
2 ##### Barrier::Request #####
1 Barrier::Reply ##### logger.info ###
```

11.4.

```
#####
#11#4)##
```



11.4. ##### →#####

```
##### trema/transparent_firewall #####
# (*.txt) #####
#####
##### 3000 #####
#####
```

1.0.0.0/8
14.0.0.0/16
14.1.0.0/20
14.1.16.0/21
14.1.32.0/19
14.1.64.0/19
14.1.128.0/17
14.2.0.0/15
14.4.0.0/14

14.8.0.0/13

...

11.4.1.

```
##### ##### 11#3### trema.conf ##### tremarun #####  
# .### ##### ## ##### ##### ##### ##### ##### #####  
##### ##### ##### #####
```

```
$ ./bin/trema run ./lib/pass_delegated.rb -c pass_delegated.conf  
aggregated-delegated-afrinic.txt: 713 prefixes  
aggregated-delegated-apnic.txt: 3440 prefixes  
aggregated-delegated-arin.txt: 11342 prefixes  
aggregated-delegated-lacnic.txt: 1937 prefixes  
aggregated-delegated-ripencc.txt: 7329 prefixes  
0xabc: connected  
0xabc: loading started  
0xabc: loading finished in 241.03 seconds
```

```
##### tremasend_packets #####  
###
```

```
$ ./bin/trema send_packets --source outside --dest inside  
$ ./bin/trema send_packets --source inside --dest outside
```

```
##### ##### ##### ##### ##### ##### ##### ##### #####  
##### ##### ##### ##### ##### ##### ##### ##### #####  
##### ##### ##### ##### tremashow_stats ##### ##### ##### #####  
##### ##### #####
```

```
$ ./bin/trema show_stats outside
```

Packets sent:

192.168.0.1 -> 192.168.0.2 = 1 packet

```
$ ./bin/trema show_stats inside
```

Packets sent:

192.168.0.2 -> 192.168.0.1 = 1 packet

Packets received:

192.168.0.1 -> 192.168.0.2 = 1 packet

```
$ ./bin/trema show_stats inspector
```

Packets received:

192.168.0.1 -> 192.168.0.2 = 1 packet

```
##### ## ##### ##### ##### ##### ## ## ##### ##### ##### #####
```

11.5.

```
##### ##### #####1918 ##### ##### ##### #####4 #####
```

(##: 64000)

```
##### ##### ## ##### ##### ##### #####3 ##### ##### #####
```

#####

(##: 65000)

```
##### ##### ##### ##### ##### ##### ##### ↔##### #####
```

(##: 1000)

```
##### ##### ## ##### ##### ##### ##### #####
```

##4## (##: 900)

```
##### ##### ##4 ##### ##### ##### ##### #####
```

###/### _#####.##

A sample transparent firewall

class PassDelegated < Trema::Controller

PORT = {

outside: 1,

inside: 2,

inspect: 3

}

PRIORITY = {

bypass: 65_000,

prefix: 64_000,

inspect: 1000,

non_ipv4: 900

}

PREFIX_FILES = %w(afrinic apnic arin lacnic ripencc).map **do** |each|

"aggregated-delegated-#{each}.txt"

end

def start(_args)

@prefixes = PREFIX_FILES.reduce([]) **do** |result, each|

data = IO.readlines(File.join __dir__, '..', each)

logger.info "#{each}: #{data.size} prefixes"

```

    result + data
end
end

def switch_ready(dpid)
  if @dpid
    logger.info "#{dpid.to_hex}: ignored"
    return
  end
  @dpid = dpid
  logger.info "#{@dpid.to_hex}: connected"
  start_loading
end

def switch_disconnected(dpid)
  return if @dpid != dpid
  logger.info "#{@dpid.to_hex}: disconnected"
  @dpid = nil
end

def barrier_reply(dpid, _message)
  return if dpid != @dpid
  finish_loading
end

private

def start_loading
  @loading_started = Time.now
  install_preamble_and_bypass
  install_prefixes
  install_postamble
  send_message @dpid, Barrier::Request.new
end

# All flows in place, safe to remove bypass.
def finish_loading
  send_flow_mod_delete(@dpid,
    strict: true,
    priority: PRIORITY[:bypass],
    match: Match.new(in_port: PORT[:outside]))
  logger.info(format('%s: loading finished in %.2f second(s)',
    @dpid.to_hex, Time.now - @loading_started))
end

def install_preamble_and_bypass

```

#####

```
send_flow_mod_add(@dpid,
    priority: PRIORITY[:bypass],
    match: Match.new(in_port: PORT[:inside]),
    actions: SendOutPort.new(PORT[:outside]))
send_flow_mod_add(@dpid,
    priority: PRIORITY[:bypass],
    match: Match.new(in_port: PORT[:outside]),
    actions: SendOutPort.new(PORT[:inside]))
end

def install_prefixes
  logger.info "#{@dpid.to_hex}: loading started"
  @prefixes.each do |each|
    send_flow_mod_add(@dpid,
        priority: PRIORITY[:prefix],
        match: Match.new(in_port: PORT[:outside],
            ether_type: 0x0800,
            source_ip_address: IPv4Address.new(each)),
        actions: SendOutPort.new(PORT[:inside]))
  end
end

# Deny any other IPv4 and permit non-IPv4 traffic.
def install_postamble
  send_flow_mod_add(@dpid,
      priority: PRIORITY[:inspect],
      match: Match.new(in_port: PORT[:outside], ether_type: 0x0800),
      actions: SendOutPort.new(PORT[:inspect]))
  send_flow_mod_add(@dpid,
      priority: PRIORITY[:non_ipv4],
      match: Match.new(in_port: PORT[:outside]),
      actions: SendOutPort.new(PORT[:inside]))
end
end
```

#####1918 ##### start_loading #####

_ ##### (###/###_#####.##)

```
def start_loading
  @loading_started = Time.now
  install_preamble_and_bypass
  install_prefixes
  install_postamble
  send_message @dpid, Barrier::Request.new
end
```

####

```
##### install_preamble_and_bypass #####
#####
#####
```

```
def install_preamble_and_bypass
    send_flow_mod_add(@dpid, ❶
        priority: PRIORITY[:bypass],
        match: Match.new(in_port: PORT[:inside]),
        actions: SendOutPort.new(PORT[:outside]))
    send_flow_mod_add(@dpid, ❷
        priority: PRIORITY[:bypass],
        match: Match.new(in_port: PORT[:outside]),
        actions: SendOutPort.new(PORT[:inside]))
end
```

1 ##→#####

② `##→#####`

```
#####
##### 1 #####
#####→#####
```

(###/###.###)

```
def install_prefixes
  logger.info "#{@dpid.to_hex}: loading started"
  @prefixes.each do |each|
    send_flow_mod_add(@dpid,
      priority: PRIORITY[:prefix],
      match: Match.new(in_port: PORT[:outside],
        ether_type: 0x0800,
        source_ip_address: IPv4Address.new(each)),
      actions: SendOutPort.new(PORT[:inside]))
  end
end
```

(###/####.####.####.##)

Deny any other IPv4 and permit non-IPv4 traffic.

```

send_flow_mod_add(@dpid, ❶
    priority: PRIORITY[:inspect],
    match: Match.new(in_port: PORT[:outside], ether_type: 0x0800),
    actions: SendOutPort.new(PORT[:inspect]))
send_flow_mod_add(@dpid, ❷
    priority: PRIORITY[:non_ipv4],
    match: Match.new(in_port: PORT[:outside]),
    actions: SendOutPort.new(PORT[:inside]))
end

```

```

❶ ##########
❷ ####4 #####
#####→#####
#→#####
#####_##### (###/###_#####.##)

```

```

def barrier_reply(dpid, _message)
    return if dpid != @dpid
    finish_loading
end

private

# All flows in place, safe to remove bypass.
def finish_loading
    send_flow_mod_delete(@dpid,
        strict: true,
        priority: PRIORITY[:bypass],
        match: Match.new(in_port: PORT[:outside]))
    logger.info(format('%s: loading finished in %.2f second(s)',
        @dpid.to_hex, Time.now - @loading_started))
end

```

11.6.

```

#####2#####
• #####
• #### Barrier::Request #####

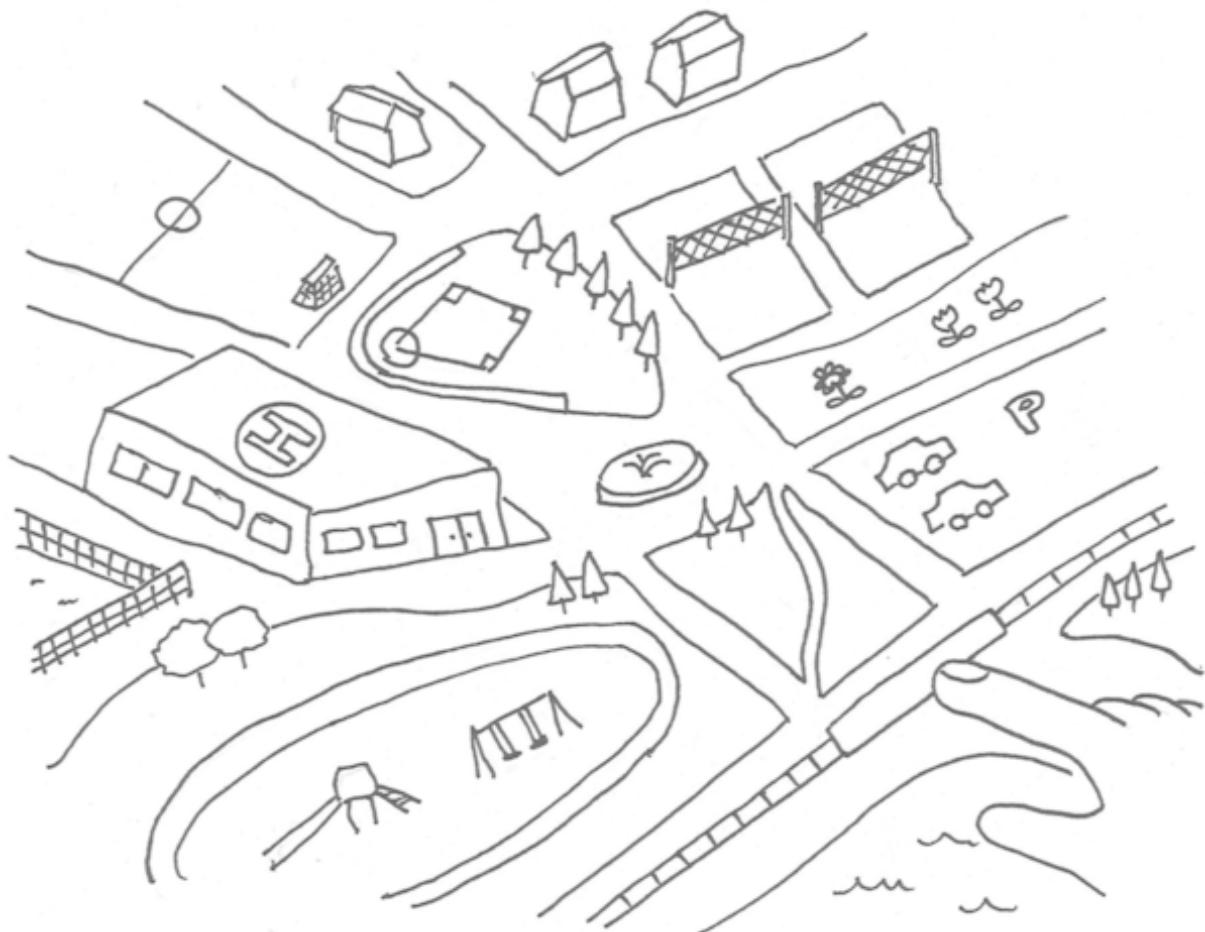
```

```

#####
#####
```

12. ### (##)

#####



12.1.

#####

####

1

- #### ##### ###### ###### #### (##### ## ##### #####)#####

- ##### ##### ##### (##### ##### ##### #####) ##### ##### ##### ##### #####
 - ##### ##### ##### ##### ##### (##### ##### ##### ##### #####) ##### ##### ##### ##### #####
#####

```
#####
##### ## (#####) ##### (#####) ##
##### ## ##### ## #####
##### #####
#####
```

12.2.

#####

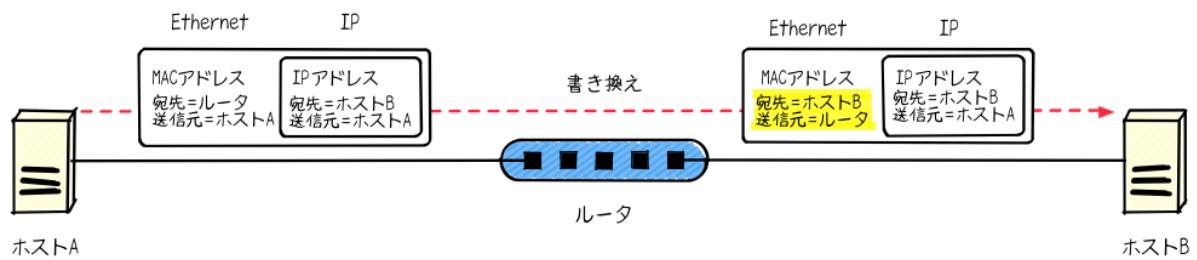
12.3 #####

#####1) #####2) ##### 2 #####

12.3.1

12#1 ##### # ##### # ##### ##### ##### ##### # ##### # ## ##### ##### ##### ##### ##### ##### ##### # #
#####

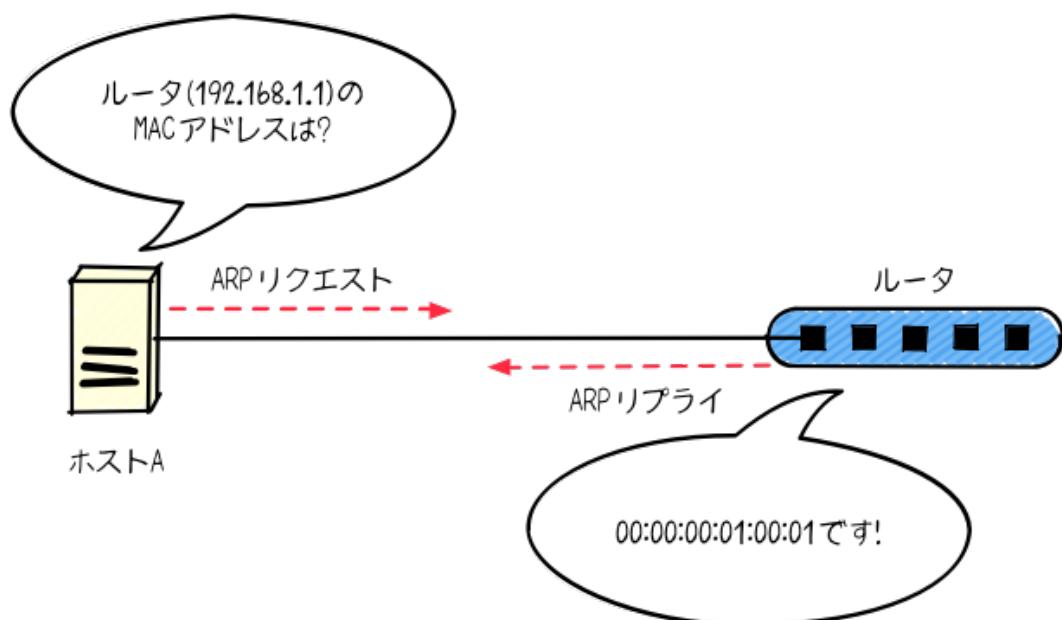
```
##### # ##### # ##### # ##### # ##### # ##### # ##### # ##### # ##### # #####
```



12.1.

#####1 #####

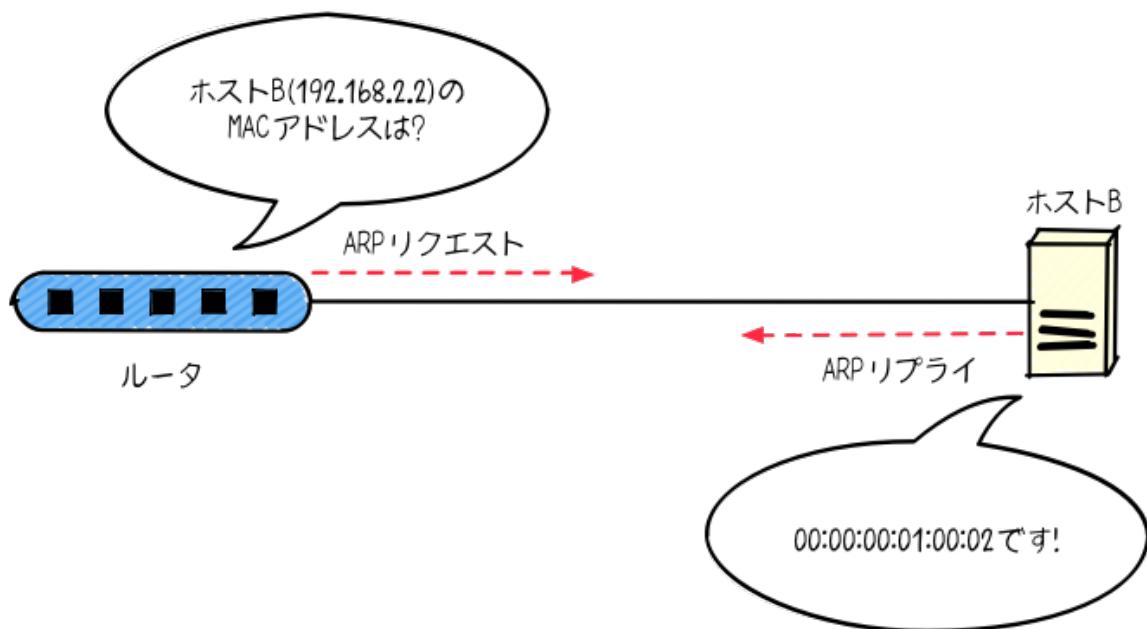
#####



12.2. ##### ##### ##### ##### ##### ##### ##### #####

#####

```
#####
##### (##:##:##:##:#) #####
```

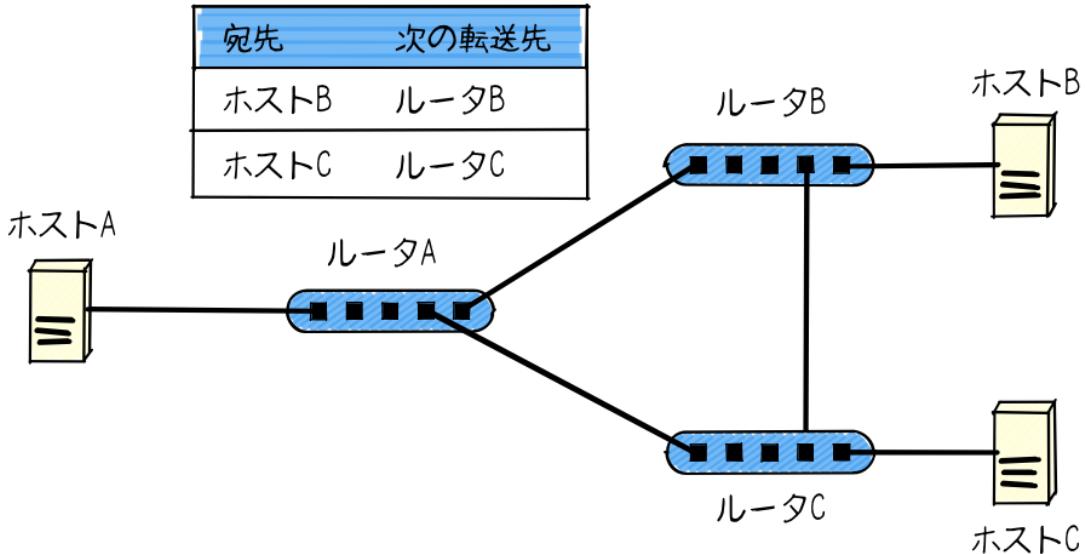


12.3. ##### ##### ##### ##### #####

12.3.2.

(# 12#4) ##### # ##### # ##### # ##### # #####

#####



12.4.

```
#####
##### 12#4 #####
#####
#####
```

12.4.

```
##### ( SimpleRouter ) ##### ( lib/
simple_router.rb ) ##### # trema/simple_router ##### (####://
#####.###/#####/#####_#####) #####
```

```
$ git clone https://github.com/trema/simple_router.git
$ cd simple_router
$ bundle install --binstubs
```

12.4.1. ##### ##

```
##### packet_in #####
##### _## (###/#####_#####.##)
#####
```

```
def packet_in(dpid, packet_in)
  return unless sent_to_router?(packet_in)
```

```

case packet_in.data
when Arp::Request
  packet_in_arp_request dpid, packet_in.in_port, packet_in.data
when Arp::Reply
  packet_in_arp_reply dpid, packet_in
when Parser::IPv4Packet
  packet_in_ipv4 dpid, packet_in
else
  logger.debug "Dropping unsupported packet type: #{packet_in.data.inspect}"
end
end

```

#####

```

#####
##### ( sent_to_router? ) #####
##### _ ## _ #####? ( ###/#####_#####.## )

```

```

def sent_to_router?(packet_in)
  return true if packet_in.destination_mac.broadcast?
  interface = Interface.find_by(port_number: packet_in.in_port)
  interface && interface.mac_address == packet_in.destination_mac
end

```

```

## sent_to_router? ##### ## ( packet_in.destination_mac ) #####
## ## ##### ( packet_in.in_port ) ##### ## ##
( interface.mac_address ) #####

```

#####

```

#####
## 3 ##### PacketIn#data #####

```

#####

```

### ##### packet_in_arp_request ##### #####
##### ## # ## #####

```

```

##### _ ## _ #####? ( ###/#####_#####.## )

```

```

def packet_in_arp_request(dpid, in_port, arp_request)
  interface =
    Interface.find_by(port_number: in_port,

```

```
ip_address: arp_request.target_protocol_address)  
return unless interface  
send_packet_out(  
    dpid,  
    raw_data: Arp::Reply.new(  
        destination_mac: arp_request.source_mac,  
        source_mac: interface.mac_address,  
        sender_protocol_address: arp_request.target_protocol_address,  
        target_protocol_address: arp_request.sender_protocol_address  
    ).to_binary,  
    actions: SendOutPort.new(in_port))  
end
```

######

```
###      #####      ######      ######      (@arp_table)      #      ###      #####  
PacketIn#sender_protocol ##### ##### ##### ##### ##### ##### #####  
##### ##### ##### ##### ## ### ##### (###/##### #####.##)
```

```
def packet_in_arp_reply(dpid, packet_in)
    @arp_table.update(packet_in.in_port,
                      packet_in.sender_protocol_address,
                      packet_in.source_mac)
    flush_unsent_packets(dpid,
                          packet_in.data,
                          Interface.find_by(port_number: packet_in.in_port))
end
```

```
#### flush_unsent_packets #####
```

###4 #####

```
####4 ##### packet_in_ipv4 ##### ####4 ##### 3 ##### ####
```

1. #####
 2. ## ## #####
 3. ##### (####)

#####4 (###/#####.##)

```
def packet_in_ipv4(dpid, packet_in)  
    if forward?(packet_in)
```

```

forward(dpid, packet_in)
elsif packet_in.ip_protocol == 1
  icmp = Icmp.read(packet_in.raw_data)
  packet_in_icmpv4_echo_request(dpid, packet_in) if icmp.icmp_type == 8
else
  logger.debug "Dropping unsupported IPv4 packet: #{packet_in.data}"
end
end

#####
##### forward? #####
####4 #####
####4 #####
####? (####/#####_#####.##)

def forward?(packet_in)
  !Interface.find_by(ip_address: packet_in.destination_ip_address)
end

#####
##### packet_in_icmpv4_echo_request #####
####4 #####
####? (####/#####_#####.##)

def packet_in_icmpv4_echo_request(dpid, packet_in)
  icmp_request = Icmp.read(packet_in.raw_data)
  if @arp_table.lookup(packet_in.source_ip_address)
    send_packet_out(dpid,
      raw_data: create_icmp_reply(icmp_request).to_binary,
      actions: SendOutPort.new(packet_in.in_port))
  else
    send_later(dpid,
      interface: Interface.find_by(port_number: packet_in.in_port),
      destination_ip: packet_in.source_ip_address,
      data: create_icmp_reply(icmp_request))
  end
end

#####
##### ( packet_in.source_ip_address ) #####
##### create_icmp_reply #####
##### send_later #####
#####

```

12.4.2.

```
#####
```

```
#####
##### (####/# ##### _ #####.##)
```

def forward(dpid, packet_in)
next_hop = resolve_next_hop(packet_in.destination_ip_address)

interface = Interface.find_by_prefix(next_hop)
return if !interface || (interface.port_number == packet_in.in_port)

arp_entry = @arp_table.lookup(next_hop)
if arp_entry
 actions = [SetSourceMacAddress.new(interface.mac_address),
 SetDestinationMacAddress.new(arp_entry.mac_address),
 SendOutPort.new(interface.port_number)]
 send_flow_mod_add(dpid,
 match: ExactMatch.new(packet_in), actions: actions)
 send_packet_out(dpid, raw_data: packet_in.raw_data, actions: actions)
else
 send_later(dpid,
 interface: interface,
 destination_ip: next_hop,
 data: packet_in.data)
end
end

```
## forward ##### 5 #####
```



```
#####1#4#####1##### resolve_next_hop #####4  
#####
```

(#### # # #####)

```
actions = [SetSourceMacAddress.new(interface.mac_address),
```

```
    SetDestinationMacAddress.new(arp_entry.mac_address),  
    SendOutPort.new(interface.port_number)]  
send_flow_mod_add(dpid,  
                  match: ExactMatch.new(packet_in), actions: actions)  
send_packet_out(dpid, raw_data: packet_in.raw_data, actions: actions)
```

12.4.3.

#####4 ##### (###/#####.##)

```
def packet_in_icmpv4_echo_request(dpid, packet_in)
    icmp_request = Icmp.read(packet_in.raw_data)
    if @arp_table.lookup(packet_in.source_ip_address)
        send_packet_out(dpid,
            raw_data: create_icmp_reply(icmp_request).to_binary,
            actions: SendOutPort.new(packet_in.in_port))
    else
        send_later(dpid,
            interface: Interface.find_by(port_number: packet_in.in_port),
            destination_ip: packet_in.source_ip_address,
            data: create_icmp_reply(icmp_request))
    end
end
```

```
send_later    #####    data: #####    ###    #####    #####  
interface: #####    ## ##### destination_ip: #####
```

```
send_later ##### (queue) #####
#####
```

(###/##### #####,##)

```
def send_later(dpid, options)
    destination_ip = options.fetch(:destination_ip)
    @unresolved_packet_queue[destination_ip] += [options.fetch(:data)]
    send_arp_request(dpid, destination_ip, options.fetch(:interface))
end
```

```
##### packet_in_arp_reply #####
flush_unsent_packets #####
```

#####_#####_##### (###/#####_#####.##)

```

def flush_unsent_packets(dpid, arp_reply, interface)
    destination_ip = arp_reply.sender_protocol_address
    @unresolved_packet_queue[destination_ip].each do |each|
        rewrite_mac =
            [SetDestinationMacAddress.new(arp_reply.sender.hardware_address),
             SetSourceMacAddress.new(interface.mac_address),
             SendOutPort.new(interface.port_number)]
        send_packet_out(dpid, raw_data: each.to_binary_s, actions: rewrite_mac)
    end
    @unresolved_packet_queue[destination_ip] = []
end

```

12.5.

#####

##13 #####

13. ### (##)

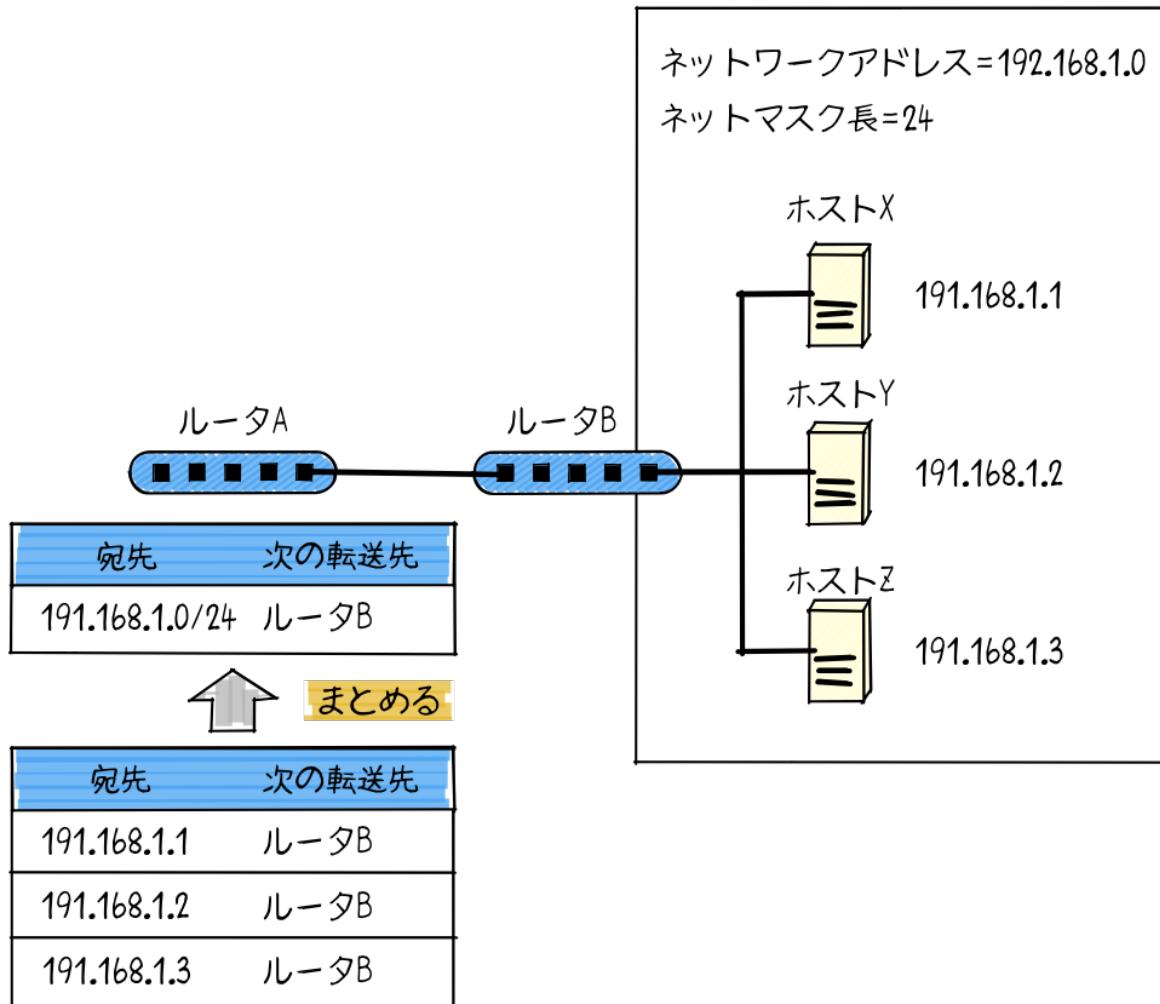
#####



13.1.

#####1#####
#####2#####
#####2016#####10#####
#####

#####1#####
#####



13.1.

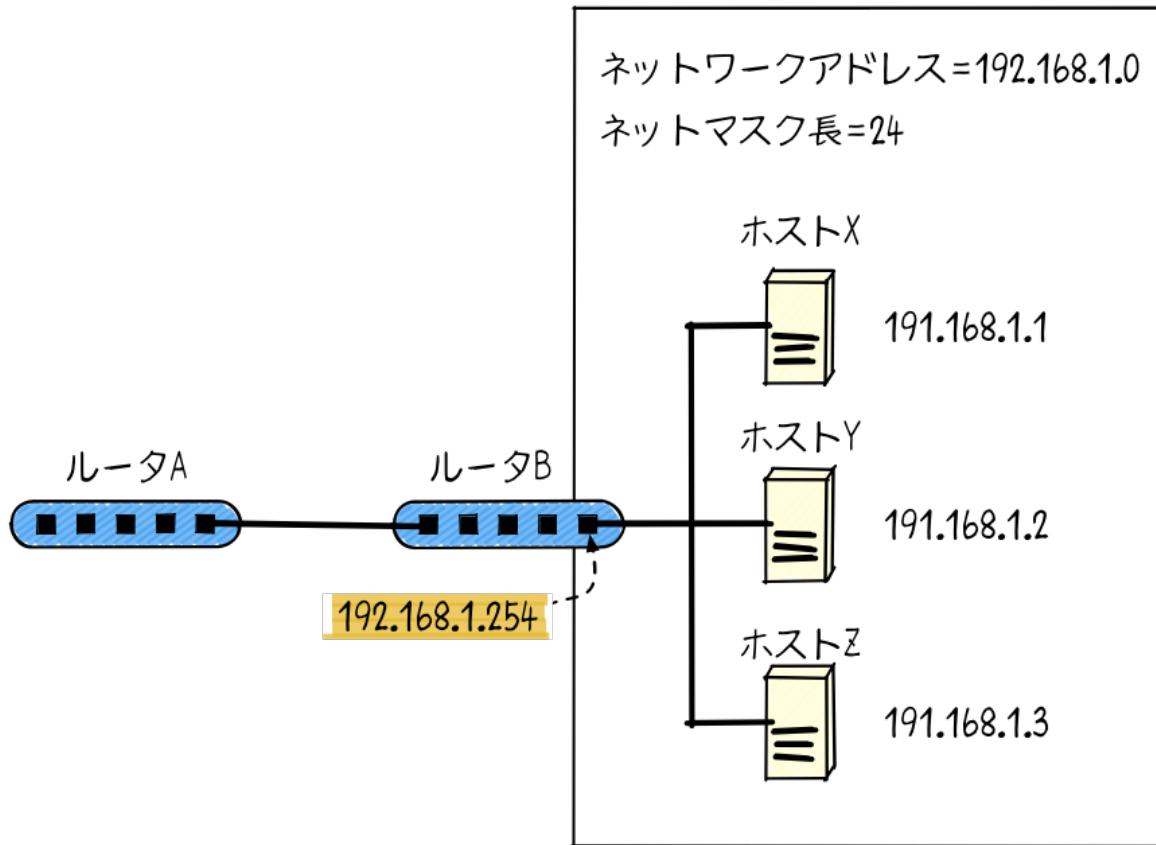
```
#####13#1#####192.168.1.0#####24
##(##192.168.1.0/24##)#####,,##24#####
#####192.168.1#####1##192.168.1.0/24####
```

```
#####13#1#####1####192.168.1.0/24#####1#####
```

```
#####(192.168.1.1)#####1#####3#####
```

13.1.1.

```
#####
##### #13#2 #####
##### 192.168.1.254 #####
```

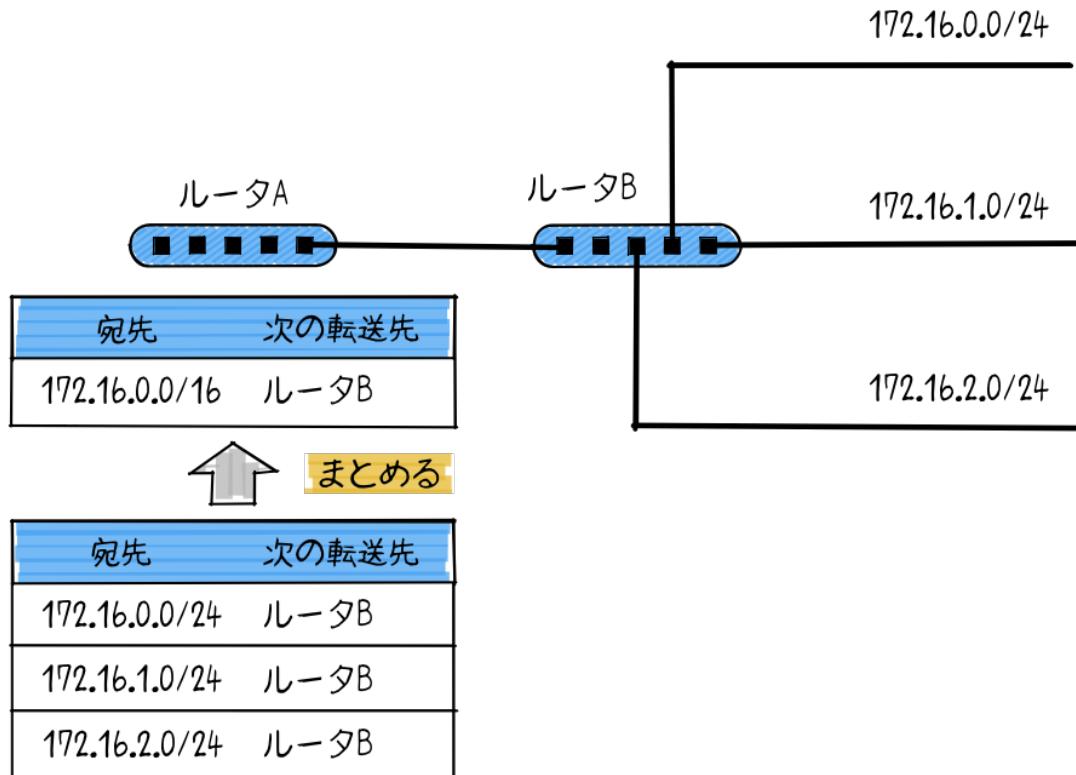


```
#####
13.2. #####
#####
#####
```

```
#####
#13#2 #####
(192.168.1.1) #####
##### 192.168.1.254 #####
##### ##### ##### #####
```

13.2.

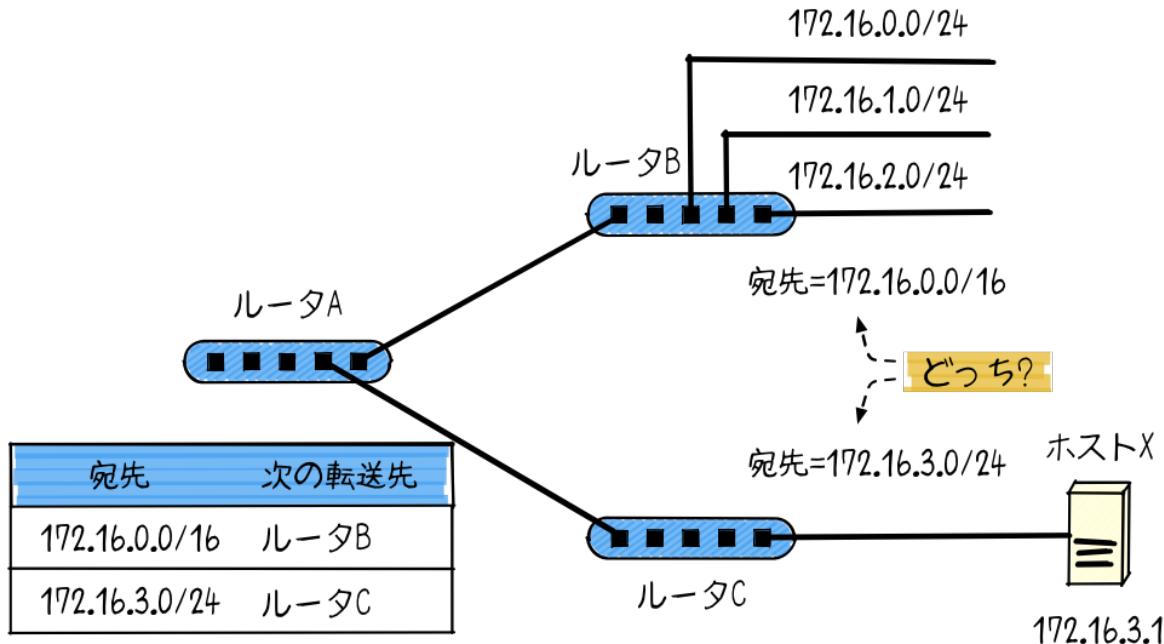
```
#####
#####
```



13.3.

13#3#3#####3#####3#####3#####16###172.16.0.0#
#####3#####3#####3#####3#####3#####3#####3#####
##172.16.0.0/16##1#####

13.2.1. 1#####

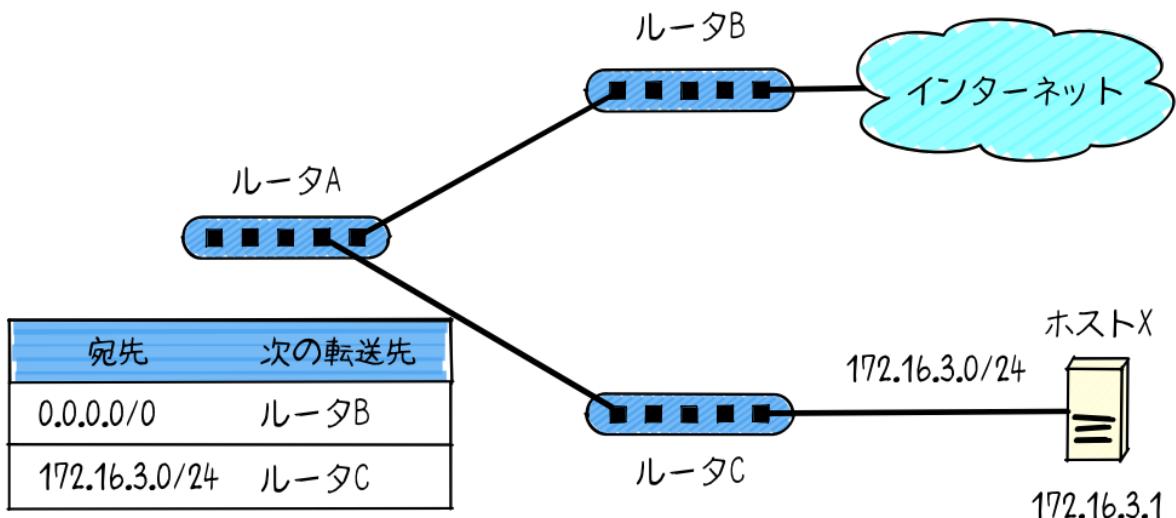


13.4.

#####
#####

13.2.2.

#####
0.0.0.0/0
0
###



13.5. 0.0.0.0/0

```
#13#5 ##### (172.16.3.0/24) #####
##172.16.3.0/24 #####
#####
```

13.3. ##### ##### ##### ##### ##### #####

13.3.1. #####(#)

```
RoutingTable ##### forward #####
##### 5 #####
```

```
#####
# (####/# ##### _#####.##)
#####
def forward(dpid, packet_in)
    next_hop = resolve_next_hop(packet_in.destination_ip_address)

    interface = Interface.find_by_prefix(next_hop)
    return if !interface || (interface.port_number == packet_in.in_port)

    arp_entry = @arp_table.lookup(next_hop)
    if arp_entry
        actions = [SetSourceMacAddress.new(interface.mac_address),
```

```

    SetDestinationMacAddress.new(arp_entry.mac_address),
    SendOutPort.new(interface.port_number)]
send_flow_mod_add(dpid,
                  match: ExactMatch.new(packet_in), actions: actions)
send_packet_out(dpid, raw_data: packet_in.raw_data, actions: actions)
else
  send_later(dpid,
              interface: interface,
              destination_ip: next_hop,
              data: packet_in.data)
end
end

```

(packet_in.destination_ip_address) ##### resolve_next_hop

#####_####_### (###/#####_#####.##)

```
def resolve_next_hop(destination_ip_address)
    interface = Interface.find_by_prefix(destination_ip_address)
    if interface
        destination_ip_address
    else
        @routing_table.lookup(destination_ip_address)
    end
end
```

```
#####
#####
```

(###/##### ####.##)

```
interface = Interface.find_by_prefix(next_hop)  
return if !interface || (interface.port_number == packet_in.in_port)
```

```
#####
#####
```

13.3.2. ##### (RoutingTable #####)

#####

###/#####.## #####.##

```

# Routing table
class RoutingTable
  include Pio

  MAX_NETMASK_LENGTH = 32

  def initialize(route)
    @db = Array.new(MAX_NETMASK_LENGTH + 1) { Hash.new }
    route.each { |each| add(each) }
  end

  def add(options)
    netmask_length = options.fetch(:netmask_length)
    prefix = IPv4Address.new(options.fetch(:destination)).mask(netmask_length)
    @db[netmask_length][prefix.to_i] = IPv4Address.new(options.fetch(:next_hop))
  end

  def lookup(destination_ip_address)
    MAX_NETMASK_LENGTH.downto(0).each do |each|
      prefix = destination_ip_address.mask(each)
      entry = @db[each][prefix.to_i]
      return entry if entry
    end
    nil
  end
end

```

```

##### @db ##### (0 # 32) #####
#####
##### ######
##### lookup ##### destination_ip_address #####
##### @db ##### (32...0) # @db #####
#####

```

13.3.3.

```

#####
simple_router.conf #####
#####

```

```

# Simple router configuration
module Configuration
  INTERFACES =

```

```
{  
    port: 1,  
    mac_address: '01:01:01:01:01:01',  
    ip_address: '192.168.1.1',  
    netmask_length: 24  
},  
{  
    port: 2,  
    mac_address: '02:02:02:02:02:02',  
    ip_address: '192.168.2.1',  
    netmask_length: 24  
}  
]
```

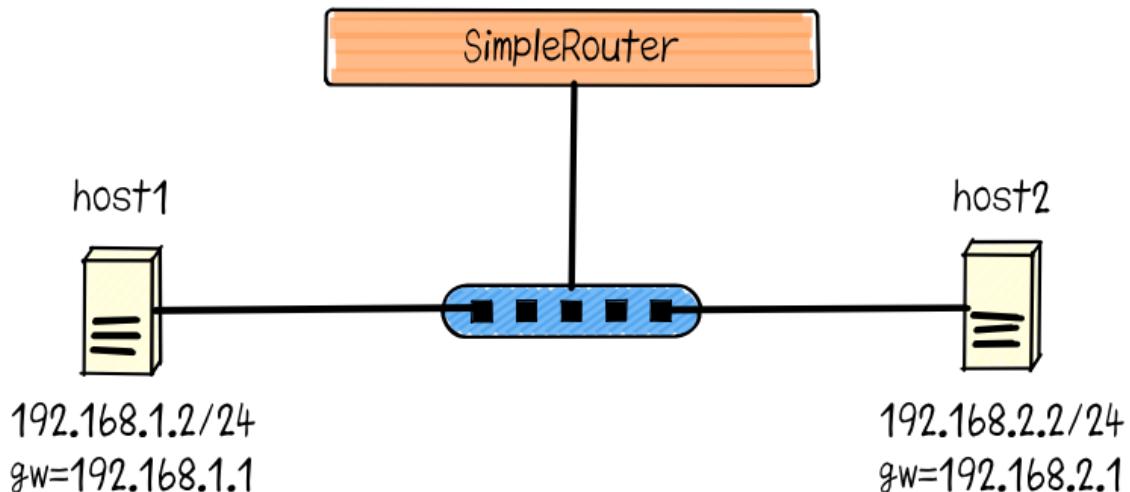
ROUTES = [

```
{  
    destination: '0.0.0.0',  
    netmask_length: 0,  
    next_hop: '192.168.1.2'  
}
```

```
##### (:mac_address)##### (:ip_address)#####  
(:netmask_length)##### (:port)#####
```

```
##### ( :destination ) ##### ( :netmask_length ) ##### ( :next_hop ) #####
####
```

13.4.



13.6.

#####.#####

```
vswitch('0x1') { dpid 0x1 }
netns('host1') {
    ip '192.168.1.2'
    netmask '255.255.255.0'
    route net: '0.0.0.0', gateway: '192.168.1.1'
}
netns('host2') {
    ip '192.168.2.2'
    netmask '255.255.255.0'
    route net: '0.0.0.0', gateway: '192.168.2.1'
}
link '0x1', 'host1'
link '0x1', 'host2'
```

```
##### trem run # lib/simple_router.rb ##### 13#6#####
```

```
$ ./bin/trema run ./lib/simple-router.rb -c ./trema.conf
```

```
##### tremा netns #####1  
#####
```

```
$ ./bin/trema netns host1
#####
#####1 #####
#####
```

```
$ route -n
Kernel IP routing table
Destination     Gateway      Genmask      Flags Metric Ref  Use Iface
0.0.0.0         192.168.1.1  0.0.0.0      UG        0      0      0 host1
192.168.1.0    0.0.0.0     255.255.255.0 U          0      0      0 host1
```

```
#####
#####192.168.1.1 ##### trema netns #####
##### exit ####:[#### + #] ####
```

13.4.1. ####

```
#####
#####1 #####192.168.1.1 #####
```

```
$ ./bin/trema netns host1
$ ping 192.168.1.1
PING 192.168.1.1 (192.168.1.1) 56(84) bytes of data.
64 bytes from 192.168.1.1: icmp_seq=1 ttl=128 time=47.4 ms
64 bytes from 192.168.1.1: icmp_seq=2 ttl=128 time=15.0 ms
64 bytes from 192.168.1.1: icmp_seq=3 ttl=128 time=15.0 ms
64 bytes from 192.168.1.1: icmp_seq=4 ttl=128 time=19.3 ms
64 bytes from 192.168.1.1: icmp_seq=5 ttl=128 time=14.8 ms
64 bytes from 192.168.1.1: icmp_seq=6 ttl=128 time=14.4 ms
64 bytes from 192.168.1.1: icmp_seq=7 ttl=128 time=15.1 ms
^C
--- 192.168.1.1 ping statistics ---
7 packets transmitted, 7 received, 0% packet loss, time 6008ms
rtt min/avg/max/mdev = 14.425/20.189/47.473/11.245 ms
```

```
#####
#####1 #####2 # ## #####
192.168.2.2 #####1 ## #####
#####
```

```
$ ping 192.168.2.2
PING 192.168.2.2 (192.168.2.2) 56(84) bytes of data.
64 bytes from 192.168.2.2: icmp_seq=1 ttl=64 time=75.5 ms
64 bytes from 192.168.2.2: icmp_seq=2 ttl=64 time=82.3 ms
64 bytes from 192.168.2.2: icmp_seq=3 ttl=64 time=101 ms
64 bytes from 192.168.2.2: icmp_seq=4 ttl=64 time=83.3 ms
```

```
64 bytes from 192.168.2.2: icmp_seq=5 ttl=64 time=78.2 ms
64 bytes from 192.168.2.2: icmp_seq=6 ttl=64 time=76.4 ms
64 bytes from 192.168.2.2: icmp_seq=7 ttl=64 time=70.9 ms
^C
--- 192.168.2.2 ping statistics ---
7 packets transmitted, 7 received, 0% packet loss, time 6008ms
rtt min/avg/max/mdev = 70.995/81.159/101.180/9.050 ms
```

13.4.2. ##### ######

```
$ sudo apt-get update  
$ sudo apt-get install iperf
```

```
$ ./bin/trema netns host2  
$ iperf -s --bind 192.168.2.2
```

```
Server listening on TCP port 5001  
Binding to local address 192.168.2.2  
TCP window size: 85.3 KByte (default)
```

```
$ ./bin/trema netns host1  
$ iperf -c 192.168.2.2 --bind 192.168.1.2
```

Client connecting to 192.168.2.2, TCP port 5001
Binding to local address 192.168.1.2
TCP window size: 85.0 KByte (default)

```
[ 3] local 192.168.1.2 port 5001 connected with 192.168.2.2 port 5001  
[ ID] Interval      Transfer     Bandwidth  
[ 3] 0.0-16.4 sec  256 KBytes  128 Kbits/sec
```

13.5.

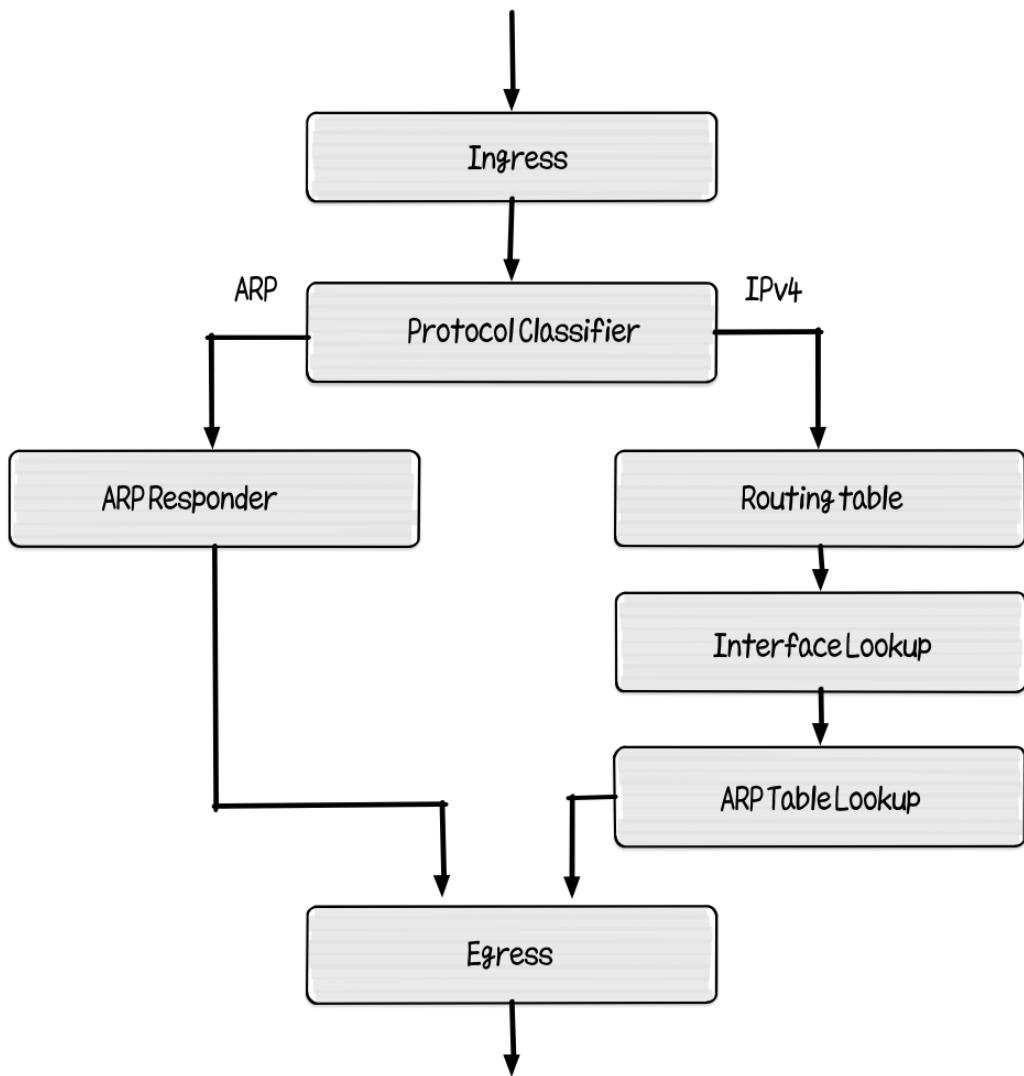
#####

- #####(#####)######1#####(#####)###############
- #####
- ##### (#####) ##
- #####0.0.0/0#####
- #####

14. #### (#####)

#####1.3

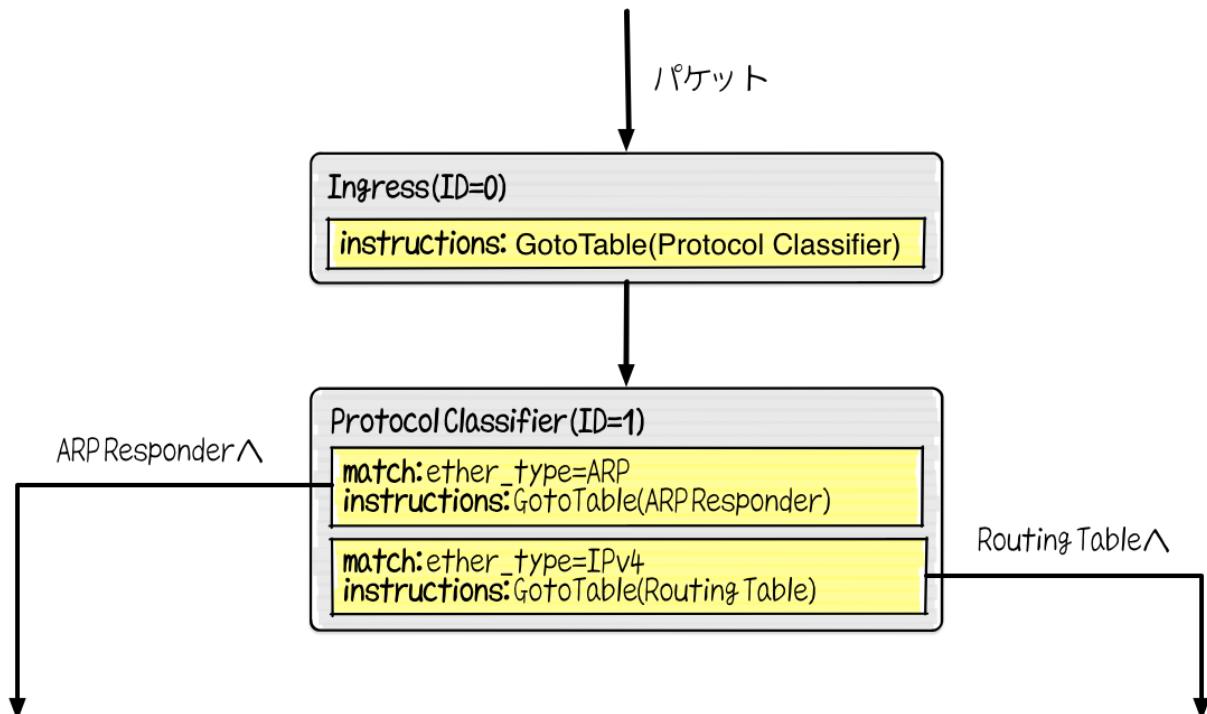
14.1.



14.1.

#####

0 ## ##### ##### (# 14#2)##



14.2. ##### ## = 0 # ##### ##### ##### ##### ##### #####
#####

#####

ether_type ##### ##### ##### ##### ##### ##### ##### ##### #####
#####

14.1.2. ##### ##### ##### #####

#####

#####

#####

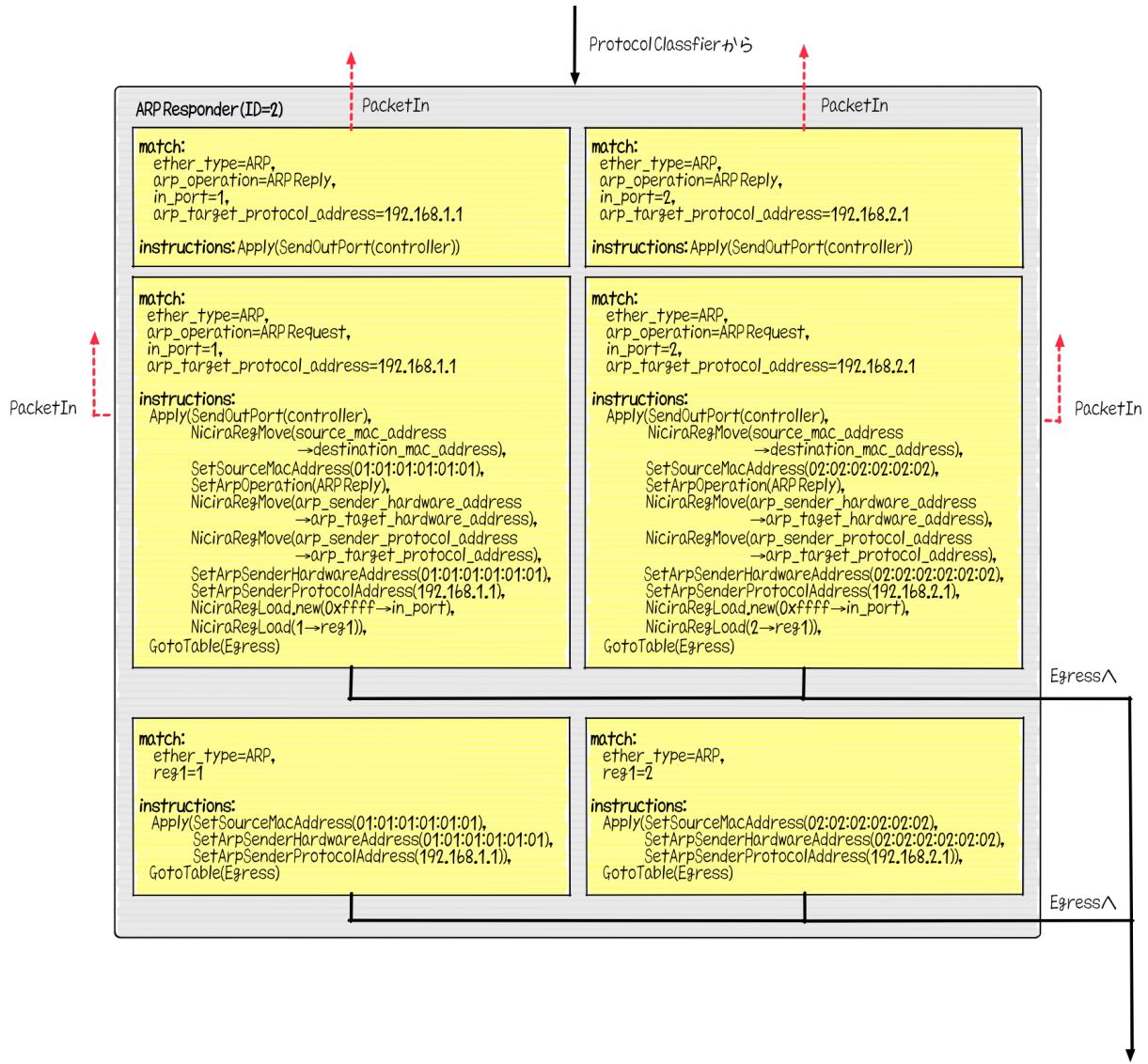
#####

#####

#####

#####

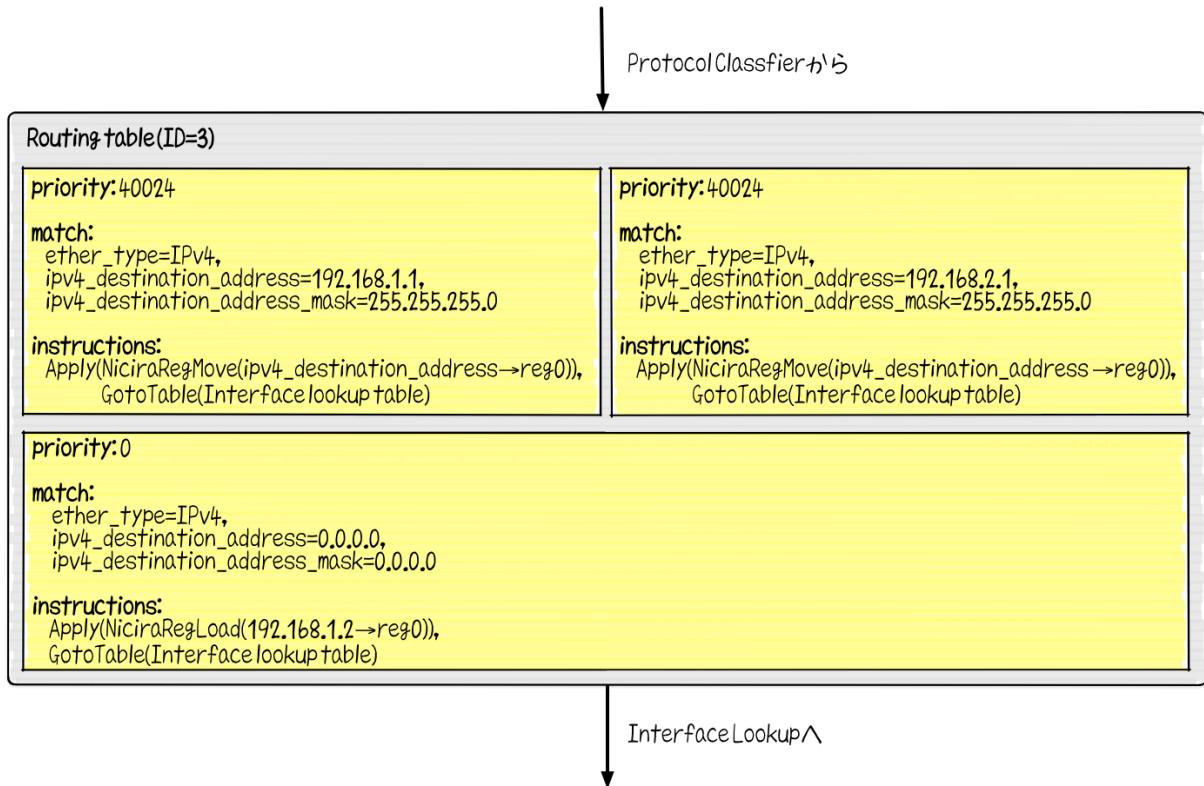
3 #####x##### ##### ##### ##### ##### ##### 2 ##### 14#3#####
6 ##### ##### ##### ##### ##### ##### ##### #####



14.1.3. ##### ####

```
##### reg0 #####
```

(# #####)

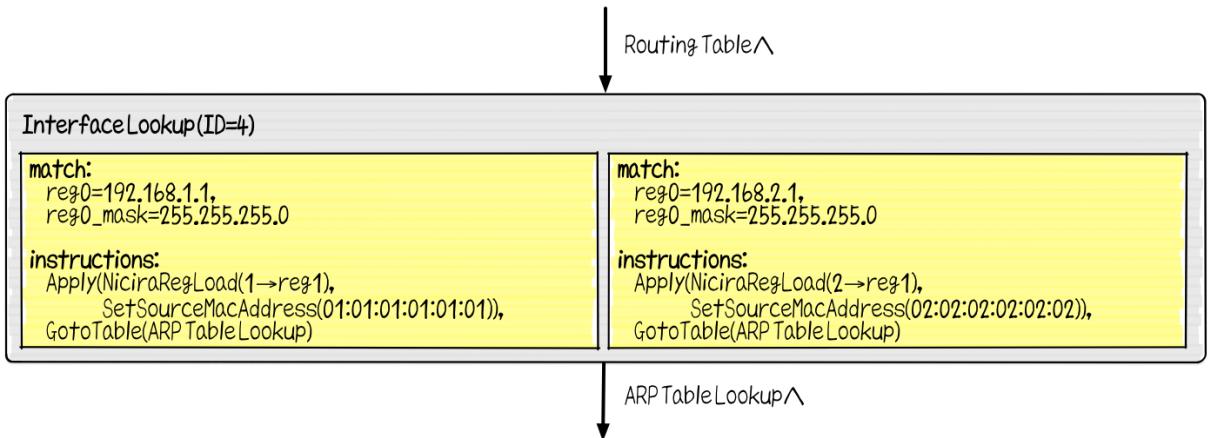


###: ####

14.1.4. ##### ###### #######

```
##### reg0 ##### reg1 #####
```

(# #####)

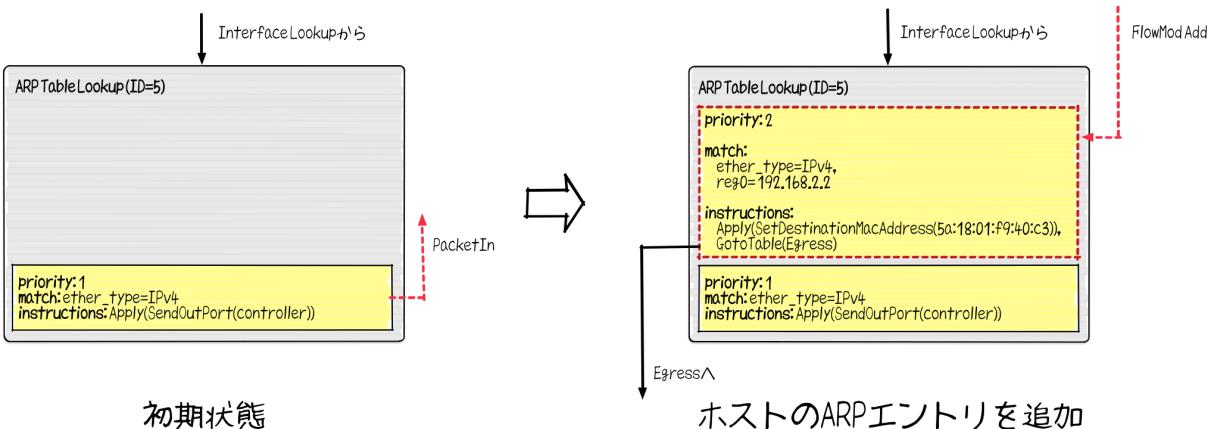


14.5. ##### ##### ##### ##### #####

14.1.5.

```
##### ##### ##### (# 14#6)##### ( reg0 )#####  
##### ##### ##### #####
```

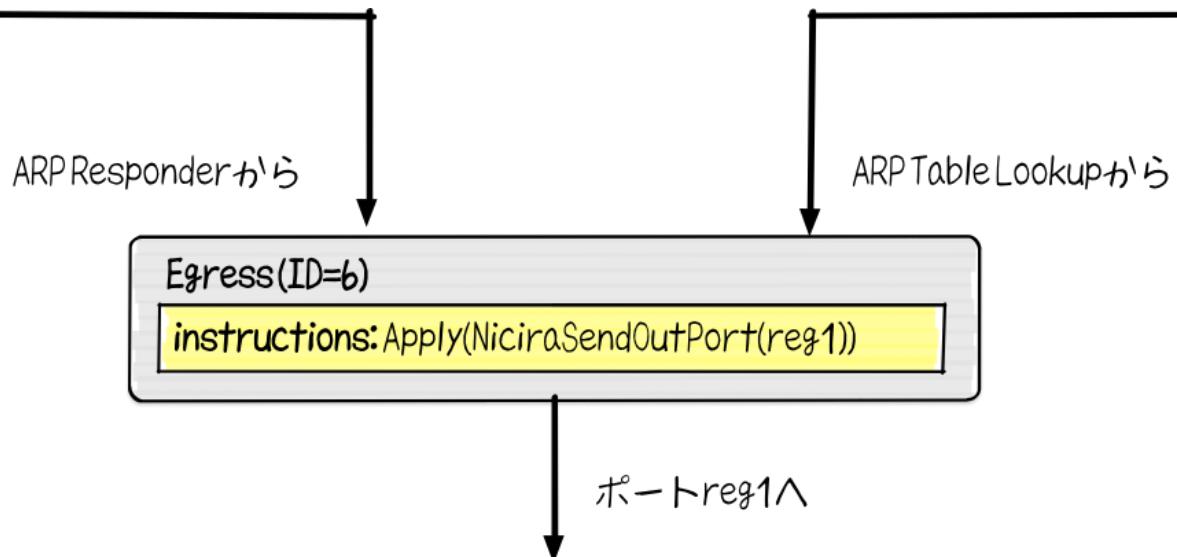
```
#####
##### 1 #####
#####
#####
```



14.1.6. #####

```
##### ##### ##### (# 14#7)##### reg1 #####  
#####
```

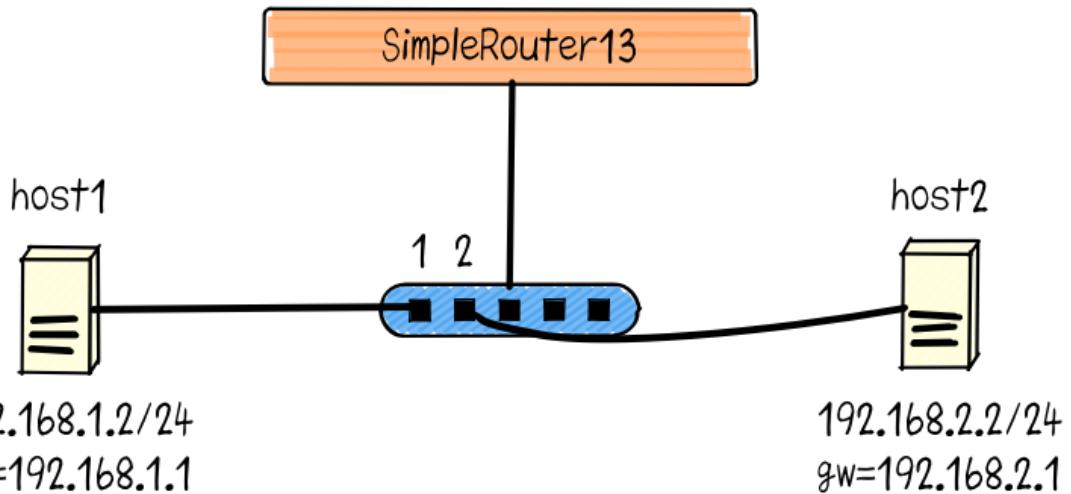
(#####)



14.7.

14.2.

14#8#####



14.8.

_ ##### # ##### / ##### _ ##### # #####

\$ git clone https://github.com/trema/simple_router.git

#####

```
$ cd simple_router
$ bundle install --binstubs
```

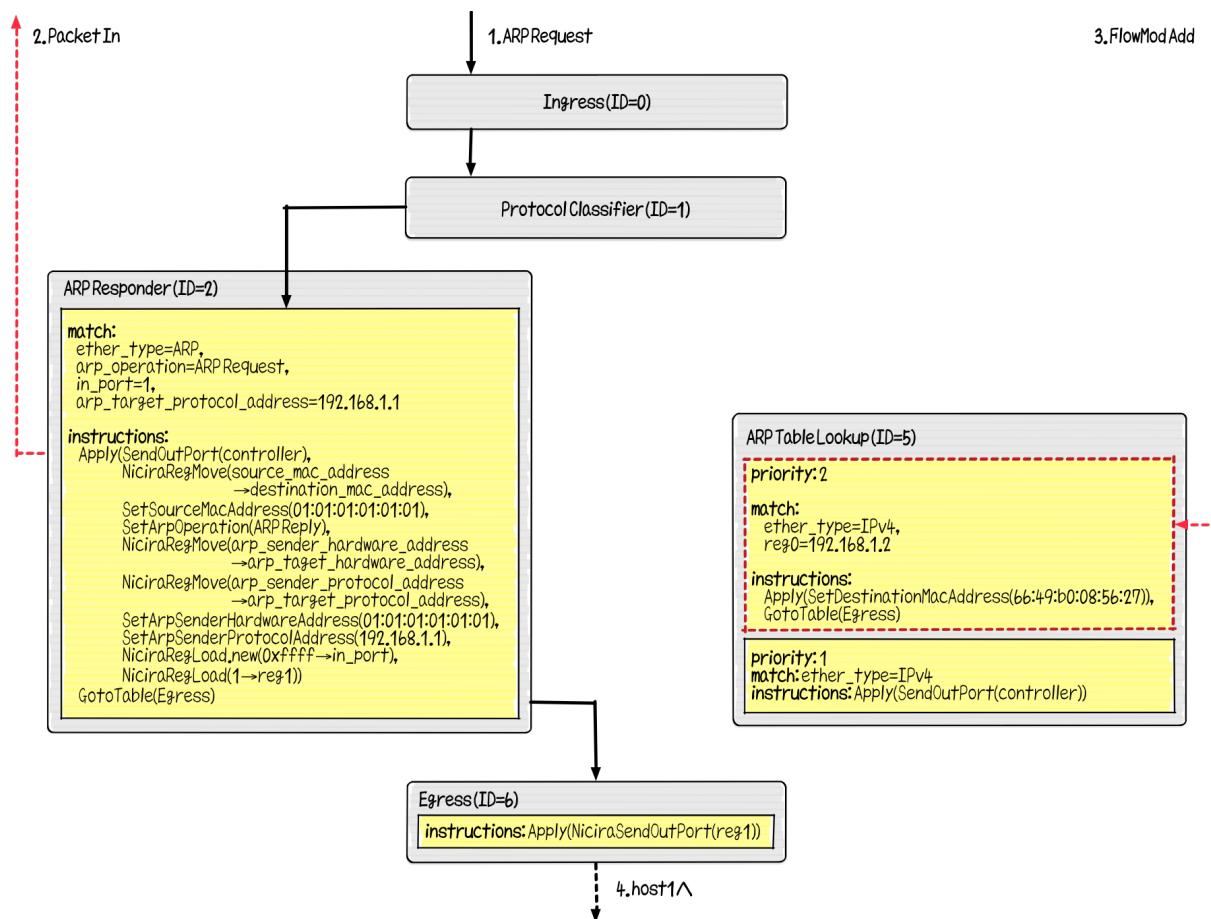
#####

14.2.1. ##### #### #####

#####1 ##### 1 #### #### ##### ##### 14#9# 2 #####:

1. #####1 # #### #####

2. #### ##### # #####1 ####



14.9. #####1 ##### 1 ## #### #####

#####1 # #### #####

```

### 1 ##### #### ##### ##### #### ##### #### #####
##### ##### (# 14#9 #1)##### #### ##### #### #####1 # #### #####
SendOutPort
##### ##### ###### ###### ###### (# 14#9 # 2)#

```

```
#####
host1 ##### (# 14#9 # 3)#
#####
```

```
#####
#####13#### _##_ ##### (##/##### _#####13.##)
#####
def add_arp_entry(ip_address, mac_address, dpid)
    send_flow_mod_add(
        dpid,
        table_id: ARP_TABLE_LOOKUP_TABLE,
        priority: 2,
        match: Match.new(ether_type: EthernetHeader::EtherType::IPV4,
            reg0: IPv4Address.new(ip_address).to_i),
        instructions: [Apply.new(SetDestinationMacAddress.new(mac_address)),
            GotoTable.new(EGRESS_TABLE)])
)
end
```

#####1

```
#####
#####
```

- ##### source_mac_address ##### destination_mac_address #####
- source_mac_address ##### ##### ##### ##### ##### #####
- ##### ##### ##### ##### ##### ##### #####
- ##### # sender_hardware_address ##### ##### ##### ##### target_hardware_address ##### ##### ##### #####
- ##### # sender_protocol_address ##### ##### ##### ##### target_protocol_address ##### ##### ##### #####
- ##### # sender_hardware_address ##### ##### ##### #####
- ##### # sender_protocol_address ##### ##### ##### #####

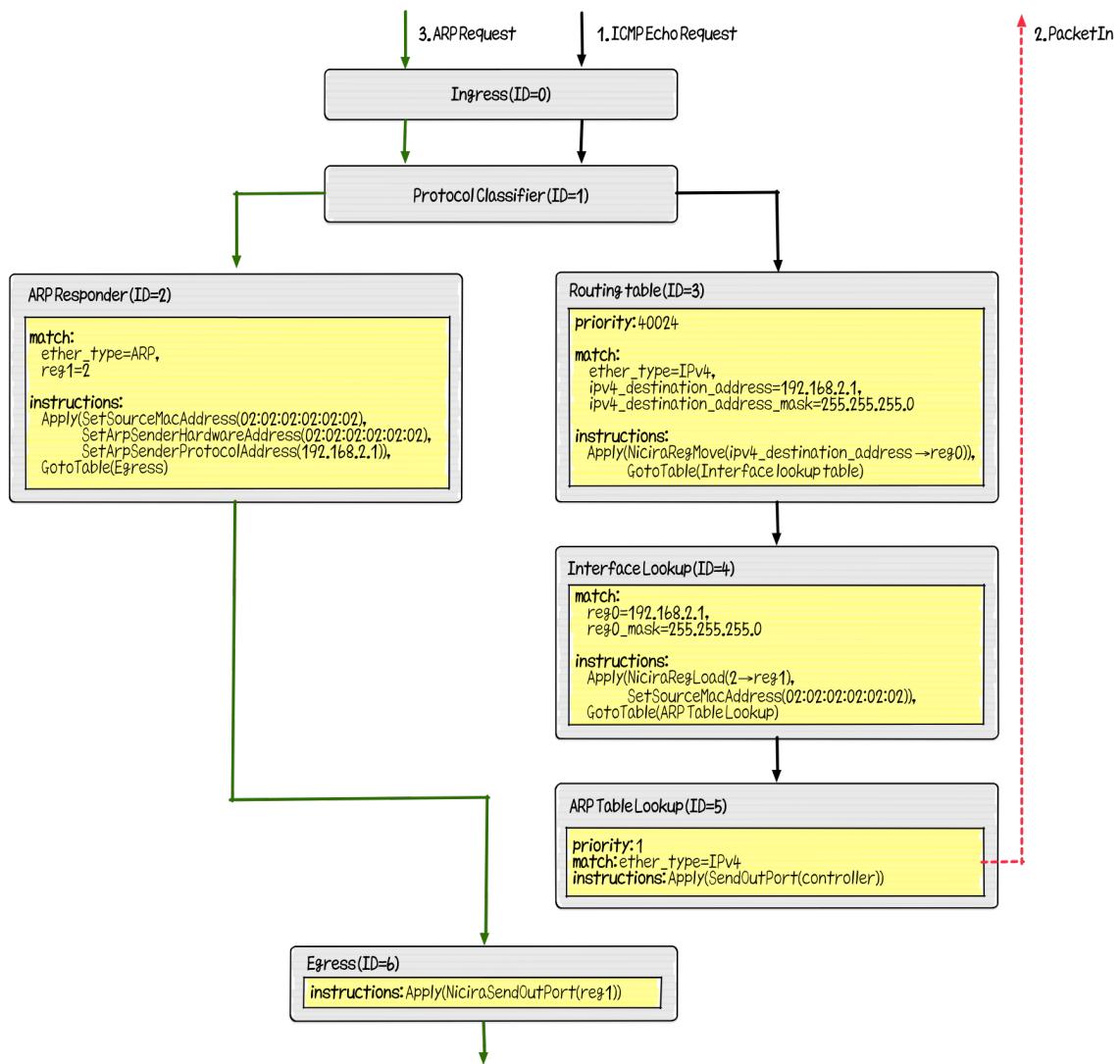
```
#####
##### 1 (= host1 #####) # reg1 ##### ##### ##### #
##### ##### (# 14#9 # 4)##### ##### reg1 # ##### ##### #####
```

14.2.2. #####1 #####2

```
# 14#8 ##### host1 ## host2 ##### ##### ##### ##### #####2 ##### #####
##### ##### ##### #####
```

1. #####1 ##### ##### ##### ##### #####1 #####
2. ##### ##### ##### ##### #####2 #####

3. #####2 # #### ##### ##### ##### ##### ##### ##### ##### #####
4. #####2 ##### #### ##### ##### #### ##### ##### #####
5. ##### ##### #### ##### ##### ##### ##### ##### ##### #####2 #####



14.2.3.

(######)

```
###1 ##### 192.168.2.2 # reg0 ##### ##### ##### ##### ##### #####  
##### 2 # reg1 #####
```

14.2.4. #####2 # #### #########

```
## ##### ##### #####2 # ### ###############2 # ### ####################  
##### ##### ##### ##### ##### ##### ##### (# 14#10 # 2)#

```

```
##### ###### ## ##### ##### ##### ##### ##### ##### ##### #####2 # #### #####  
## #### ##### ##### ##### ##### ##### ##### ##### ##### (# 14#10 # 3)##### ##### ##### ## reg1 (#  
#####) # 2 #####
```

#####13##### ## ##4 (###/##### #####13.#)

```

def packet_in_ipv4(dpid, packet_in)
    dest_ip_address = IPv4Address.new(packet_in.match.reg0.to_i)
    @unresolved_packet_queue[dest_ip_address] += [packet_in.raw_data]
    send_packet_out(
        dpid,
        raw_data: Arp::Request.new(target_protocol_address: dest_ip_address,
                                    source_mac: '00:00:00:00:00:00',
                                    sender_protocol_address: '0.0.0.0').to_binary,
        actions: [NiciraRegLoad.new(packet_in.match.reg1, :reg1),
                  SendOutPort.new(:table)])
)
end

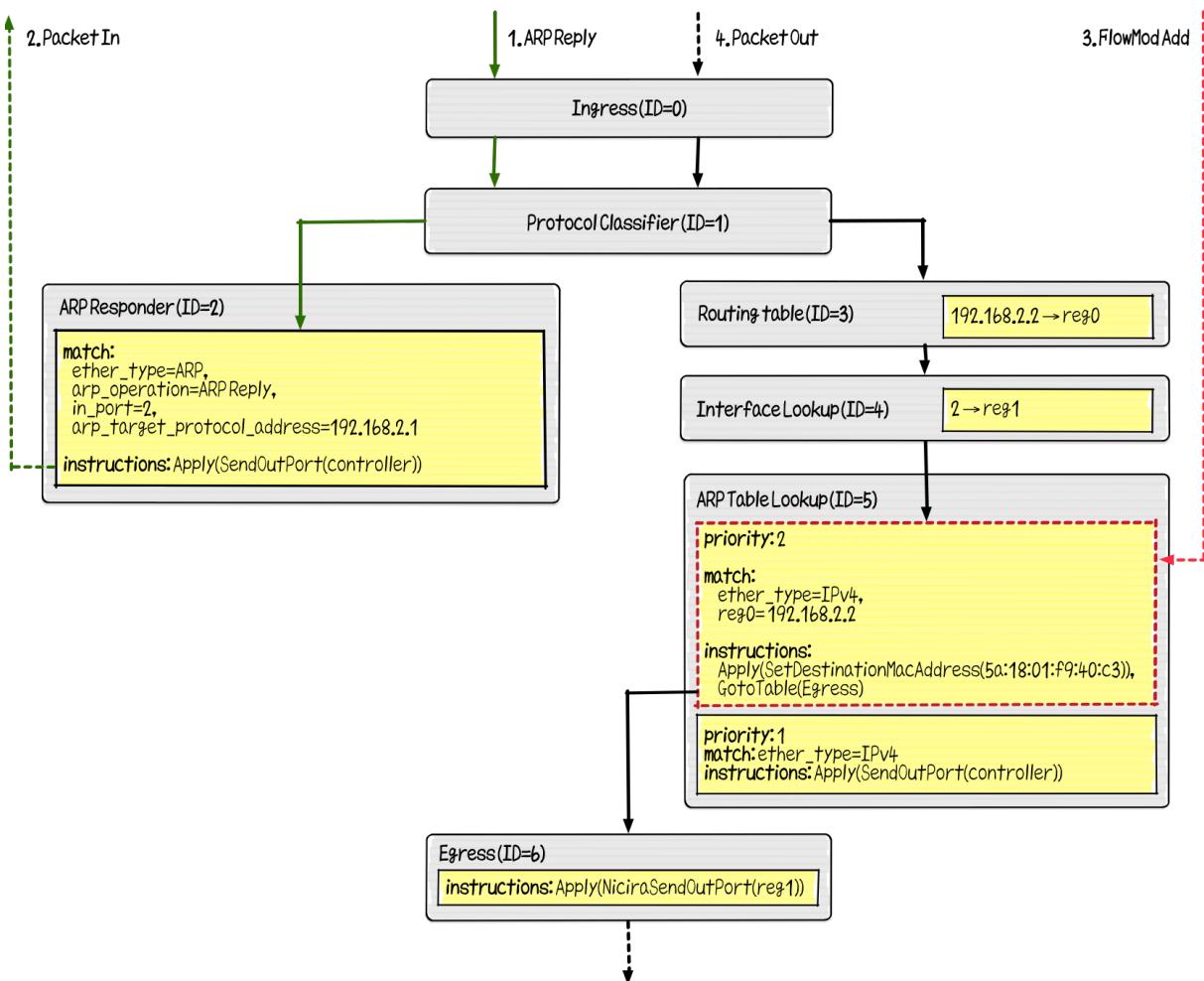
```

```
##### reg1 ##### #####
##### 2 ##### #####
##### 2 ##### #####
#####
```

14.2.5. #####2 #### #### ######

#####2 #### ## ##### ##### ##### ##### ##### ##### ##### (# 14#11 # 1, 2)##

```
1 ##### (#### ###### ######) ##### ###### ##### ###### ##### ###### ##### ###### #####  
##### lib/simple_router13.rb # SimpleRouter13#add_routing_table_flow_entries #####  
#####
```



14.11. #####2 # ##### ##### ##### ##### ##### ##### ##### ##### #####2

(# 14#11 # 3)##### ##### ##### ##### ##### ##### #####
(# 14#11 # 4)
##########13#####_##_## (##/#####_#####13.##)

```

def packet_in_arp(dpid, packet_in)
    add_arp_entry(packet_in.sender_protocol_address,
                  packet_in.sender.hardware_address,
                  dpid)
    @unresolved_packet_queue[packet_in.sender_protocol_address].each do |each|
        send_packet_out(dpid, raw_data: each, actions: SendOutPort.new(:table))
    end
    @unresolved_packet_queue[packet_in.sender_protocol_address] = []
end
    
```

#####1 ## #####2 ## ##### ##### ##### ##### ##### ##### ##### ##### #####
#####1

14.3.

```
##### (######_#####13.#) #####12 #13 #####1.3 ##### trema run ##### --openflow13 #####
```

```
$ ./bin/trema run ./lib/simple-router.rb -c ./trema.conf --openflow13  
SimpleRouter13 started.
```

```
##### host1 ## host2 # ##### ##### #####
```

```
$ bundle exec trema netns host1 "ping -c1 192.168.2.2"  
PING 192.168.2.2 (192.168.2.2) 56(84) bytes of data.  
64 bytes from 192.168.2.2: icmp_seq=1 ttl=64 time=132 ms
```

```
--- 192.168.2.2 ping statistics ---  
1 packets transmitted, 1 received, 0% packet loss, time 0ms  
rtt min/avg/max/mdev = 132.738/132.738/132.738/0.000 ms
```

```
##### #####2 ##### trema dump_flows ##### ##### ##### ##### ##### ##### ##### #####
```

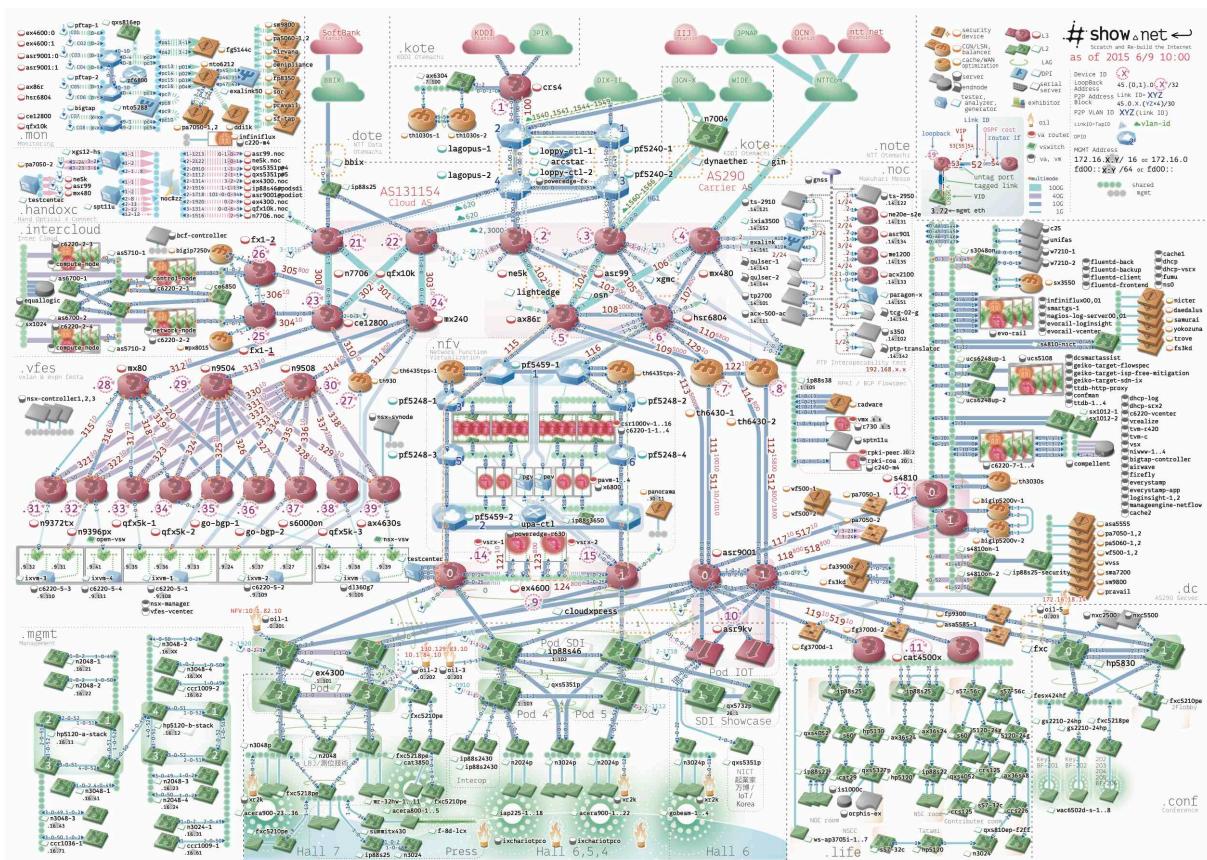
```
$ bundle exec trema dump_flows 0x1
OFPST_FLOW reply (OF1.3) (xid=0x2):
cookie=0x0, duration=153.160s, table=0, n_packets=21, n_bytes=1546, priority=0 actions=goto_table:1
cookie=0x0, duration=153.160s, table=1, n_packets=6, n_bytes=296, priority=0,arp actions=goto_table:2
cookie=0x0, duration=153.160s, table=1, n_packets=4, n_bytes=392, priority=0,ip actions=goto_table:3
cookie=0x0, duration=153.152s, table=2, n_packets=1, n_bytes=42,
priority=0,arp,in_port=1,arp_tpa=192.168.1.1,arp_op=1 actions=move:NXM_OF_ETH_SRC[]->NXM_OF_ETH_DST[],set_field:01:01:01:01:01:01->eth_src,set_field:2->arp_op,move:NXM_NX_ARP_SHA[]->NXM_NX_ARP_THA[],move:NXM_OF_ARP_SPA[]->NXM_OF_ARP_TPA[],set_field:01:01:01:01:01:01->arp_sha,set_field:192.168.1.1->arp_spa,load:0xffff->OXM_OF_IN_PORT[],load:0x1->NXM_NX_REG1[],goto_table:6
cookie=0x0, duration=153.142s, table=2, n_packets=1, n_bytes=42,
priority=0,arp,in_port=1,arp_tpa=192.168.1.1,arp_op=2 actions=CONTROLLER:65535
cookie=0x0, duration=153.103s, table=2, n_packets=1, n_bytes=42,
priority=0,arp,in_port=2,arp_tpa=192.168.2.1,arp_op=1 actions=move:NXM_OF_ETH_SRC[]->NXM_OF_ETH_DST[],set_field:02:02:02:02:02:02->eth_src,set_field:2->arp_op,move:NXM_NX_ARP_SHA[]->NXM_NX_ARP_THA[],move:NXM_OF_ARP_SPA[]->NXM_OF_ARP_TPA[],set_field:02:02:02:02:02:02->arp_sha,set_field:192.168.2.1->arp_spa,load:0xffff->OXM_OF_IN_PORT[],load:0x2->NXM_NX_REG1[],goto_table:6
cookie=0x0, duration=153.093s, table=2, n_packets=1, n_bytes=42,
priority=0,arp,in_port=2,arp_tpa=192.168.2.1,arp_op=2 actions=CONTROLLER:65535
```

cookie=0x0, duration=153.130s, table=2, n_packets=1, n_bytes=64, priority=0,arp,reg1=0x1
actions=set_field:01:01:01:01:01:01->eth_src,set_field:01:01:01:01:01:>arp_sha,set_field:192.168.1.1->arp_spa,goto_table:6
cookie=0x0, duration=153.083s, table=2, n_packets=1, n_bytes=64, priority=0,arp,reg1=0x2
actions=set_field:02:02:02:02:02:02->eth_src,set_field:02:02:02:02:02:>arp_sha,set_field:192.168.2.1->arp_spa,goto_table:6
cookie=0x0, duration=153.064s, table=3, n_packets=2, n_bytes=196,
priority=40024,ip,nw_dst=192.168.1.0/24 actions=move:NXM_OF_IP_DST[]->NXM_NX_REG0[],goto_table:4
cookie=0x0, duration=153.055s, table=3, n_packets=2, n_bytes=196,
priority=40024,ip,nw_dst=192.168.2.0/24 actions=move:NXM_OF_IP_DST[]->NXM_NX_REG0[],goto_table:4
cookie=0x0, duration=153.073s, table=3, n_packets=0, n_bytes=0, priority=0,ip actions=load:0xc0a80102->NXM_NX_REG0[],goto_table:4
cookie=0x0, duration=153.047s, table=4, n_packets=2, n_bytes=196, priority=0,reg0=0xc0a80100/0xffffffff00
actions=load:0x1->NXM_NX_REG1[],set_field:01:01:01:01:01:>eth_src,goto_table:5
cookie=0x0, duration=153.039s, table=4, n_packets=2, n_bytes=196, priority=0,reg0=0xc0a80200/0xffffffff00
actions=load:0x2->NXM_NX_REG1[],set_field:02:02:02:02:02:>eth_src,goto_table:5
cookie=0x0, duration=122.241s, table=5, n_packets=1, n_bytes=98, priority=2,ip,reg0=0xc0a80202
actions=set_field:1e:36:b3:90:02:e5->eth_dst,goto_table:6
cookie=0x0, duration=122.180s, table=5, n_packets=1, n_bytes=98, priority=2,ip,reg0=0xc0a80102
actions=set_field:e6:b6:de:b6:ed:1e->eth_dst,goto_table:6
cookie=0x0, duration=153.027s, table=5, n_packets=2, n_bytes=196, priority=1,ip
actions=CONTROLLER:65535
cookie=0x0, duration=153.022s, table=6, n_packets=6, n_bytes=408, priority=0
actions=output:NXM_NX_REG1[]

14.4. ####

15.

15.1.



#####

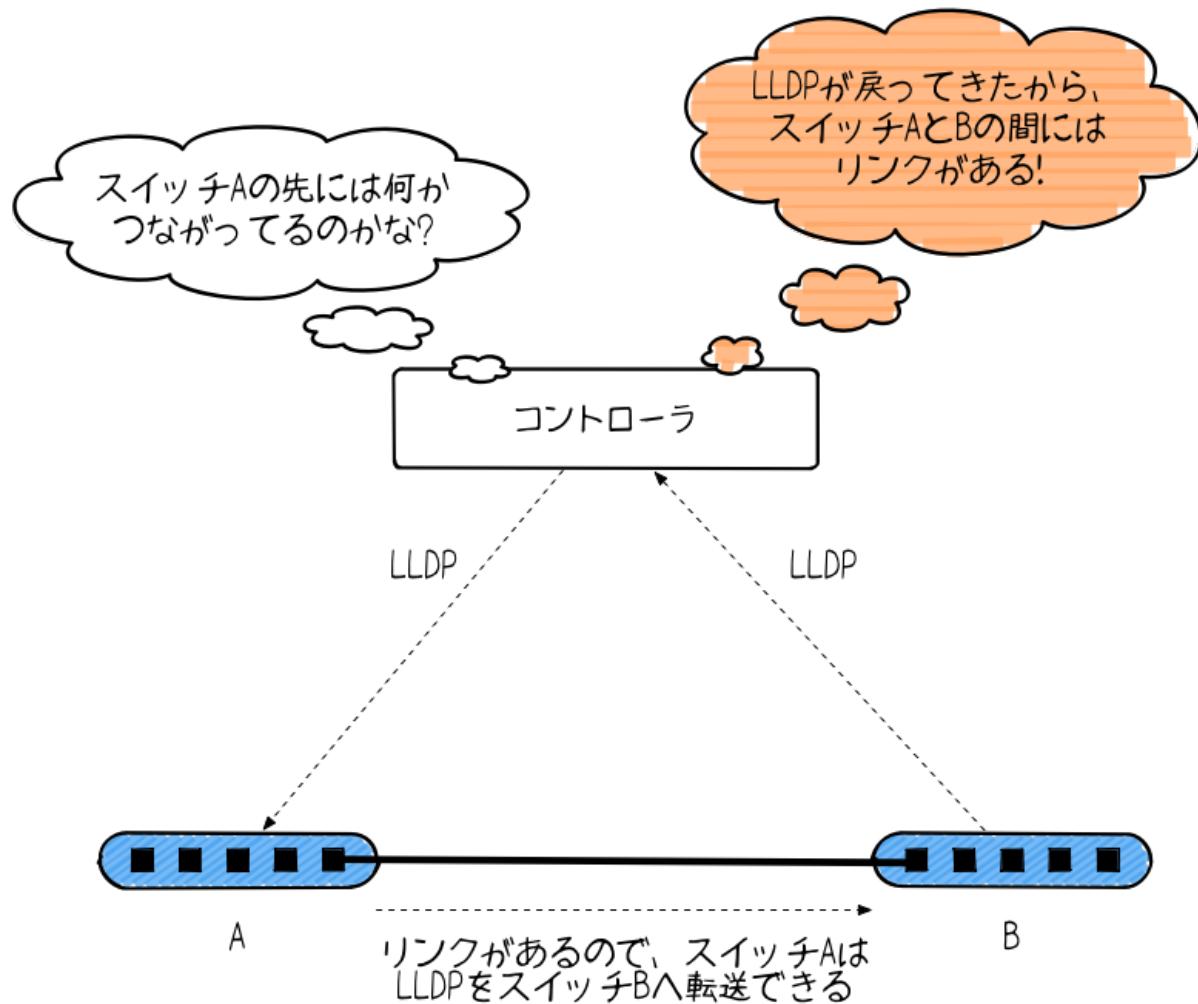
#####1#####

```
##### (#####) #####
```

15.2.

```
#####
## switch_ready #####
#####
```

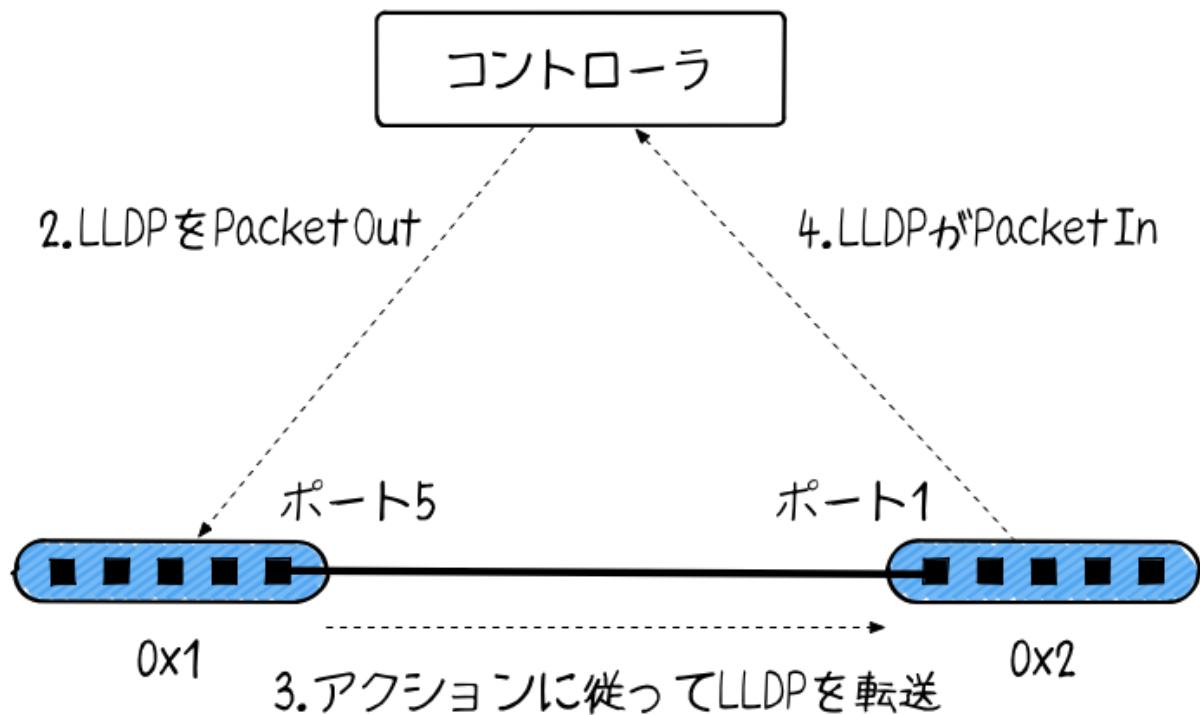
15.2.1.



#####

- ## 1. LLDPパケットを作る

- ## 5. リンクを発見



#####

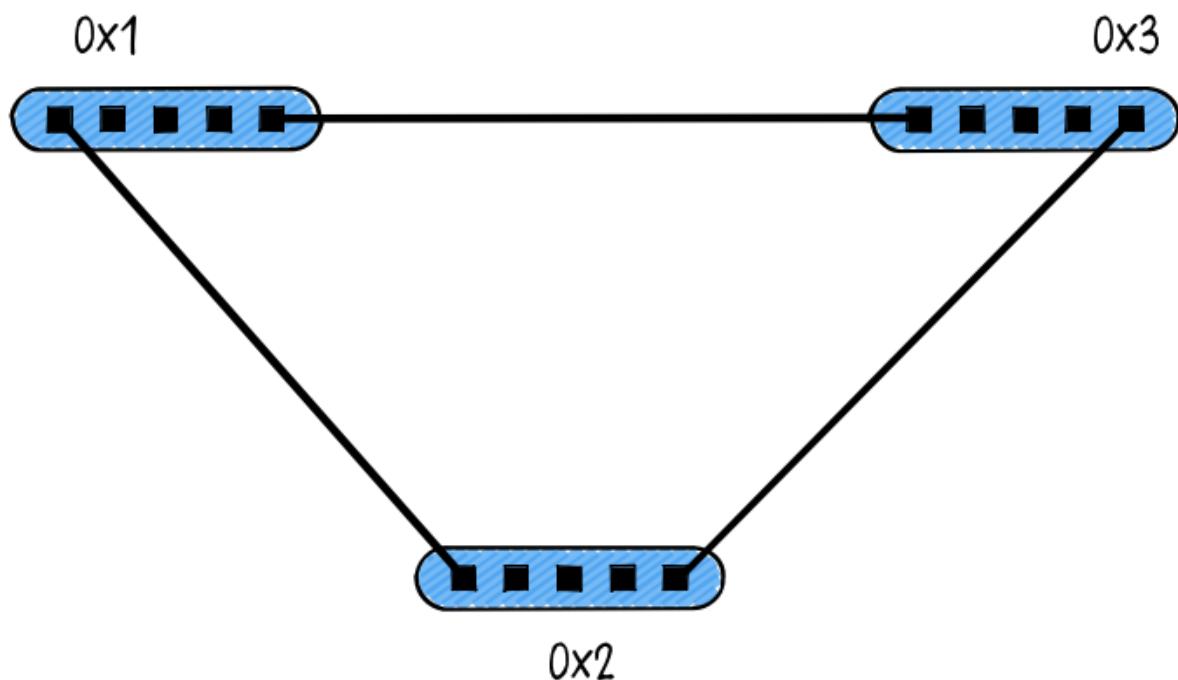
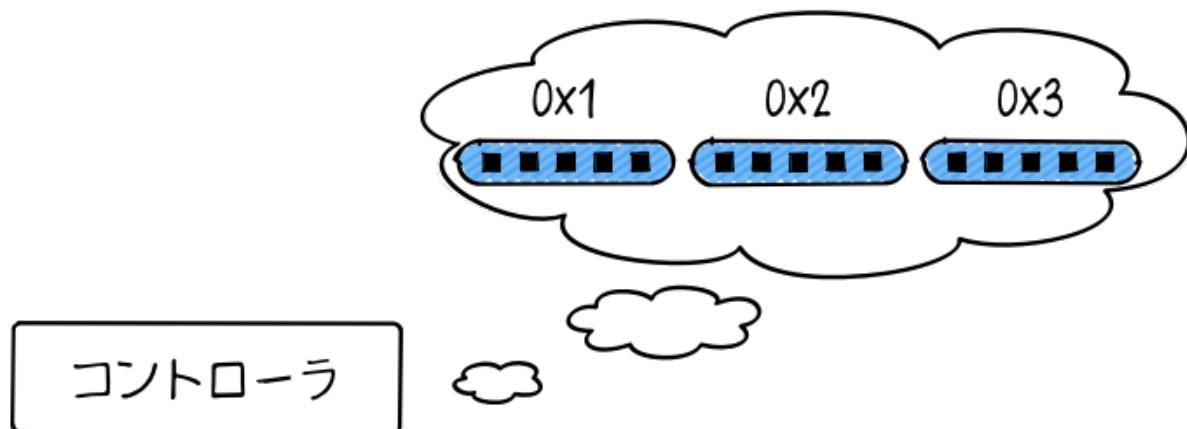
Packet In メッセージ

LLDPパケット
スイッチ=0x1,送信ポート=5

15.4. ##### 0#2 ##### ##### ##### ##

15.2.2.

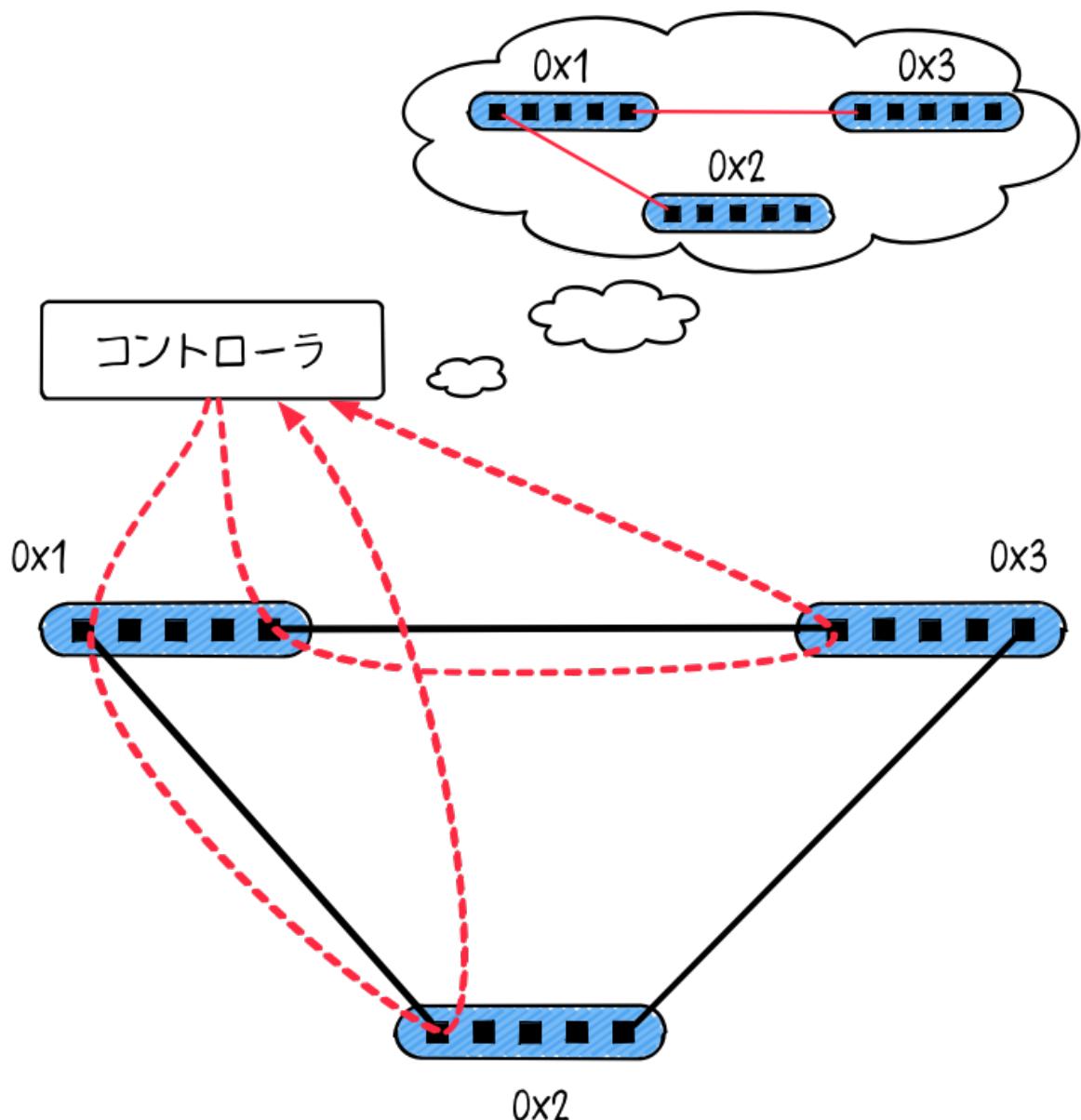
#####



15.5.

```
##### 0#1 ##### ##### ##### ##### ##### ##### ##### ##### 0#1 #####
##### ##### ##### ##### ##### ##### ##### ##### (# 15#6)#####
##### 0#1 ##### 0#2 ##### 0#3 #
##### ##### ##### #####
```

#####



15.6. #### 0#1

0#2, 0#3 #####
#####

15.3.

```
##### git clone #####:  
##### (#####://#####.###/#####/#####) ##### git clone  
##### bundle install #####
```

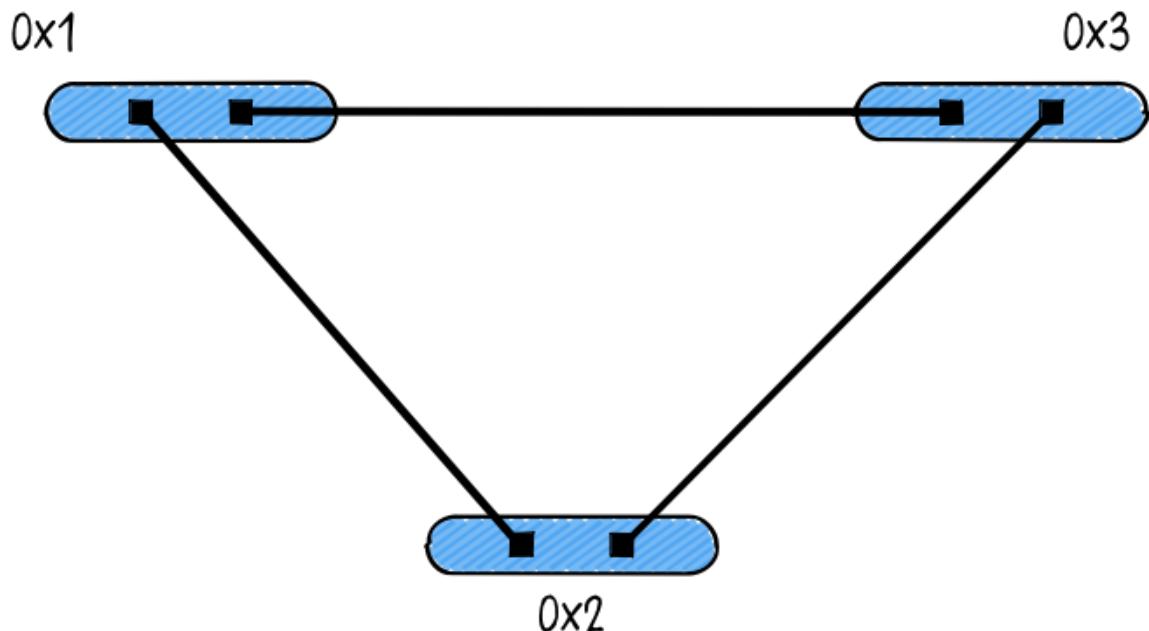
```
$ git clone https://github.com/trema/topology.git  
$ cd topology
```

```
#####
```

```
$ bundle install --binstubs
```

```
##### triangle.conf ##### 3 ##### ##### (# 15#7)#

```



```
##### 15.7. ####.#####

```

```
#####

```

```
$ ./bin/trema run ./lib/topology_controller.rb -c triangle.conf
```

```
Topology started (text mode).
```

```
Port 0x1:1 added: 1
```

```
Port 0x1:2 added: 1, 2
```

```
Switch 0x1 added: 0x1
```

```
Port 0x3:1 added: 1
```

```
Port 0x3:2 added: 1, 2
```

```
Switch 0x3 added: 0x1, 0x3
```

```
Port 0x2:1 added: 1
```

```
Port 0x2:2 added: 1, 2
```

```
Switch 0x2 added: 0x1, 0x2, 0x3
```

```
Link 0x1-0x2 added: 0x1-0x2
```

```
Link 0x1-0x3 added: 0x1-0x2, 0x1-0x3
```

```
Link 0x2-0x3 added: 0x1-0x2, 0x1-0x3, 0x2-0x3
```

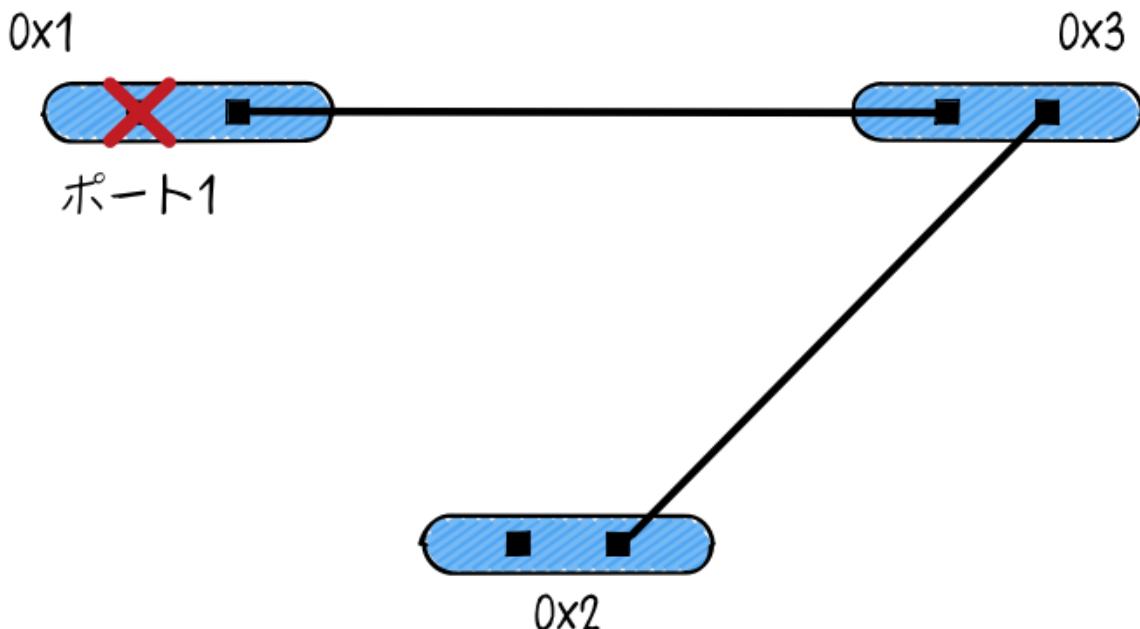
```
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### Port 0x1:1
added ##### 0#1 #### 1 ##### ##### ##### ##### ##### Switch 0x1 added #####
##### ##### ##### ##### ###### ## #####

```

```
#####
```

```
##### Link 0x1-0x2 added ##### 0#1 ## 0#2 # ##### #####  
##### ##### ##### ##### ##### ##### ##### ##### #####  
added: 0x1-0x2, 0x1-0x3, 0x2-0x3 ##### ##### #####
```

```
#####
```



```
##### 15.8. ##### 0#1 ##### 1 #####
```

```
##### 15#8##### 0#1 ##### 1 #####
```

```
$ ./bin/trema port_down --switch 0x1 --port 1
```

```
##### 0#1#0#2 ##### 0#1#0#3 # 0#2#0#3 ##  
#####
```

```
Link 0x1-0x2 deleted: 0x1-0x3, 0x2-0x3
```

```
Port 0x1:1 deleted: 2
```

```
#####
```

```
$ ./bin/trema port_up --switch 0x1 --port 1
```

```
Port 0x1:1 added: 1, 2
```

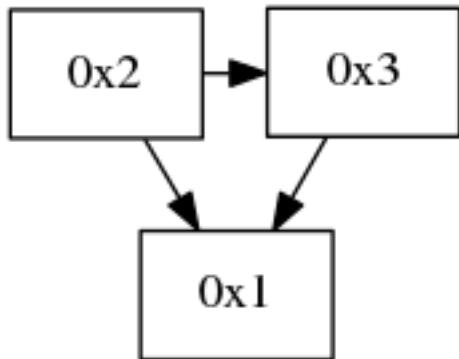
```
Link 0x1-0x2 added: 0x1-0x2, 0x1-0x3, 0x2-0x3
```

#####

```
##### apt-get #####
##### trema run #####
##### -- # graphviz #####
##### #####
```

```
$ ./bin/trema run ./lib/topology_controller.rb -c triangle.conf -- graphviz /tmp/topology.png
```

15#9



15.9.

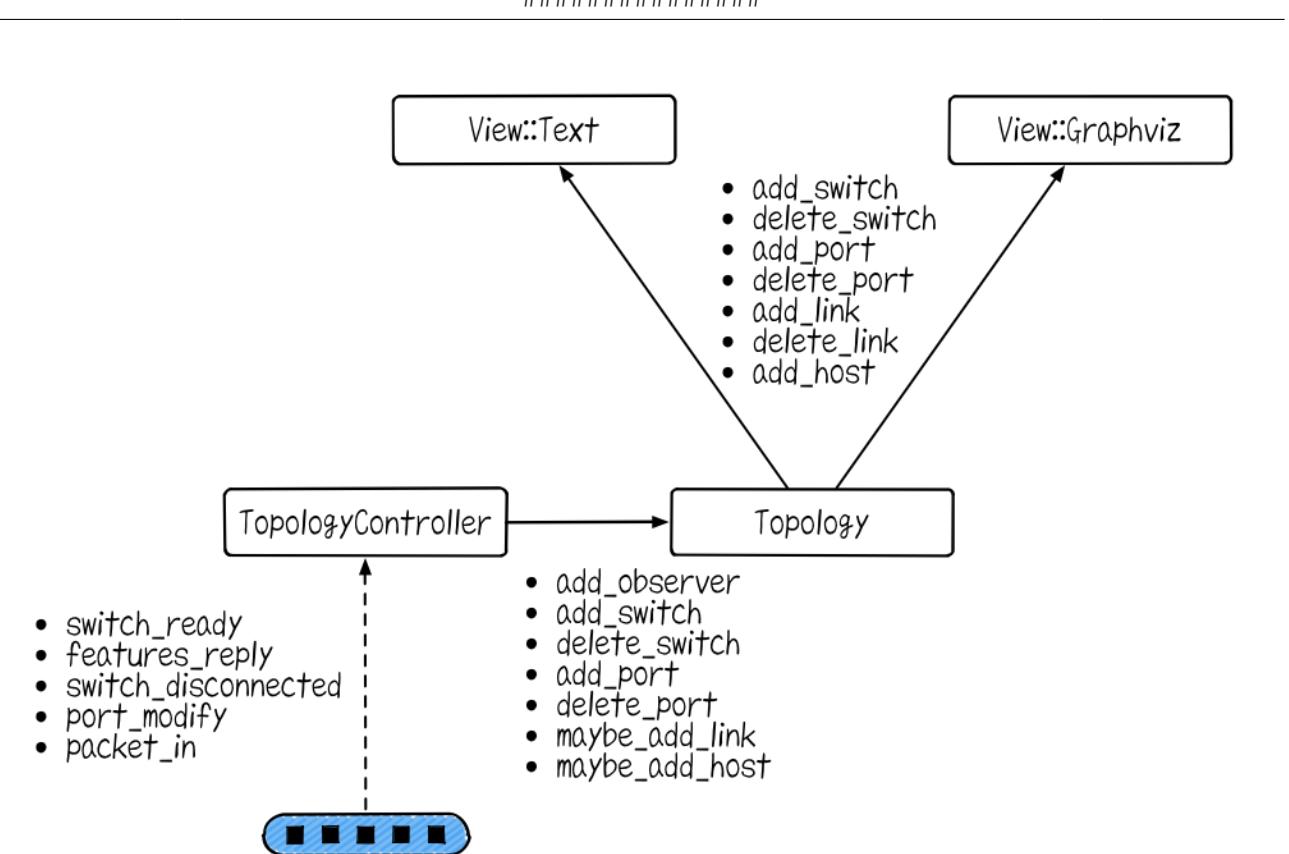
15.4.

```
##### 3 ##### (# 15#10)#
#####
```

```
TopologyController #####
#####
```

```
Topology #####
#####
```

```
View::Text , View::Graphviz #####
#####
```



15.10.

```

#####
  ######  ###  ## (#####)  ##### TopologyController  #
  ###  #  #####  #####  #####  #####  #####  #####  #####  #####
##### Topology  ######  #####  #####  #####  #####  #####  #####  #####  #####
View::Text  #
View::Graphviz  #####  ######  #####  #####  #####  #####  #####
  ######  ##  #####  #####  #####  #####  #####  #####  #####  ##  ##
  #####  #####  View::Html  #####  #####  #####  #####  TopologyController  #
Topology  #####  #####  #####  #####  #####  #####  #####  #####  #####  #####
  #####  #####  #####  #####  #####  #####  #####  #####  #####  #####

```

15.4.1.

```

TopologyController #####1##### ##### ##### start #####
##### ( View::Text ) ##### ( View::Graphviz ) #####
##### ( Topology ) ##### (@topology.add_observer) #####
  #####

```

#####


```

def start(args)
  @command_line = CommandLine.new(logger)
  @command_line.parse(args)
  @topology = Topology.new
  @topology.add_observer @command_line.view

```

```

logger.info "Topology started (#{@command_line.view})."
end

#####
# Topology #####
# View::Text #####
# View::Graphviz #####
# Topology #####
#####

#####
# add_switch : #####
# delete_switch : #####
# add_port : #####
# delete_port : #####
# add_link : #####
# delete_link : #####
#####

#####
# View::Text #####
# add_switch # add_port #####
#####

#####
# module View
# Topology controller's CUI.
class Text
  def initialize(logger)
    @logger = logger
  end

  def add_switch(dpid, topology)
    show_status("Switch #{dpid.to_hex} added",
               topology.switches.map(&:to_hex))
  end

  def delete_switch(dpid, topology)
    show_status("Switch #{dpid.to_hex} deleted",
               topology.switches.map(&:to_hex))
  end

  def add_port(port, topology)
    add_or_delete_port :added, port, topology
  end

  def delete_port(port, topology)
    add_or_delete_port :deleted, port, topology
  end

```

```

#####
add_or_delete_port :deleted, port, topology
end

def add_link(port_a, port_b, topology)
  link = format("%#x-%#x", *[port_a.dpid, port_b.dpid].sort)
  show_status "Link #{link} added", topology.links
end

def delete_link(port_a, port_b, topology)
  link = format("%#x-%#x", *[port_a.dpid, port_b.dpid].sort)
  show_status "Link #{link} deleted", topology.links
end

def to_s
  'text mode'
end

private

def add_or_delete_port(message, port, topology)
  ports = topology.ports[port.dpid].map(&:number).sort
  show_status "Port #{port.dpid.to_hex}:#{port.number} #{message}", ports
end

def show_status(message, objects)
  status = objects.sort.map(&:to_s).join(',')
  @logger.info "#{message}: #{status}"
end
end

```

```

###      ##### Topology      #####
Topology#add_observer ##### Topology #####
#####
## Topology #####

```

15.4.2.

```

TopologyController #####
switch_ready ##### #####
##### features_reply #####
##### @topology #####
#####
##### _ ####, ##### _ #####

```

```

#####
.....
```

```

def switch_ready(dpid)
  send_message dpid, Features::Request.new
end

def features_reply(dpid, features_reply)
  @topology.add_switch dpid, features_reply.physical_ports.select(&:up?)
end
```

```
#####
.....
```

- **switch_disconnected** : ##### (@topology) #####
- **port_modify** : ##### (######) ##### @topology #####
- **packet_in** : ##### #### ##### ##### ##### @topology #####

```
#####
.....
```

```

def switch_disconnected(dpid)
  @topology.delete_switch dpid
end
```

```

def port_modify(_dpid, port_status)
  updated_port = port_status.desc
  return if updated_port.local?
  if updated_port.down?
    @topology.delete_port updated_port
  elsif updated_port.up?
    @topology.add_port updated_port
  else
    fail 'Unknown port status.'
  end
end
```

```

def packet_in(dpid, packet_in)
  if packet_in.lldp?
    @topology.maybe_add_link Link.new(dpid, packet_in)
  else
    @topology.maybe_add_host(packet_in.source_mac,
      packet_in.source_ip_address,
      dpid,
      packet_in.in_port)
  end
end
```

```
#####
```

15.4.3. ##### ##### #####

```
##### ##### ##### ##### flood_lldp_frames ##### ##### ##### ##### @topology #####  
### (@topology.ports) ##### ##### ##### ##### ##### ##### ##### #####  
##### ##### ##### ##### _ ##### _ #####  
.....  
class TopologyController < Trema::Controller  
  timer_event :flood_lldp_frames, interval: 1.sec  
  
def flood_lldp_frames  
  @topology.ports.each do |dpid, ports|  
    send_lldp dpid, ports  
  end  
  end  
  
  private  
  
def send_lldp(dpid, ports)  
  ports.each do |each|  
    port_number = each.number  
    send_packet_out(  
      dpid,  
      actions: SendOutPort.new(port_number),  
      raw_data: lldp_binary_string(dpid, port_number)  
    )  
  end  
  end  
  end
```

15.4.4. #####

```
Topology ##### TopologyController ##### ##### ##### #####  
##### ##### ##### ##### ##### ##### ##### ##### ##### add_switch #####  
##### ##### ##### ##### ##### ##### ##### ##### add_switch #####  
##### ##### _ ##### (#####/#####.##)  
.....  
def add_switch(dpid, ports)  
  ports.each { |each| add_port(each) }  
  maybe_send_handler :add_switch, dpid, self  
  end  
  
  private  
  
def maybe_send_handler(method, *args)
```

```
#####
```

```
@observers.each do |each|
  if each.respond_to?(:update)
    each.__send__ :update, method, args[0..2], args.last
  end
  each.__send__ method, *args if each.respond_to?(method)
end
```

```
##### delete_switch #####
#####
#####
```

```
##### _ ##### (###/#####.##)
```

```
def delete_switch(dpid)
  delete_port(@ports[dpid].pop) until @ports[dpid].empty?
  @ports.delete dpid
  maybe_send_handler :delete_switch, dpid, self
end
```

```
def delete_port(port)
  @ports[port.dpid].delete_if { |each| each.number == port.number }
  maybe_send_handler :delete_port, Port.new(port.dpid, port.number), self
  maybe_delete_link port
end
```

```
private
```

```
def maybe_delete_link(port)
  @links.each do |each|
    next unless each.connect_to?(port)
    @links -= [each]
    port_a = Port.new(each.dpid_a, each.port_a)
    port_b = Port.new(each.dpid_b, each.port_b)
    maybe_send_handler :delete_link, port_a, port_b, self
  end
end
```

15.5.

```
#####
```

- ##### ##### #####
- ##### ##### ##### ##### #####
- ##### ##### ##### ##### #####

#####

#2 #####
###

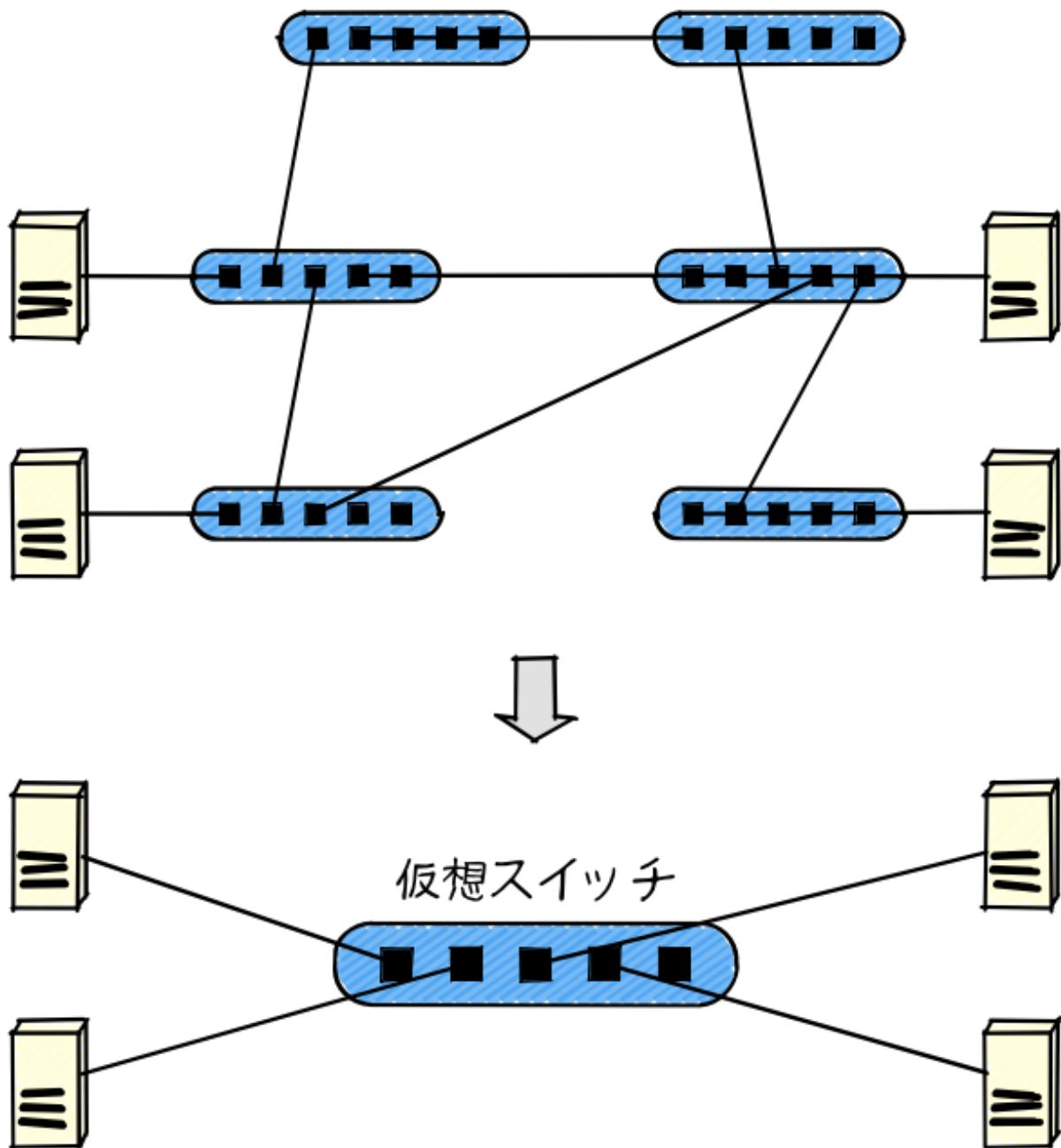
16.

#####

16.1.

```
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####  
##### 1 ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### (# 16#1)#####  
##### 7 ##8 ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####  
##### ##### ##### 1 ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #  
##### ##### ##### 1 ##### ##### ##### #####
```

#####



16.1. ##### 1

```
#####
#####
```

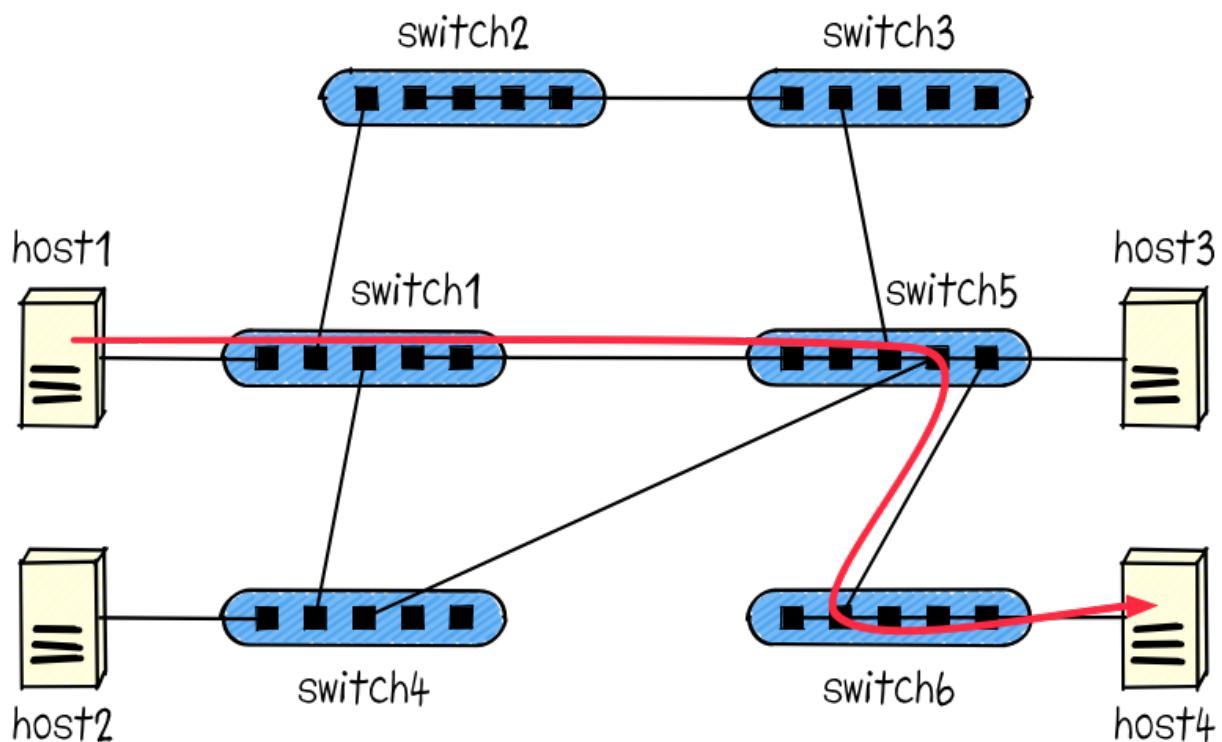
16.1.1.

#####

#####

ルーティングスイッチ

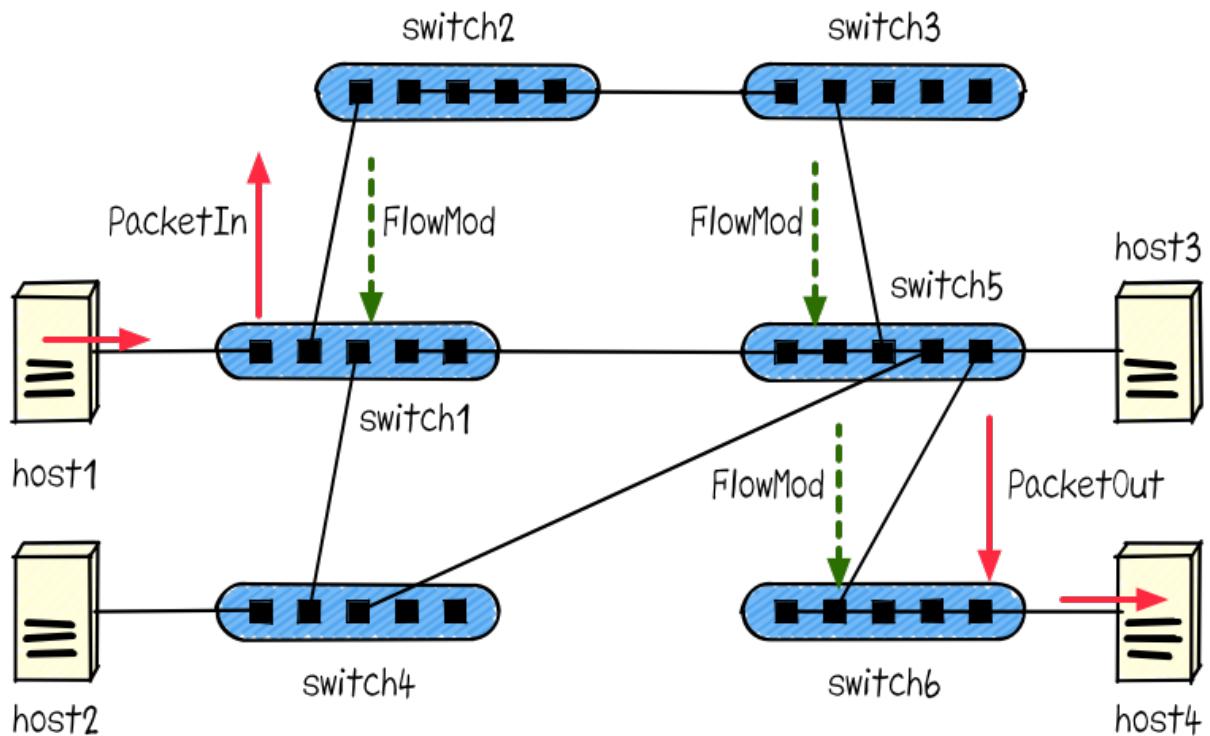
フローの書き込み



16.2.

16##### 1 ##### 4 ##### 1 →
1 → #### 5 → #### 6 → #### 4 ##### 1, 5, 6

#####16######:



16.3. ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####

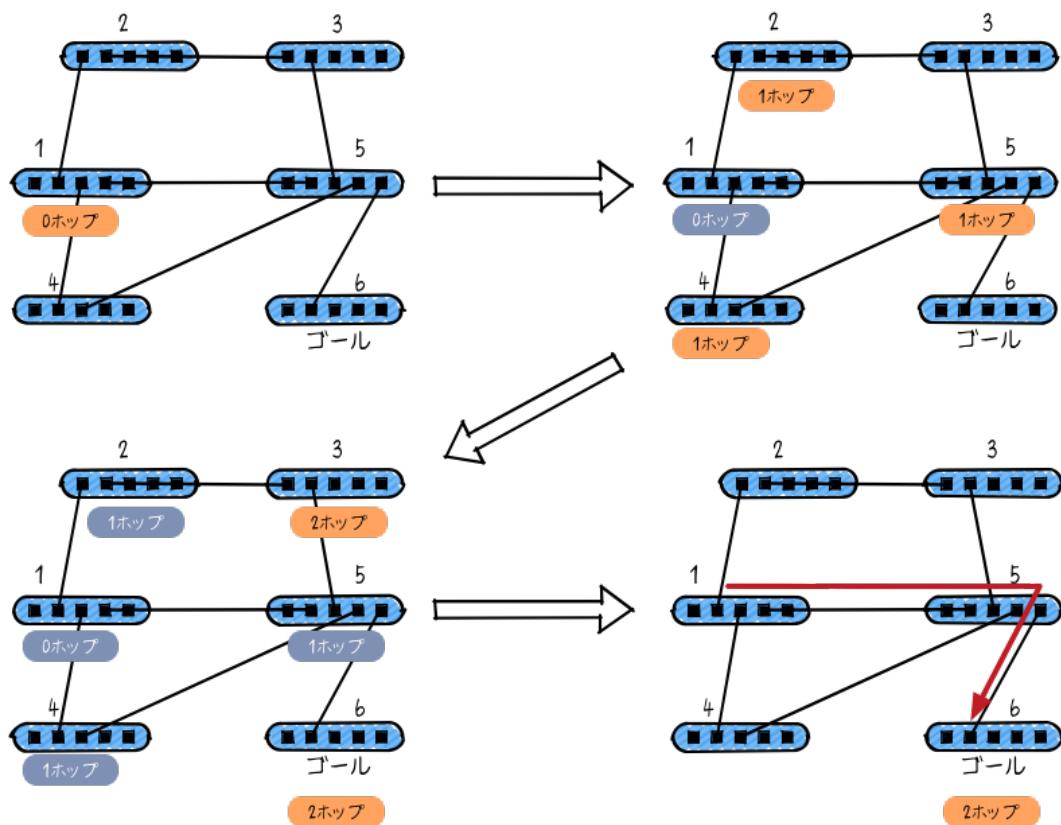
3 ##### ##### ##### ##### ##### #####

16.2.

```
#####
##### 1 #####
#####
#####
```

```
#####
##### 1 #####
#####
##### 1 #####
##### 2 #####
## 3 #####
4 ####....#####
#####
#####1
```

1 #####1#####
#####



16.4.

16#2 ##### 1 ##### 6 ##### 16#4 #####:

1. ##### 1 # 0 #####
 2. #### 1 ## 1 ##### 1 ##### 2, 4, 5 ##
 3. ##### 2 ##### 1 ##### 3, 6 ##### 2 #####
 4. #### 3 ##### 6 ##### 1 → #### 5 → #### 6 ####

16.3.

```
#####
#####
```

```
$ git clone https://github.com/trema/routing_switch.git
```

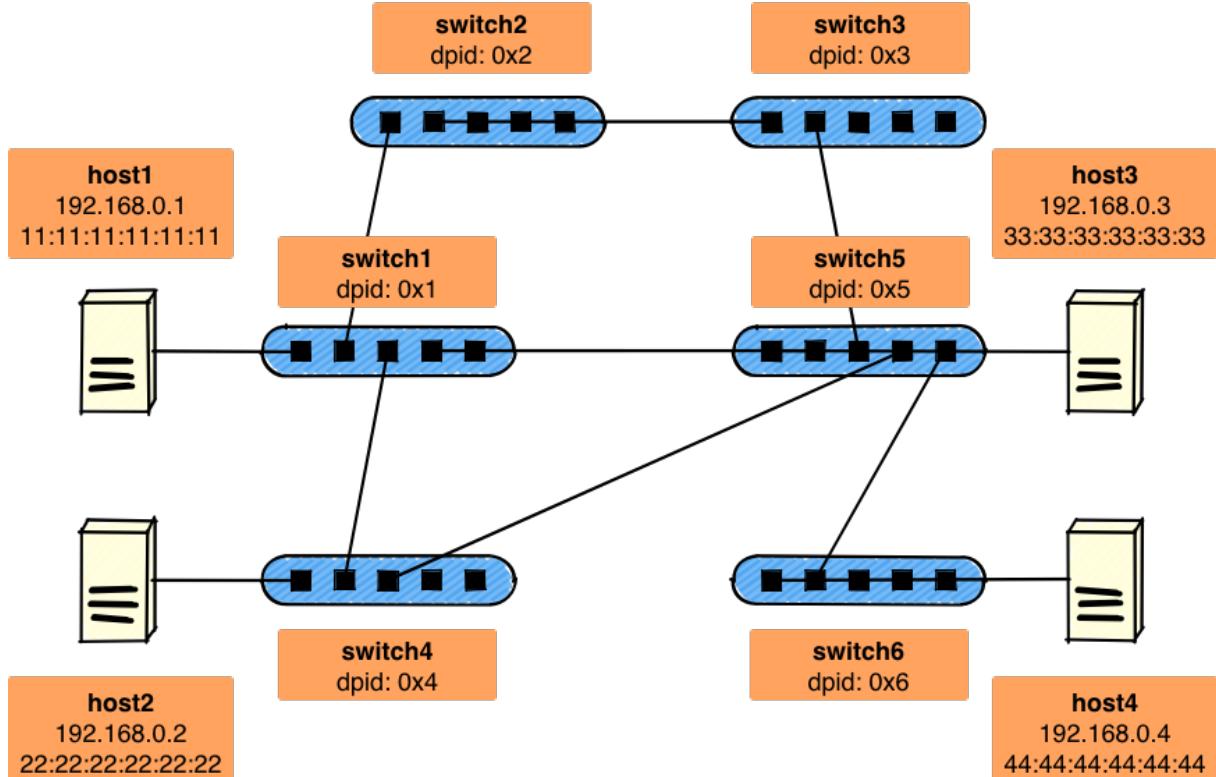
```
##### ##### ##### ##### ##### bundle install #####
```

```
#####
#  
$ cd routing_switch  
$ bundle install --binstubs
```

```
#####
```

16.3.1.

```
##### 16#5 #####
```



```
##### 16.5. ## 4 ##### 6 #####
```

```
##### ( trema.conf )#####  
#####
```

```
$ ./bin/trema run ./lib/routing_switch.rb -c trema.conf
```

16.3.2.

```
## ####1 # ####4 ##### ###### ##### ###### ##### ###### ##### ###### #####  
#### # ## ##### ###### #####1 ## ####4 ##### ###### ##### ###### #####  
##### ###### ##### ###### ##### ###### ##### ###### #####
```

```
$ ./bin/trema send_packets --source host1 --dest host4
```

```
#####
```

```
$ ./bin/trema send_packets --source host4 --dest host1  
$ ./bin/trema send_packets --source host1 --dest host4
```

```
#####4 → #####1 # #####1 → #####4 # 2 #####1 #####  
#####
```

```
Creating path: 44:44:44:44:44:44 -> 0x6:1 -> 0x6:2 -> 0x5:5 -> 0x5:2 -> 0x1:4 -> 0x1:1 -> 11:11:11:11:11:11  
Creating path: 11:11:11:11:11:11 -> 0x1:1 -> 0x1:4 -> 0x5:2 -> 0x5:5 -> 0x6:2 -> 0x6:1 -> 44:44:44:44:44:44
```

```
##### trema dump_flows #####1 #  
# #####4 #####1, #####5, #####6 #####
```

```
$ ./bin/trema dump_flows switch1  
cookie=0x0, duration=8.949s, table=0, n_packets=0, n_bytes=0, idle_age=8,  
priority=65535, udp, in_port=4, vlan_tci=0x0000, dl_src=44:44:44:44:44, dl_dst=11:11:11:11:11:11, nw_src=192.168.0.4, nw_dst=  
actions=output:1  
cookie=0x0, duration=4.109s, table=0, n_packets=0, n_bytes=0, idle_age=4,  
priority=65535, udp, in_port=1, vlan_tci=0x0000, dl_src=11:11:11:11:11:11, dl_dst=44:44:44:44:44, nw_src=192.168.0.1, nw_dst=  
actions=output:4  
$ ./bin/trema dump_flows switch5  
cookie=0x0, duration=14.230s, table=0, n_packets=0, n_bytes=0, idle_age=14,  
priority=65535, udp, in_port=5, vlan_tci=0x0000, dl_src=44:44:44:44:44, dl_dst=11:11:11:11:11:11, nw_src=192.168.0.4, nw_dst=  
actions=output:2  
cookie=0x0, duration=9.320s, table=0, n_packets=0, n_bytes=0, idle_age=9,  
priority=65535, udp, in_port=2, vlan_tci=0x0000, dl_src=11:11:11:11:11:11, dl_dst=44:44:44:44:44, nw_src=192.168.0.1, nw_dst=  
actions=output:5  
$ ./bin/trema dump_flows switch6  
cookie=0x0, duration=18.688s, table=0, n_packets=0, n_bytes=0, idle_age=18,  
priority=65535, udp, in_port=1, vlan_tci=0x0000, dl_src=44:44:44:44:44, dl_dst=11:11:11:11:11:11, nw_src=192.168.0.4, nw_dst=  
actions=output:2  
cookie=0x0, duration=13.723s, table=0, n_packets=0, n_bytes=0, idle_age=13,  
priority=65535, udp, in_port=2, vlan_tci=0x0000, dl_src=11:11:11:11:11:11, dl_dst=44:44:44:44:44, nw_src=192.168.0.1, nw_dst=  
actions=output:1
```

```
#####1, #####5, #####6 #####1 # #####4 ## 2 #####1 #####  
#####
```

```
#####2, #####3, #####4 #####
```

```
$ ./bin/trema dump_flows switch2
```

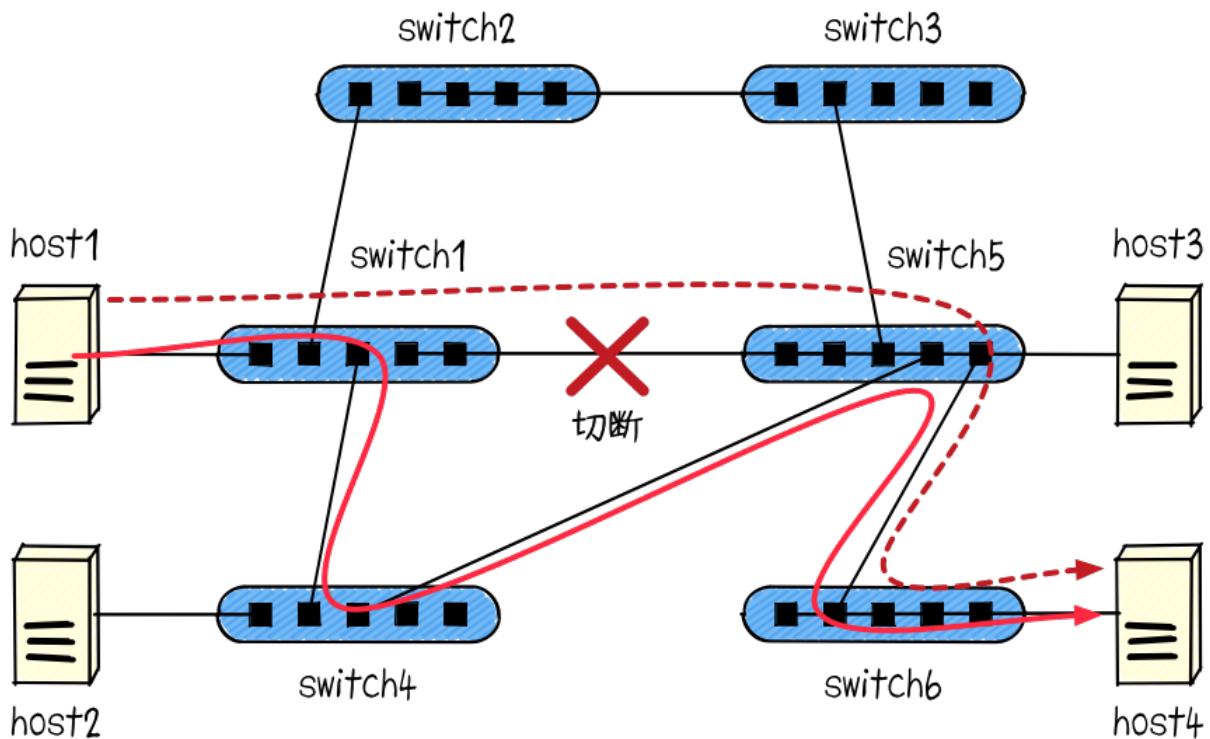
```
$ ./bin/trema dump_flows switch3
```

```
#####
```

```
$ ./bin/trema dump_flows switch4
```

16.3.3.

```
##### 16#5 #####1 # #####5 #
##### (#####1 ⇌ #####1 ⇌ #####5 ⇌ #####6
⇒ #####4) #####1 # #####2 #####1 #####2 #####5 #####6
(#####1 → #####1 → #####4 → #####5 → #####6) ##### (# 16#6)#
#####
```



16.6.

```
##### trema delete_link #####
```

```
$ ./bin/trema delete_link switch1 switch5
```

```
#####1 ⇌ #####4 # 2 #####1 #####2 #####5 #####6 #####
```

```
Deleting path: 44:44:44:44:44:44 -> 0x6:1 -> 0x6:2 -> 0x5:5 -> 0x5:2 -> 0x1:4 -> 0x1:1 -> 11:11:11:11:11:11  
Deleting path: 11:11:11:11:11:11 -> 0x1:1 -> 0x1:4 -> 0x5:2 -> 0x5:5 -> 0x6:2 -> 0x6:1 -> 44:44:44:44:44
```

```
## #####1 ## #####4 #####1 #####2 #####5 #####6 #####
```

```
$ ./bin/trema send_packets --source host1 --dest host4
```

#####

#####1 → ####4 #####

Creating path: 11:11:11:11:11:11 -> 0x1:1 -> 0x1:3 -> 0x4:2 -> 0x4:3 -> 0x5:4 -> 0x5:5 -> 0x6:2 -> 0x6:1 -> 44:44:44:44:44:44

#####

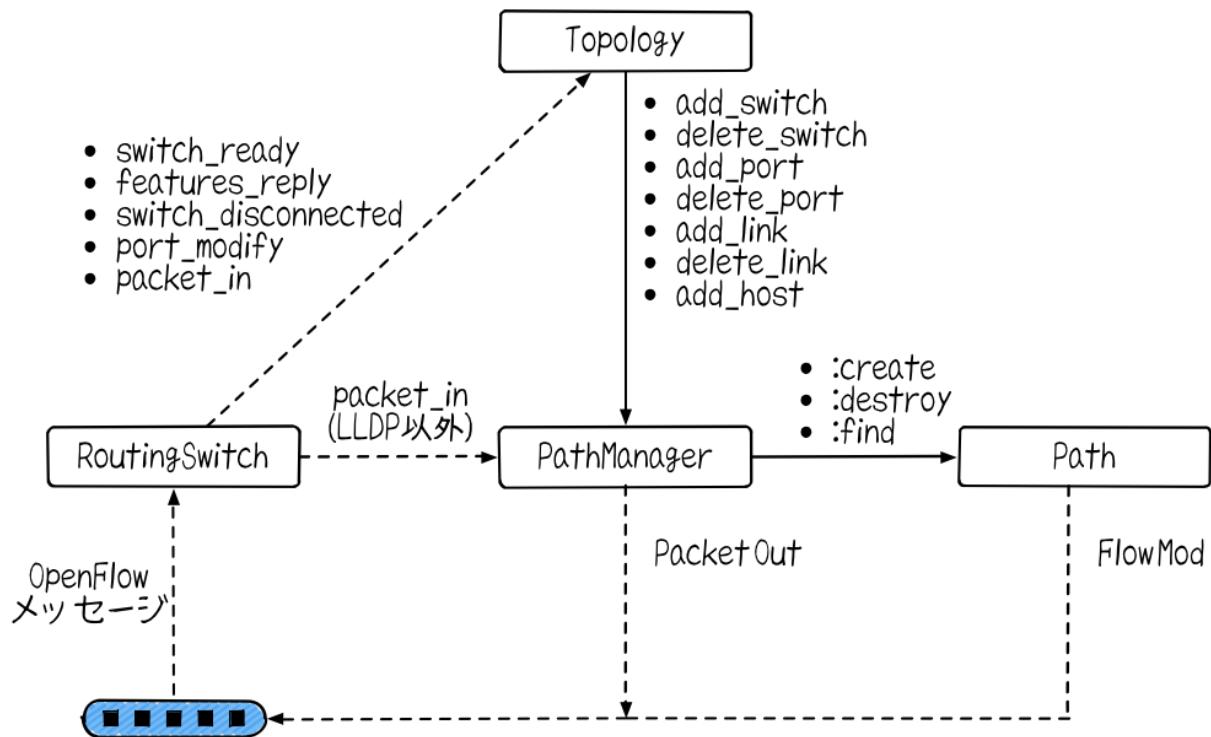
16.4.

4 ##### (# 16#7)##

#####, ##### (15 ####)

####

##



16.7.

16.4.1. ##### (#####.##)

####/# ##### ###### #######.##

```
delegate :switch_ready, to: :@topology  
delegate :features_reply, to: :@topology  
delegate :switch_disconnected, to: :@topology  
delegate :port_modify, to: :@topology
```

```
def packet_in(dpid, packet_in)
    @topology.packet_in(dpid, packet_in)
    @path_manager.packet_in(dpid, packet_in) unless packet_in.lldp?
end
```

2 16 #####

```
#####
```

```
#### ##### #### ##### _ ##### ##### ##### delegate ##### ##### ##### #####  
### switch_ready ##### ##### _ ## ##### ##### # ##### ##### ##### ##### #####  
##### _ ## ##### ##### ##### ##### _ ## ##### ##### ##### ##### #####
```

16.4.2. ##### (#### _ #####.##)

```
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####  
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####  
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####
```

```
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####
```

```
def add_port(port, _topology)  
    @graph.add_link port.dpid, port  
end
```

```
def delete_port(port, _topology)  
    @graph.delete_node port  
end
```

```
# TODO: update all paths
```

```
def add_link(port_a, port_b, _topology)  
    @graph.add_link port_a, port_b  
end
```

```
def delete_link(port_a, port_b, _topology)  
    @graph.delete_link port_a, port_b  
    Path.find { |each| each.link?(port_a, port_b) }.each(&:destroy)  
end
```

```
def add_host(mac_address, port, _topology)  
    @graph.add_link mac_address, port  
end
```

```
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####  
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####  
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####
```

```
##### # packet_in ##### ##### ##### ##### ##### #####
```

```
##### _ ##
```

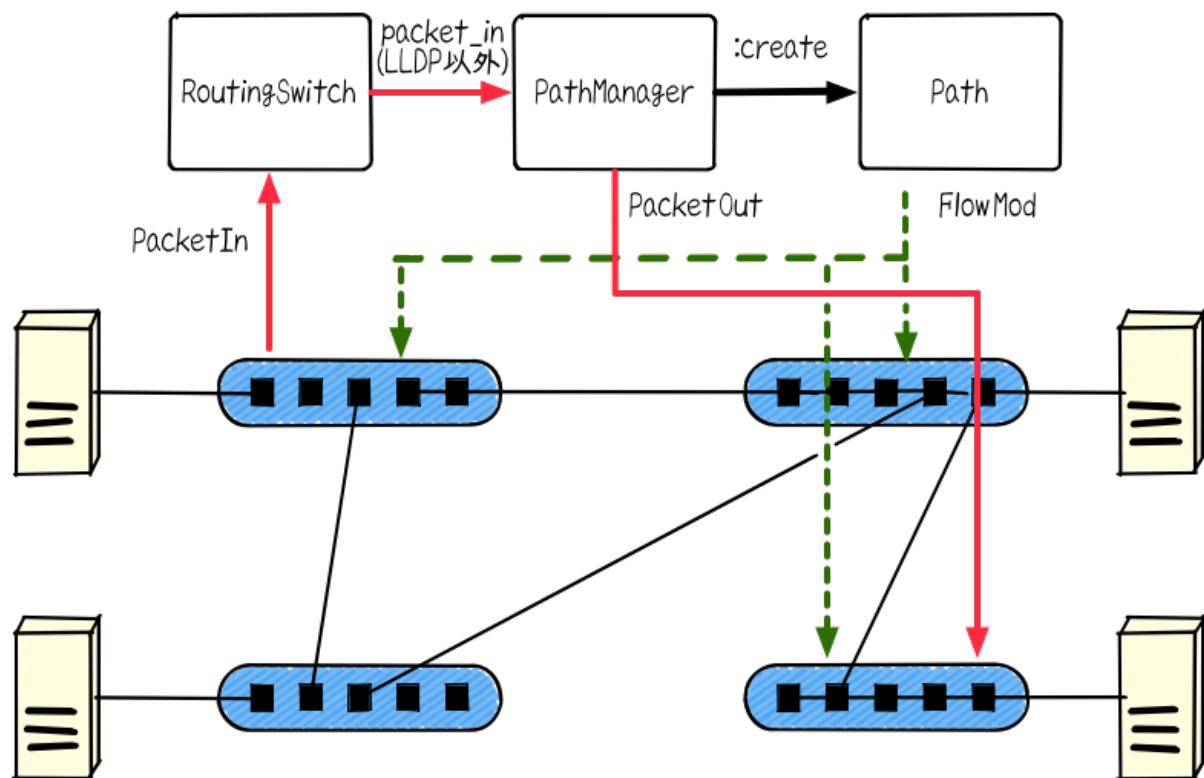
```
def packet_in(_dpid, packet_in)  
    path = maybe_create_shortest_path(packet_in)
```

#####

```
ports = path ? [path.out_port] : @graph.external_ports
ports.each do |each|
  send_packet_out(each.dpid,
    raw_data: packet_in.raw_data,
    actions: SendOutPort.new(each.number))
end
end

def maybe_create_shortest_path(packet_in)
  shortest_path =
    @graph.dijkstra(packet_in.source_mac, packet_in.destination_mac)
  return unless shortest_path
  Path.create shortest_path, packet_in
end
```

packet_in ##### 16#6 #####:



16.8. #####

1. ##### → ##### Path.create #####
###
2. ##### ##### (#####) #####

#####

16.4.3. ##### ##### (####.##)

#####.##### (###/####.##)

```
def self.create(shortest_path, packet_in)
    new.save(shortest_path, packet_in).tap { |new_path| all << new_path }
end
```

```
def save(full_path, packet_in)
    @full_path = full_path
    @packet_in = packet_in
    logger.info 'Creating path: ' +
    flow_mod_add_to_each_sw
    self
end
```

```
def flow_mod_add_to_each_switch
    path.each_slice(2) do |in_port, out_port|
        send_flow_mod_add(out_port.dpid,
                           match: exact_match(in_port.number),
                           actions: SendOutPort.new(out_port.number))
    end
end
```

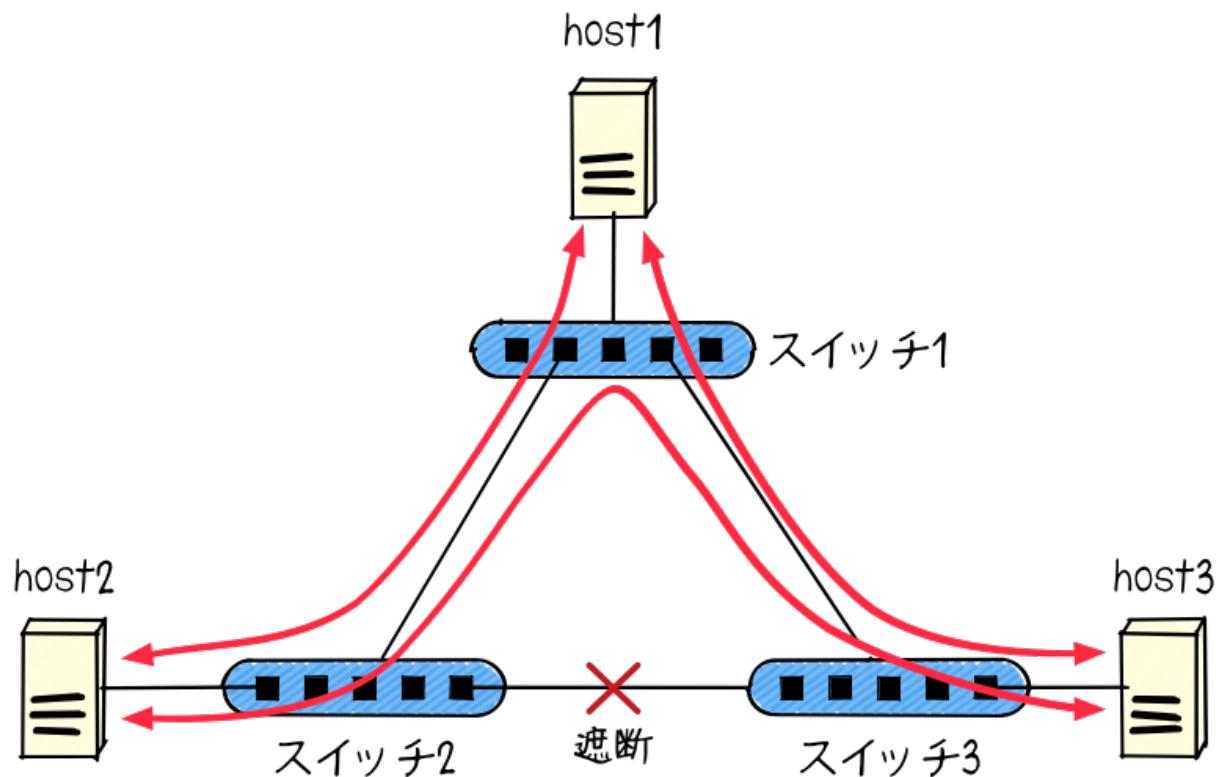
```
##### Path.create ##### Path ##### save ##### save #####  
##### flow mod add to each switch #####
```

16.5. ##### ##### #####

16.5.1.

```
#####
#####2#####3#####1#####
#####
```

#####



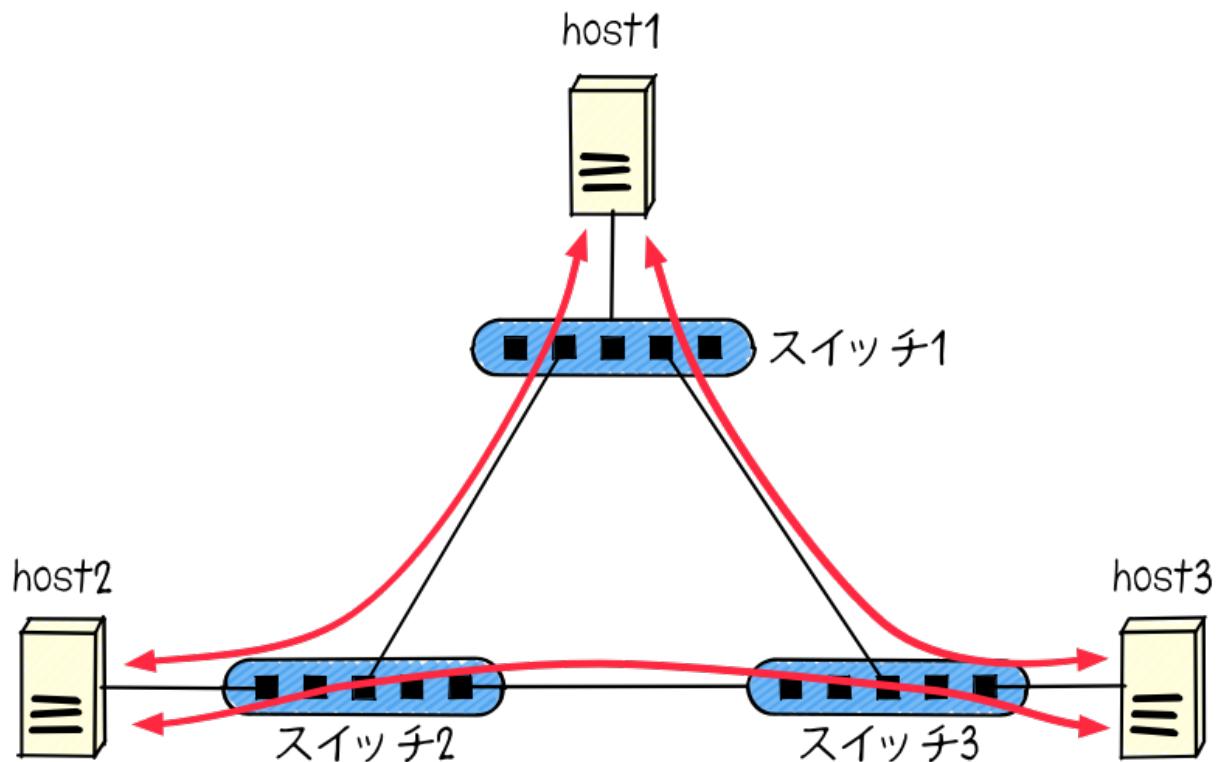
16.9.

#####

#####

16#8##

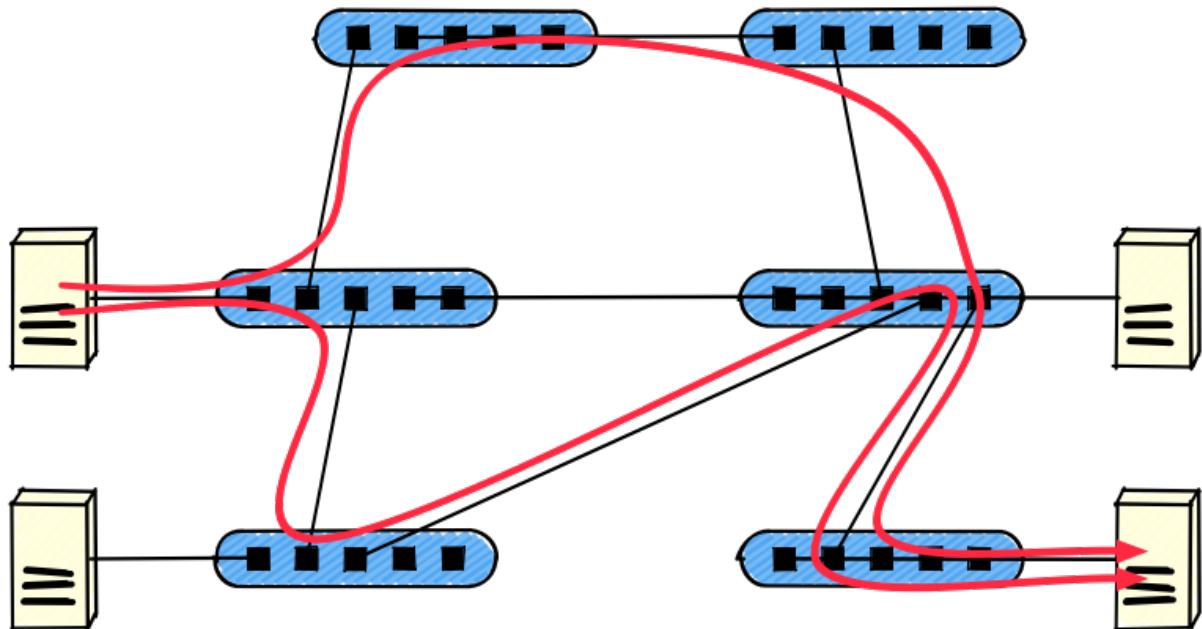
#####



16.10.

16.5.2.

16#9 #####
#####



16.11.

#####

16.6.

#####

- #####
 - #####
 - #####

#####

16.6.1.

- #####

#####
 - #####/#
#####3#####1#####

17.

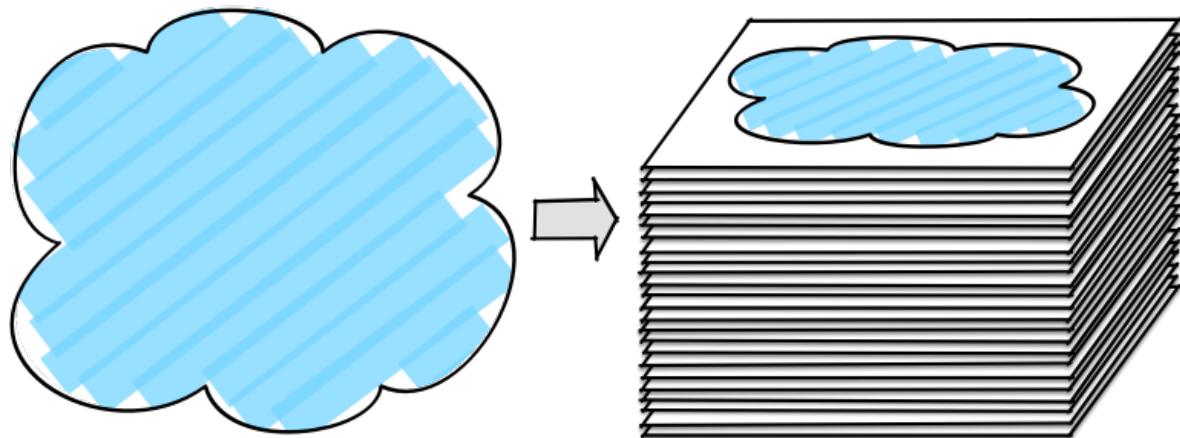
(##### ##### ##### ## # #####) ##### ##### ##### ##### **16** #####
#####

17.1.

```
#####
## (####) #####
###
```

```
#####
##### #####
#####
##### #####
##### #####
##### #####
##### + #####
```

(# 17#1)#####
#####1#####



17.2.

4094 #####
#####

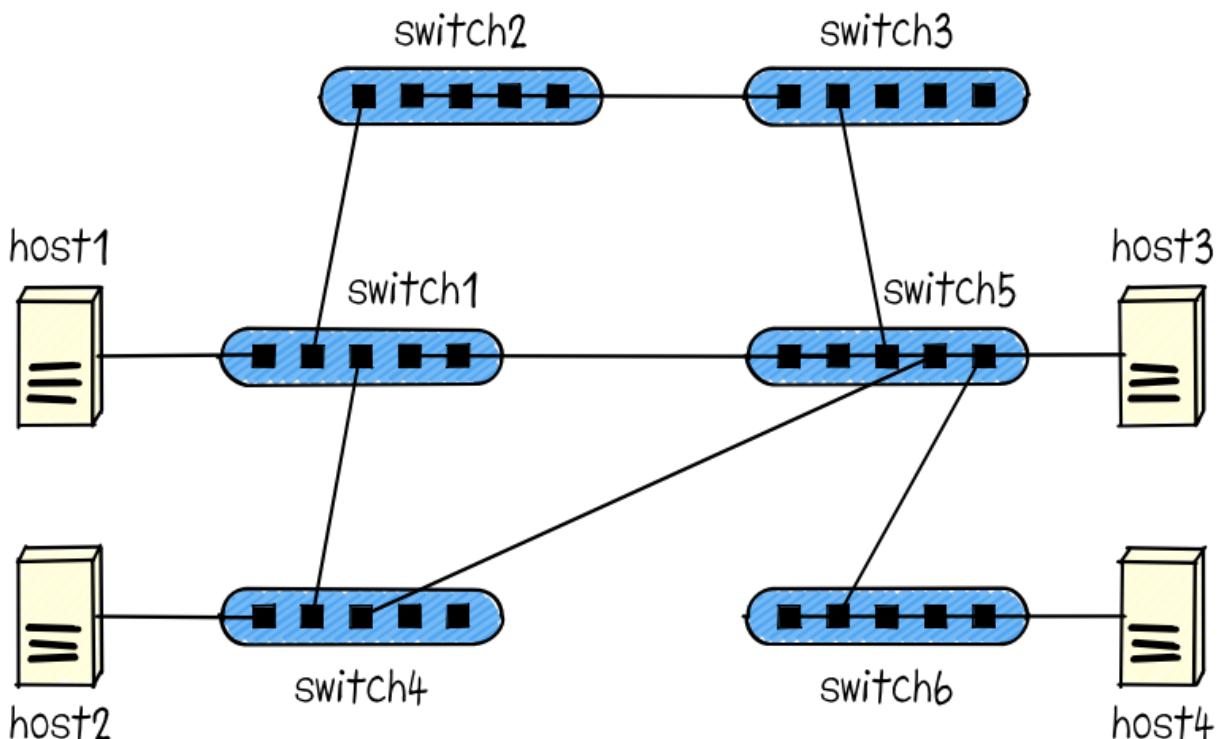
17.3.

#####

```
$ git clone https://github.com/trema/routing_switch.git  
$ cd routing_switch  
$ bundle install --binstubs
```

17.3.1.

```
##### ( trema.conf ) #####
```



17.2.

```
##### trema run # --slicing #####
```

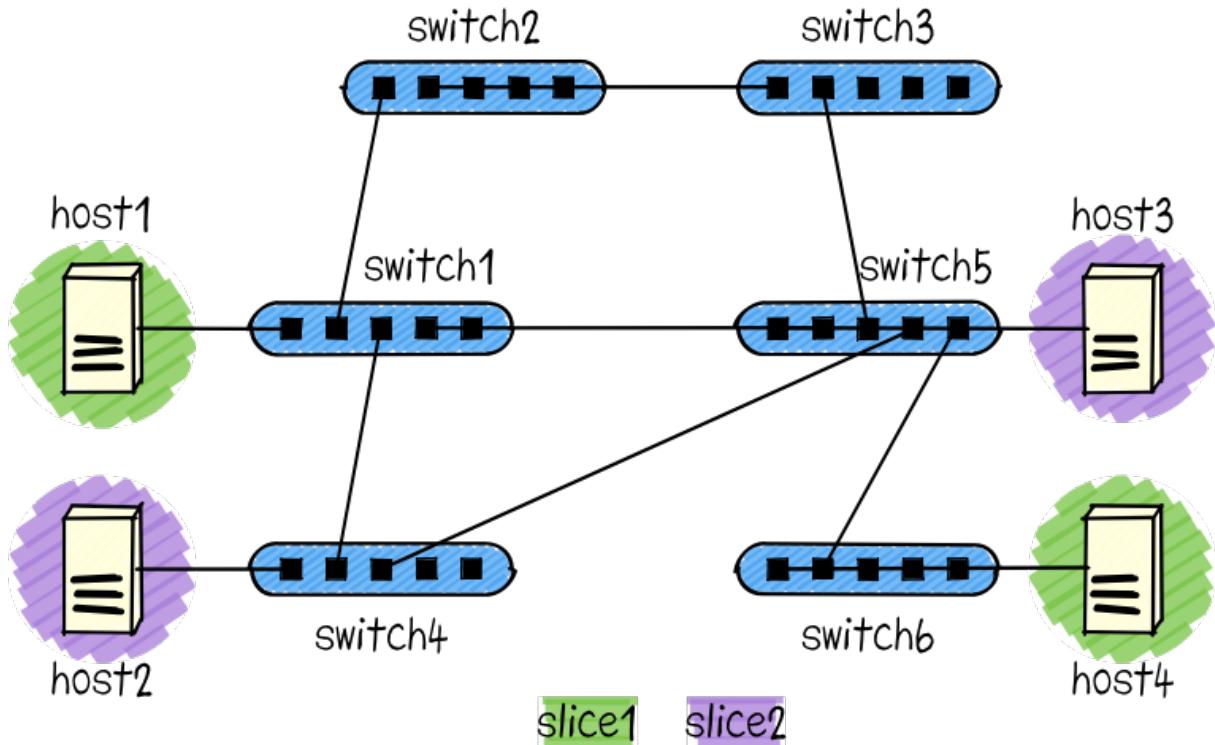
#####

```
$ ./bin/trema run ./lib/routing_switch.rb -c trema.conf -- --slicing
```

#####

17.3.2.

```
##### slice #####2 ##### slice1 # slice2 #####2 ##### (#17#3) #
```



17.3.

slice add

```
$ ./bin/slice add slice1  
$ ./bin/slice add slice2
```

```
slice add_host ##### host1 # host4 ##### slice1 ## host2 #
host3 # slice2 #####
```

```
$ ./bin/slice add_host --port 0x1:1 --mac 11:11:11:11:11:11 --slice slice1  
$ ./bin/slice add_host --port 0x6:1 --mac 44:44:44:44:44:44 --slice slice1  
$ ./bin/slice add_host --port 0x4:1 --mac 22:22:22:22:22:22 --slice slice2  
$ ./bin/slice add_host --port 0x5:1 --mac 33:33:33:33:33:33 --slice slice2
```

```
#####
```

```
#####
```

17.3.3.

```
##### 2 ##### ## ####
```

```
1. #####
```

```
2. #####
```

```
##### trema send_packet # trema show_stats #####
slice1 ##### host1 # host4 ##### 1 #####
1 #####
```

```
$ ./bin/trema send_packet --source host1 --dest host4
```

```
$ ./bin/trema send_packet --source host4 --dest host1
```

```
$ ./bin/trema show_stats host1
```

Packets sent:

```
192.168.0.1 -> 192.168.0.4 = 1 packet
```

Packets received:

```
192.168.0.4 -> 192.168.0.1 = 1 packet
```

```
$ ./bin/trema show_stats host4
```

Packets sent:

```
192.168.0.4 -> 192.168.0.1 = 1 packet
```

Packets received:

```
192.168.0.1 -> 192.168.0.4 = 1 packet
```

```
#####
```

```
$ ./bin/trema reset_stats host1
```

```
$ ./bin/trema send_packet --source host1 --dest host2
```

```
$ ./bin/trema send_packet --source host2 --dest host1
```

```
$ ./bin/trema show_stats host1
```

Packets sent:

```
192.168.0.1 -> 192.168.0.2 = 1 packet
```

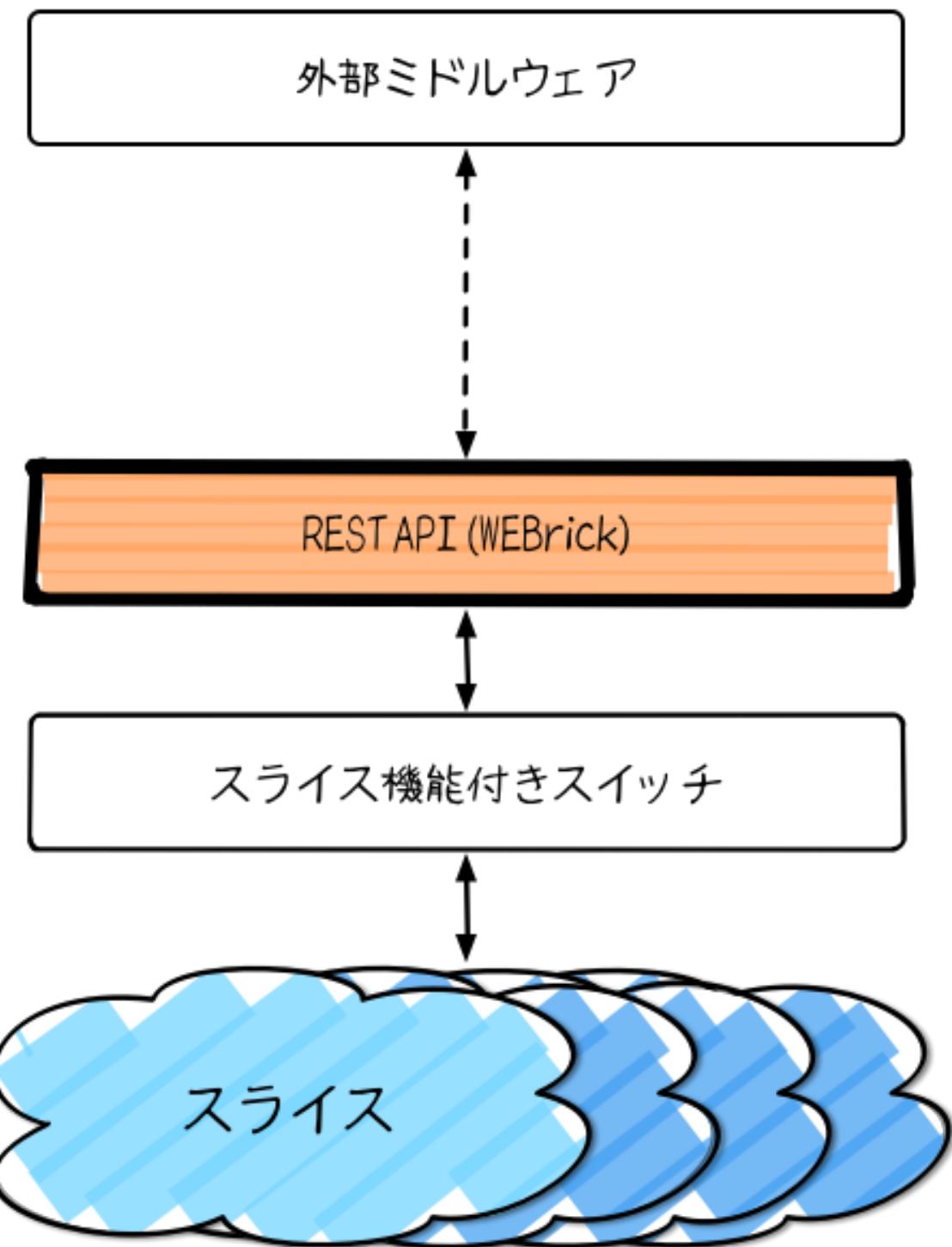
```
$ ./bin/trema show_stats host2
```

Packets sent:

```
192.168.0.2 -> 192.168.0.1 = 1 packet
```

```
##### slice1 # host1 ## slice2 # host2 ##### 1 ##### 2 #####
#####
```

17.4. ##### ####



```
$ ./bin/trema run ./lib/routing_switch.rb -c trema.conf -d --slicing  
$ ./bin/rackup
```

#####

```
#####
```

17.4.1. ##### #### #####

```
#### ## ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####  
##### _ ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### #####
```

```
.....  
{"name": "yutaro_slice"}
```

```
#### #### # /##### #### # #### # #### ##### curl ##### ##### ##### ##### #####  
##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### 9292 ####
```

```
.....  
$ curl -sS -X POST -d '{"name": "yutaro_slice"}' 'http://localhost:9292/slices' -H Content-Type:application/json -v
```

```
##### ##### ##### ##### ##### ##### ##### ##### 201 #####
```

```
.....  
* Hostname was NOT found in DNS cache  
* Trying 127.0.0.1...  
* Connected to localhost (127.0.0.1) port 9292 (#0)  
> POST /slices HTTP/1.1  
> User-Agent: curl/7.35.0  
> Host: localhost:9292  
> Accept: */*  
> Content-Type:application/json  
> Content-Length: 21  
>  
* upload completely sent off: 21 out of 21 bytes  
< HTTP/1.1 201 Created ❶  
< Content-Type: application/json  
< Content-Length: 21  
* Server WEBrick/1.3.1 (Ruby/2.0.0/2014-10-27) is not blacklisted  
< Server: WEBrick/1.3.1 (Ruby/2.0.0/2014-10-27)  
< Date: Mon, 30 Mar 2015 08:15:22 GMT  
< Connection: Keep-Alive  
<  
* Connection #0 to host localhost left intact  
{"name": "yutaro_slice"}
```

```
❶ ##### ##### ##### 201
```

17.4.2.

```
#####
##### /slices/:slice_id/ports/:port_id/mac_addresses # #### #####
##### yutaro_slice # #### = 0#1, #### = 1, #### = 11:11:11:11:11:11
#####
```

```
$ curl -sS -X POST -d '{"name": "11:11:11:11:11:11"}' 'http://localhost:9292/slices/yutaro_slice/ports/0x1:1/mac_addresses' -H Content-Type:application/json -v
```

```
#####
##### 201 #####
```

```
[{"name": "11:11:11:11:11:11"}]
* Hostname was NOT found in DNS cache
* Trying 127.0.0.1...
* Connected to localhost (127.0.0.1) port 9292 (#0)
> POST /slices/foo/ports/0x1:1/mac_addresses HTTP/1.1
> User-Agent: curl/7.35.0
> Host: localhost:9292
> Accept: */*
> Content-Type:application/json
> Content-Length: 29
>
} [data not shown]
* upload completely sent off: 29 out of 29 bytes
< HTTP/1.1 201 Created ❶
< Content-Type: application/json
< Content-Length: 31
* Server WEBrick/1.3.1 (Ruby/2.0.0/2014-10-27) is not blacklisted
< Server: WEBrick/1.3.1 (Ruby/2.0.0/2014-10-27)
< Date: Tue, 31 Mar 2015 00:20:45 GMT
< Connection: Keep-Alive
<
{ [data not shown]
* Connection #0 to host localhost left intact
```

❶ ##### 201

17.4.3.

```
##### /slices/:slice_id/ports # #### ## ##### ##### #####
##### slice_yutaro #####1 #
```

```
$ curl -sS -X GET 'http://localhost:9292/slices/yutaro_slice/ports'
[{"name": "0x1:1", "dpid": 1, "port_no": 1}]
```

```
##### yutaro_slice ##### 0x1 #### 1 ##### host1 #### /
slices/:slice_id/ports/:port_id/mac_addresses #####
```

```
$ curl -sS -X GET 'http://localhost:9292/slices/yutaro_slice/ports/0x1:1/mac_addresses'
[{"name": "11:11:11:11:11:11"}]
```

17.5. #### ## ##

```
#### ## ##### #### ## ##### (# 17#1)##### #### ##### ###### ####:/
#####.###/#####/#####/#####/#####/#####/#####/#####/#####/#####
#####
```

17.1. # 17#1: #### ##

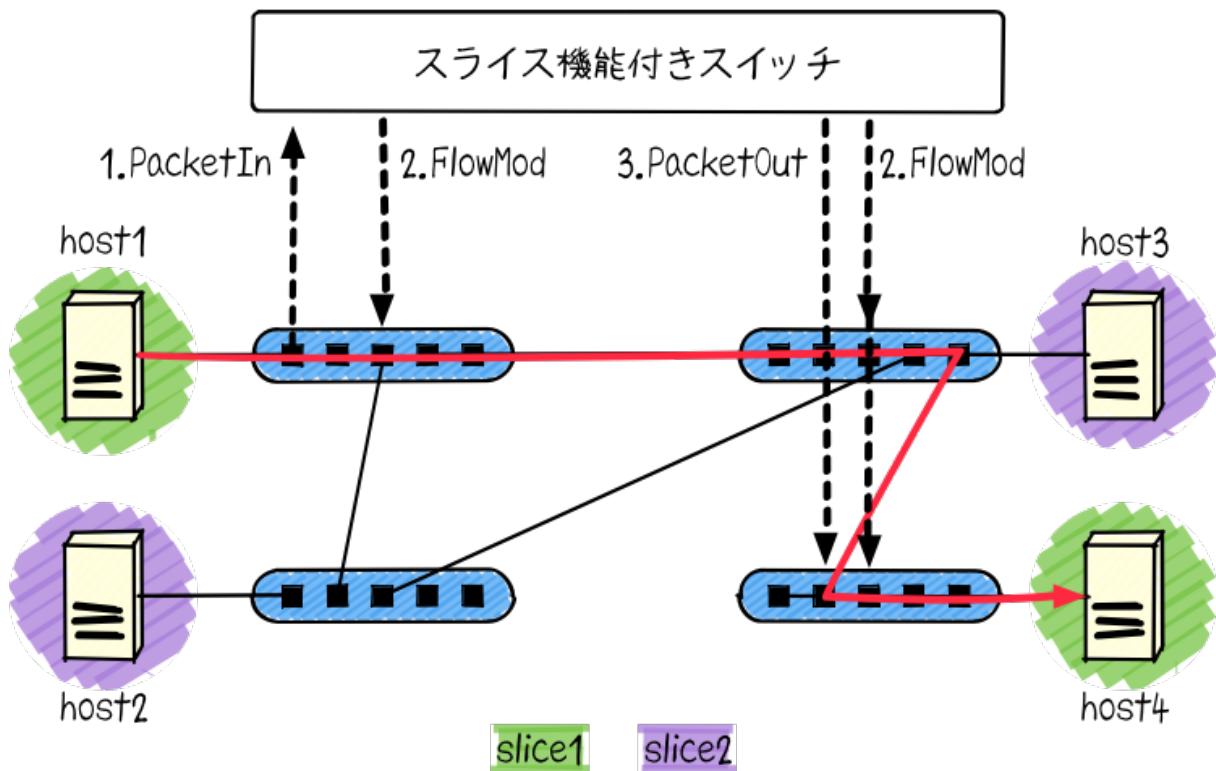
| | | |
|-------|-------|-----------------------------------|
| ## | #### | ## |
| ##### | #### | /slices |
| ##### | ##### | /slices/:slice_id |
| ##### | ## | /slices |
| ##### | ## | /slices/:slice_id |
| ##### | #### | /slices/:slice_id/ports |
| ##### | ##### | /slices/:slice_id/ ports/:port_id |
| ##### | ## | /slices/:slice_id/ports |
| ##### | ## | /slices/:slice_id/ ports/:port_id |

¹ curl ##### (-v) #####

| | | |
|-----------|-------|--|
| ## | #### | ### |
| ### ##### | #### | /slices/:slice_id/ ports/:port_id/ mac_addresses |
| ### ##### | ##### | /slices/:slice_id/ ports/:port_id/ mac_addresses/:mac_address_id |
| ### ##### | ### | /slices/:slice_id/ ports/:port_id/ mac_addresses |

17.6.

#####
15#####
#####
#17#5#



#####
17.5. #####

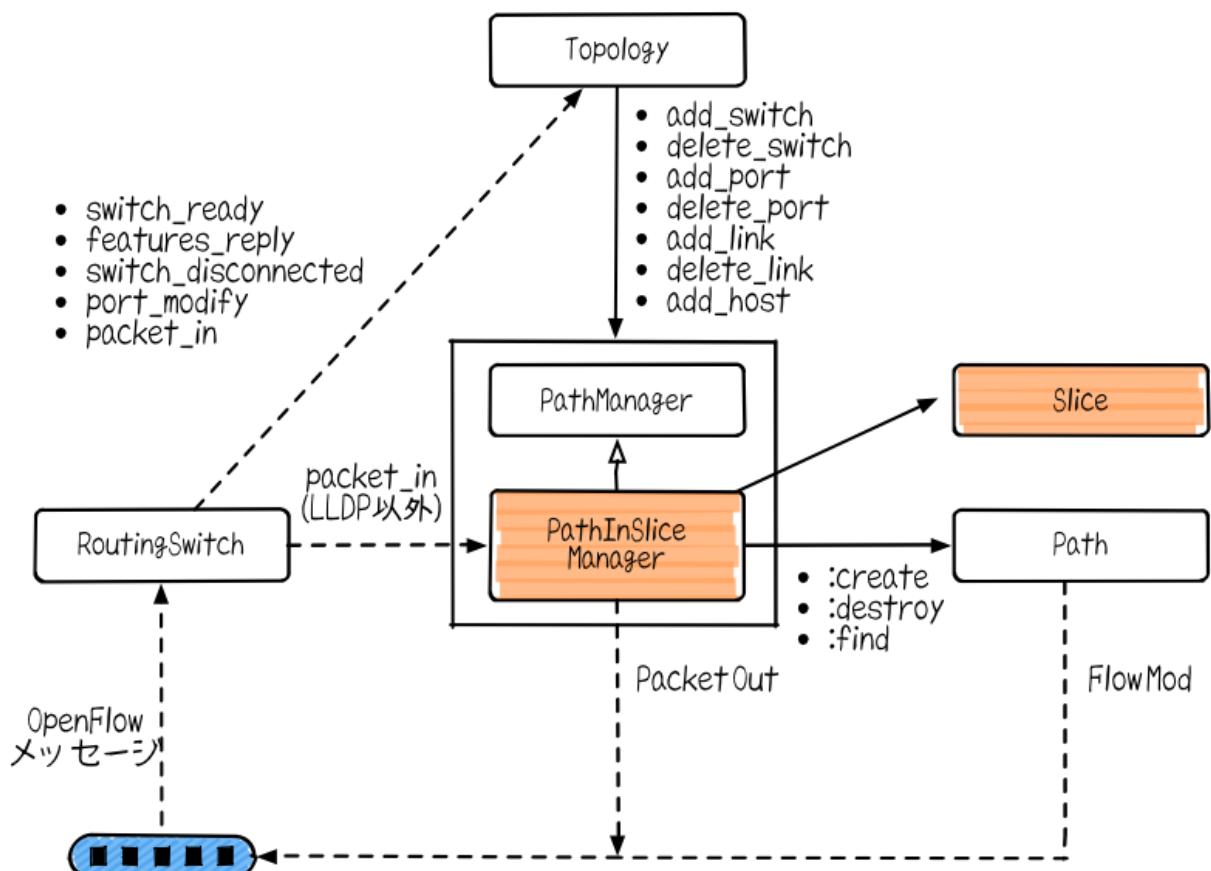
1. ### 1 #### 4 ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### ##### 1 ##### (## ##### ## # ## _ ##### ##### # ##)
2. ##### ##### ##### ##### ##### ##### (14#) ##### ##### 4 ##### ##### (##### 6) ##### (# # ##) ##

#####

3 ##### 3 #####
#####

17.7.

2 ##### (# 17#6)##



17.6.

```

def packet_in(_dpid, packet_in)
    slice = Slice.find do |each|
        each.member?(packet_in.slice_source) &&
        each.member?(packet_in.slice_destination(@graph))
    end
    ports = if slice
        path = maybe_create_shortest_path_in_slice(slice.name, packet_in)
        path ? [path.out_port] : []
    else
        external_ports(packet_in)
    end
    packet_out(packet_in.raw_data, ports)
end

```

1. ##### ### ##### ### #####

2. ##### (#####) #
#####²

```
#### 1 ##### Slice.find #### (#####) #####
Slice #####
```

1772 ##### ####

Slice.find ##### (all) ##### find

(###/#####.##)

2 #####

```

#####
#####

def self.find(&block)
  all.find(&block)
end

#####
      Slice.create      #####
Slice.find_by ##### Slice.new #####( all ) #####
##### (###/####.##)

def self.create(name)
  if find_by(name: name)
    fail SliceAlreadyExistsError, "Slice #{name} already exists"
  end
  new(name).tap { |slice| all << slice }
end

#####
Slice.destroy      #      create      #####
Slice.find_by! #####( Path #####) #####
## all #####
##### (###/####.##)

def self.destroy(name)
  find_by!(name: name)
  Path.find { |each| each.slice == name }.each(&:destroy)
  all.delete_if { |each| each.name == name }
end

```

17.8.

```

#####
#####

• #####
• #####
#####

#####
#####
```

18.

#####

18.1.

#####(##### #####)
#####)####################
#####3####################

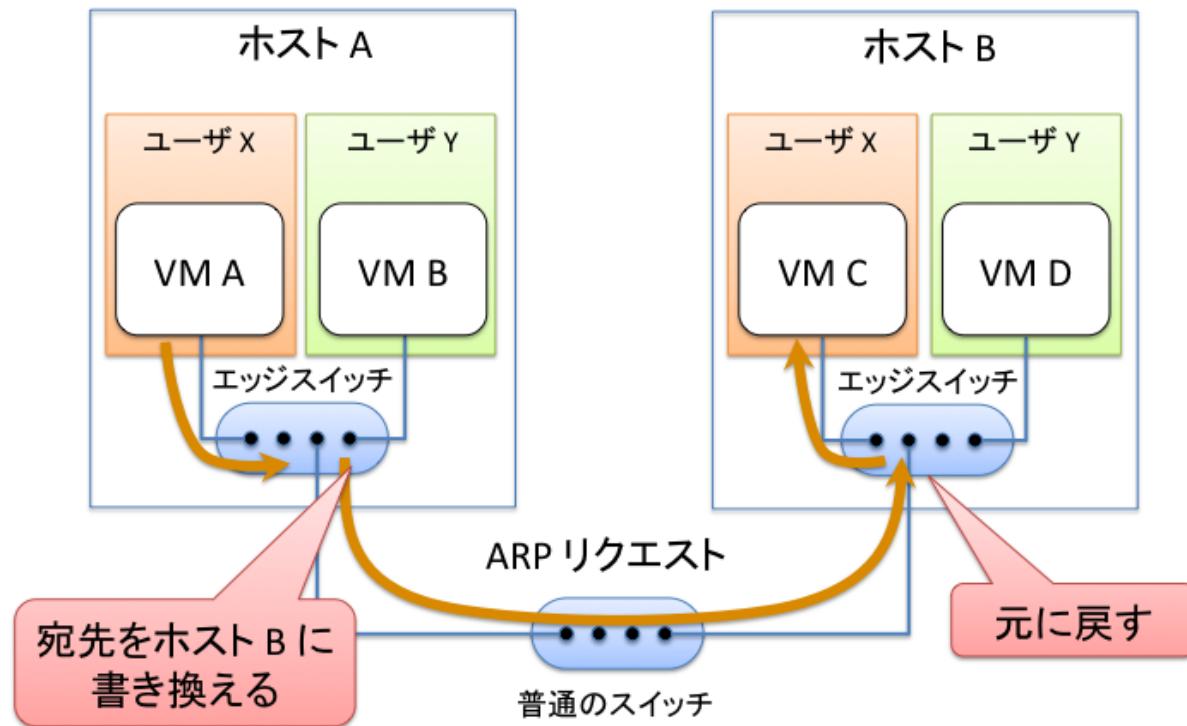
1

- ##### (##): #####
- ##: #####
- ## #####: ##### ##### #####
- ##### #####: ##### ##### ##### ##### #####
- #####: ##### ##### ##### ##### ##### (##)

18.1.1.

#####(#####)###############
#####

#####



18.1.

1. #####
 2. #####
#####

```
#####
#####
```

```
#####
##### #17#####
#####
#####
```

18.2.

#####2#####

1. #####
 2. #####

18.2.1.

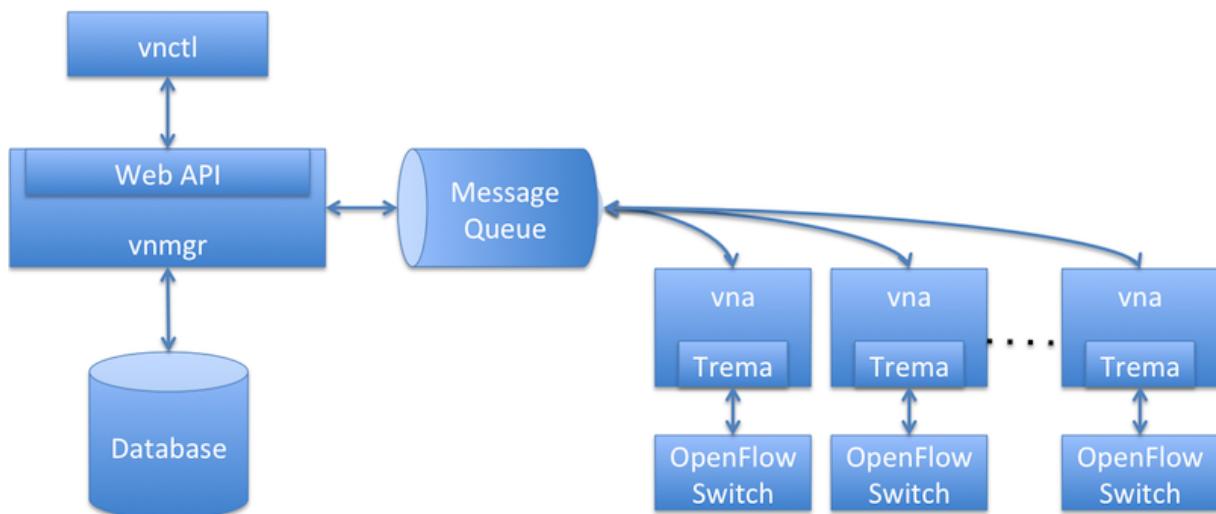
#####
#####

18.2.2.

```
#####
#####10#####10#####10#####
#####
```

18.3.

```
#####
#####(#####      #####
#####)#####(##### #####
##### ##### # ##### #####
##### #####
#####
```



18.2.

```
#####
##### #####
##### #####
#####
```

| | | |
|------------|-------------|-------------------------------------|
| ##### | ## | ## |
| ##### #### | #### #### | ####://#####.###/ |
| ##### #### | #### | ####://###.####.###/ |
| ##### | #### & #### | ####://####.###/ ####:/ ####.##/ |

18.4.

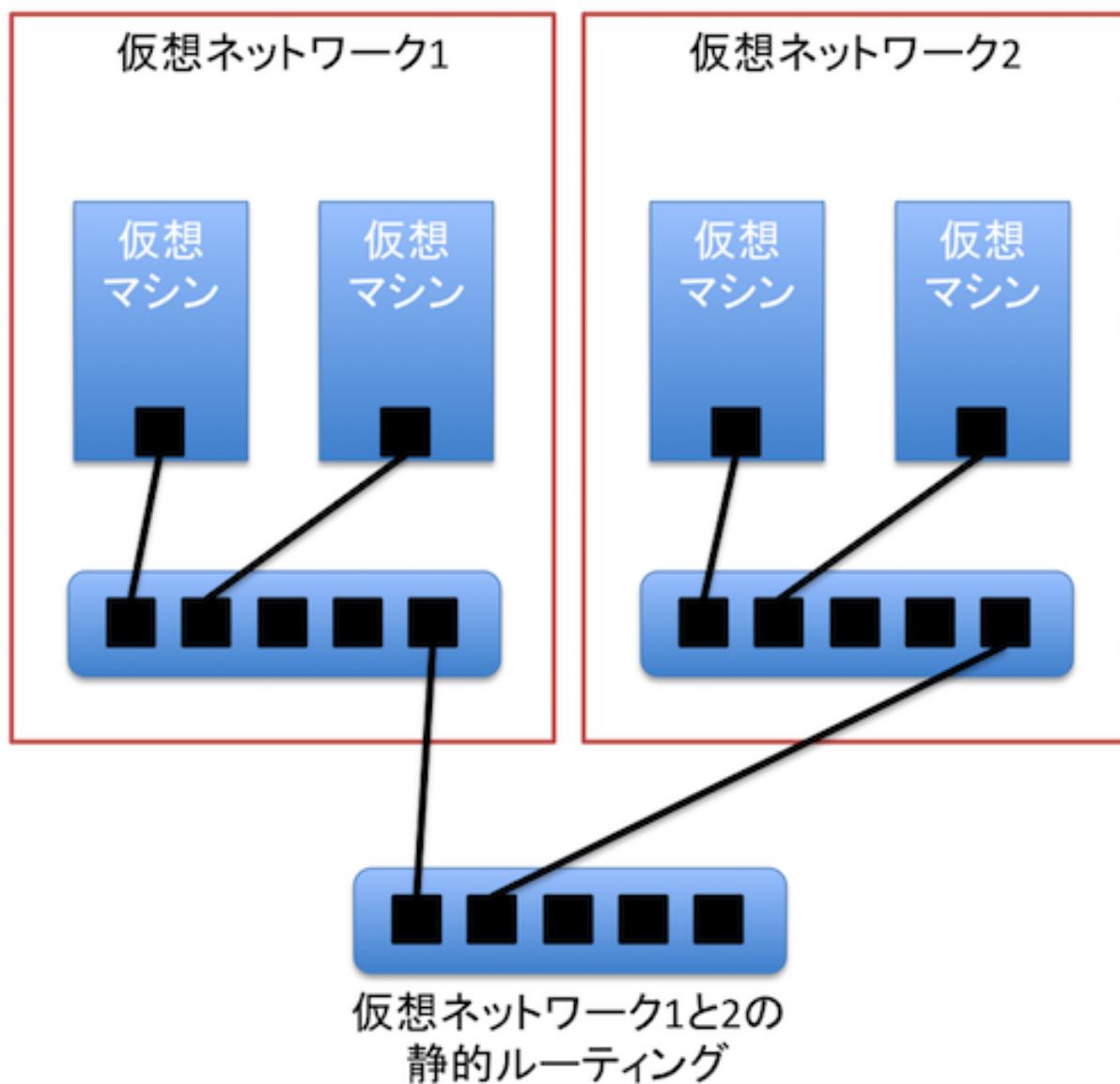
```
##### 4 #####
```

1. #####
2. #####
3. #####
4. #####

18.4.1.

#####

#####



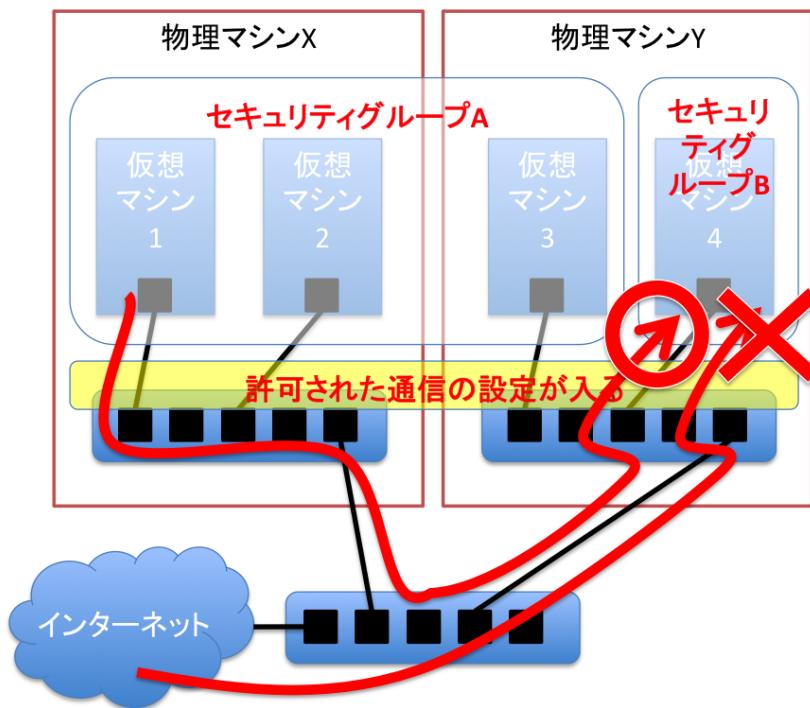
18.3.

#####

#####

18.4.2.

```
#####
#####
```

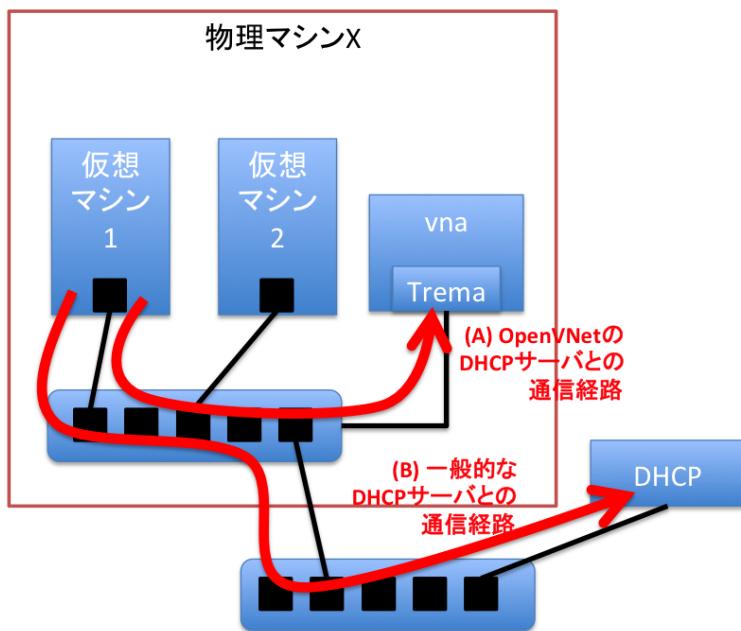


18.4.

```
#####
#####
```

18.4.3.

```
#####
#####
```



#####

#####

#####

18.4.4.

#####

#####

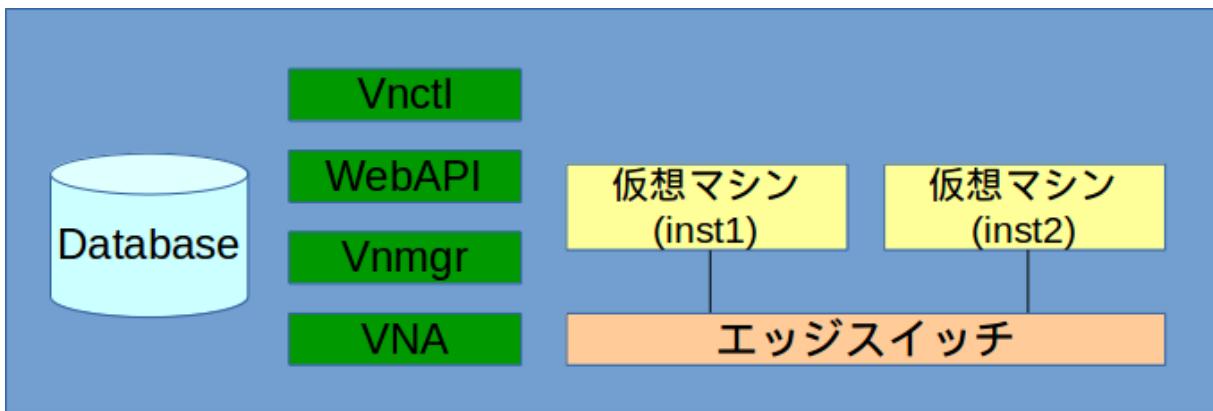
#####

#####

18.5.

#####

- ##### 6.6##(#####6#)#####
- #####



```
#####
# 18.6. 1#####
#
```

18.5.1.

```
#####
#
```

1. #####
2. #####
3. #####
4. #####

#####

```
##### yum ##### openvnet.repo # /etc/yum/repos.d/
#####
```

```
$ sudo curl -o /etc/yum.repos.d/openvnet.repo -R https://raw.githubusercontent.com/axsh/openvnet/master/deployment/yum_repositories/stable/openvnet.repo
```

```
##### openvnet-third-party.repo # /etc/yum.repos.d/ #####
#####
```

```
$ sudo curl -o /etc/yum.repos.d/openvnet-third-party.repo -R https://raw.githubusercontent.com/axsh/openvnet/master/deployment/yum_repositories/stable/openvnet-third-party.repo
```

```
##### epel-release #####
###
```

```
$ sudo yum install -y epel-release
```

#####

```
##### openvnet #####
```

```
$ sudo yum install -y openvnet
```

#####

#####

```
$ sudo yum install -y mysql-server redis
```

#####

```
br0 ##### inst1 ### inst2 #####
br0 ##### /etc/sysconfig/network-scripts/ifcfg-br0 #####
```

```
DEVICE=br0
DEVICETYPE=ovs
TYPE=OVSBridge
ONBOOT=yes
BOOTPROTO=static
HOTPLUG=no
OVS_EXTRA="

set bridge ${DEVICE} protocols=OpenFlow10,OpenFlow12,OpenFlow13 --
set bridge ${DEVICE} other_config:disable-in-band=true --
set bridge ${DEVICE} other-config:datapath-id=0000aaaaaaaaaa --
set bridge ${DEVICE} other-config:hwaddr=02:01:00:00:00:01 --
set-fail-mode ${DEVICE} standalone --
set-controller ${DEVICE} tcp:127.0.0.1:6633
"
```

```
##### datapath-id # 0000aaaaaaaaaaaa #####  
#####16#####
```

#####

openvswitch

```
$ sudo service openvswitch start  
$ sudo ifup br0
```

#####

```
$ sudo service mysqld start
```

#####

```
$ PATH=/opt/axsh/openvnet/ruby/bin:${PATH}
```

#####

```
$ cd /opt/axsh/openvnet/vnet  
$ bundle exec rake db:create  
$ bundle exec rake db:init
```

#####

```
$ service redis start
```

(vnmgr # webapi # vna)

```
$ sudo initctl start vnet-vnmgr  
$ sudo initctl start vnet-webapi
```

```
vnctl ##### vna ##### #####
#####
```

```
$ vnctl datapaths add --uuid dp-test1 --display-name test1 --dpid 0x0000aaaaaaaaaaaa --node-id vna
```

vna # ##### ## ##### ##### vna #####

```
$ sudo initctl start vnet-vna
```

```
ovs-vsctl ##### vna #####
```

```
$ ovs-vsctl show
```

fbe23184-7f14-46cb-857b-3abf6153a6d6

Bridge "br0"

Controller "tcp;127.0.0.1:6633"

```
#####
```

```
is_connected: true
```

```
#### is_connected: true ##### vna #####
#####
#####2#####( inst1 # inst2 )#####
#####
```

```
$ sudo yum -y install lxc lxc-templates
```

```
lxc ### lxc-templates ##### cgroup #####
#####
```

```
$ sudo mkdir /cgroup
$ echo "cgroup /cgroup cgroup defaults 0 0" >> /etc/fstab
$ sudo mount /cgroup
```

```
##### lxc-create ##### rsync #####
#####
```

```
$ sudo yum install -y rsync
```

```
##### inst1 # inst2 #####
#####
```

```
$ sudo lxc-create -t centos -n inst1
$ sudo lxc-create -t centos -n inst2
```

```
lxc-create ##### root #####
#####
#####
```

```
##### /var/lib/lxc/inst1/config #####
#####
#####
```

```
lxc.network.type = veth
lxc.network.flags = up
lxc.network.veth.pair = inst1
lxc.network.hwaddr = 10:54:FF:00:00:01
lxc.rootfs = /var/lib/lxc/inst1/rootfs
lxc.include = /usr/share/lxc/config/centos.common.conf
lxc.arch = x86_64
lxc.utsname = inst1
lxc.autodev = 0
```

```
### /var/lib/lxc/inst2/config #####
#####
#####
```

```
#####
```

```
lxc.network.type = veth
lxc.network.flags = up
lxc.network.veth.pair = inst2
lxc.network.hwaddr = 10:54:FF:00:00:02
lxc.rootfs = /var/lib/lxc/inst2/rootfs
lxc.include = /usr/share/lxc/config/centos.common.conf
lxc.arch = x86_64
lxc.utsname = inst2
lxc.autodev = 0
```

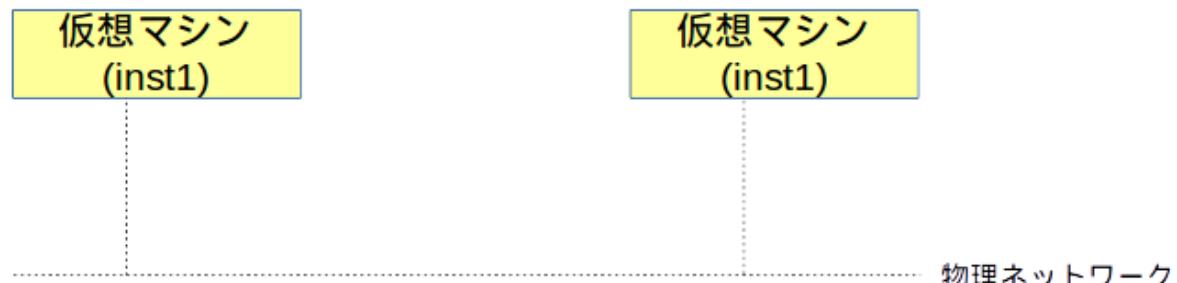
```
#####
```

```
$ sudo lxc-start -d -n inst1
$ sudo lxc-start -d -n inst2
```

```
#####
#####
```

```
$ sudo ovs-vsctl add-port br0 inst1
$ sudo ovs-vsctl add-port br0 inst2
```

```
#####
#####
```



```
##### 18.7. #####
```

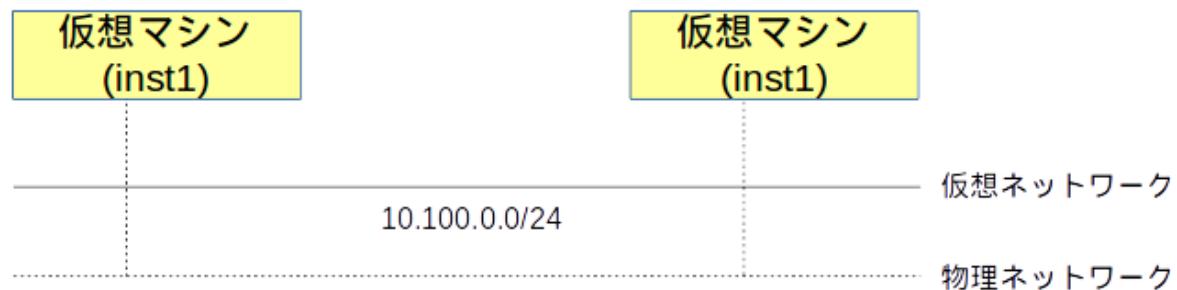
```
#####1#####
```

18.5.2.

```
##### vnctl #####1#####
##### 10.100.0.0/24 ### inst1 ##### 10.100.0.10 # inst2 #####
10.100.0.11 ##### vnctl networks #####
```

```
#####
```

```
$ vnctl networks add \  
--uuid nw-test1 \  
--display-name testnet1 \  
--ipv4-network 10.100.0.0 \  
--ipv4-prefix 24 \  
--network-mode virtual
```



18.8.

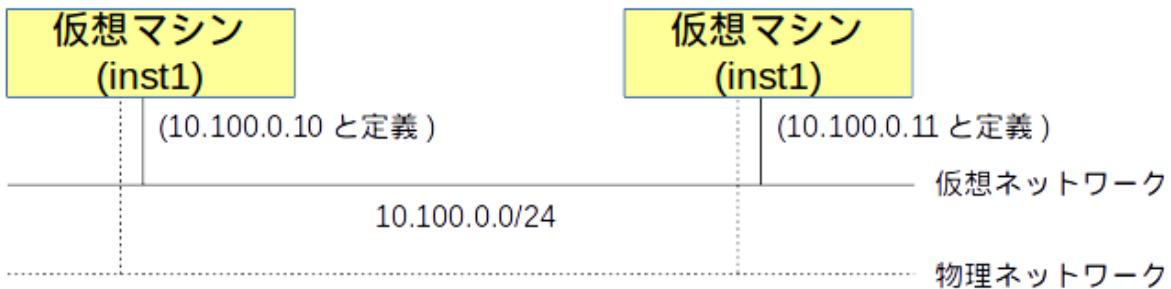
```
##### vnctl ##### vnctl  
interfaces ##### inst1 #####
```

```
$ vnctl interfaces add \  
--uuid if-inst1 \  
--mode vif \  
--owner-datatype-uuid dp-test1 \  
--mac-address 10:54:ff:00:00:01 \  
--network-uuid nw-test1 \  
--ipv4-address 10.100.0.10 \  
--port-name inst1
```

```
### inst2 #####
```

```
vnctl interfaces add \  
--uuid if-inst2 \  
--mode vif \  
--owner-datatype-uuid dp-test1 \  
--mac-address 10:54:ff:00:00:02 \  
--network-uuid nw-test1 \  
--ipv4-address 10.100.0.11 \  
--port-name inst2
```

```
##### 10.100.0.0/24 ##### 10.100.0.10 # 10.100.0.11 #  
#####
```



18.9.

18.5.3.

```
#####2##### inst1 #####
```

```
$ lxc-console -n inst1
```

```
$ ip addr show
```

```
##### inst1 # eth0 #####
```

```
inst1 ##### eth0 ##### 10.100.0.10 ##### vnctl # inst1
```

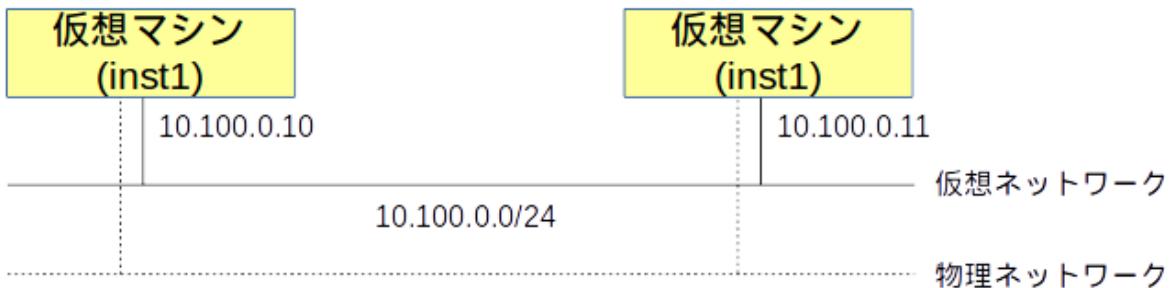
```
$ ip addr add 10.100.0.10/24 dev eth0
```

```
##1##### inst2 ##### inst2 # eth0 ##### 10.100.0.11 ####
```

```
$ lxc-console -n inst2
```

```
$ ip addr add 10.100.0.11/24 dev eth0
```

```
#####2#####
```



18.10.

```
#####
```

```
##### ping ##### inst2 ## inst1 # ping #####
```

```
$ ping 10.100.0.10
```

```
#####
```

```
##### inst2 ## eth0 ##### 10.100.0.11/24 ## 10.100.0.15/24 ##### inst2 #
```

```
$ sudo ip addr del 10.100.0.11/24 dev eth0
```

```
$ sudo ip addr add 10.100.0.15/24 dev eth0
```

```
##### inst1 #### ping #####
```

```
$ ping 10.100.0.10
```

```
##### 10.100.0.0/24 #####
```

```
##### inst2 ###### 10.100.0.11 #####
```

```
##
```

18.5.4.

```
##### vnflows-monitor #####
```

```
#####
```

```
$ cd /opt/axsh/openvnet/vnet/bin/
```

```
$ ./vnflows-monitor
```

```
#####
```

```
(0): TABLE_CLASSIFIER
```

```
0-00 0 0 => SWITCH(0x0)
```

```
actions=write_metadata:REMOTE(0x0),goto_table:TABLE_TUNNEL_PORTS(3)
```

```
0-01 0 0 => SWITCH(0x0) tun_id=0 actions=drop
```

```
0-02 28 0 => PORT(0x1) in_port=1 actions=write_metadata:TYPE_INTERFACE|  
LOCAL(0x1),goto_table:TABLE_INTERFACE_EGRESS_CLASSIFIER(15)
```

```
0-02 22 0 => PORT(0x2) in_port=2 actions=write_metadata:TYPE_INTERFACE|  
LOCAL(0x5),goto_table:TABLE_INTERFACE_EGRESS_CLASSIFIER(15)
```

```
0-02 0 0 => SWITCH(0x0) in_port=CONTROLLER actions=write_metadata:LOCAL|  
NO_CONTROLLER(0x0),goto_table:TABLE_CONTROLLER_PORT(7)
```

```
0-02      0      0 => PORT(0x7fffffe)      in_port=LOCAL
actions=write_metadata:LOCAL(0x0),goto_table:TABLE_LOCAL_PORT(6)
(3): TABLE_TUNNEL_PORTS
 3-00      0      0 => SWITCH(0x0)        actions=drop
(4): TABLE_TUNNEL_NETWORK_IDS
 4-00      0      0 => SWITCH(0x0)        actions=drop
 4-30      0      0 => ROUTE_LINK(0x1)      tun_id=0x10000001,dl_dst=02:00:10:00:00:01
actions=write_metadata:TYPE_ROUTE_LINK(0x1),goto_table:TABLE_ROUTER_CLASSIFIER(33)
 4-30      0      0 => NETWORK(0x1)        tun_id=0x80000001
actions=write_metadata:TYPE_NETWORK(0x1),goto_table:TABLE_NETWORK_SRC_CLASSIFIER(20)
 4-30      0      0 => NETWORK(0x2)        tun_id=0x80000002
actions=write_metadata:TYPE_NETWORK(0x2),goto_table:TABLE_NETWORK_SRC_CLASSIFIER(20)
(6): TABLE_LOCAL_PORT
 6-00      0      0 => SWITCH(0x0)        actions=drop
...

```


#####

1. ##### (0#00#0#01##)
 2. ##### (0#28#22##)
 3. #### cookie (0 ⇒ #####(0#0)##)
 4. #### match (###_#=0###_###=1##)
 5. #### action (#####=#####)

18.6.

#####

18.6.1.

1 #####

#####

1 #####(#####://#####.#####.#####.#####)#####

#####

#####2#####1#####3#####

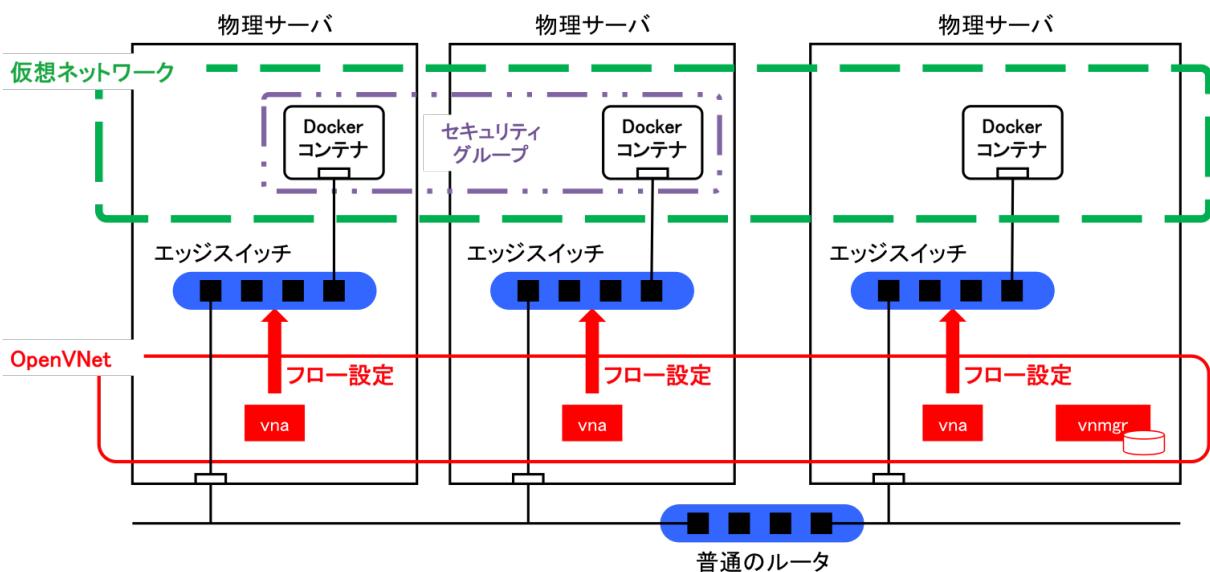
#####

#####

1. #####
2. #####
3. #####
4. #####
5. #####
6. #####
7. #####
8. #####

#####

#####



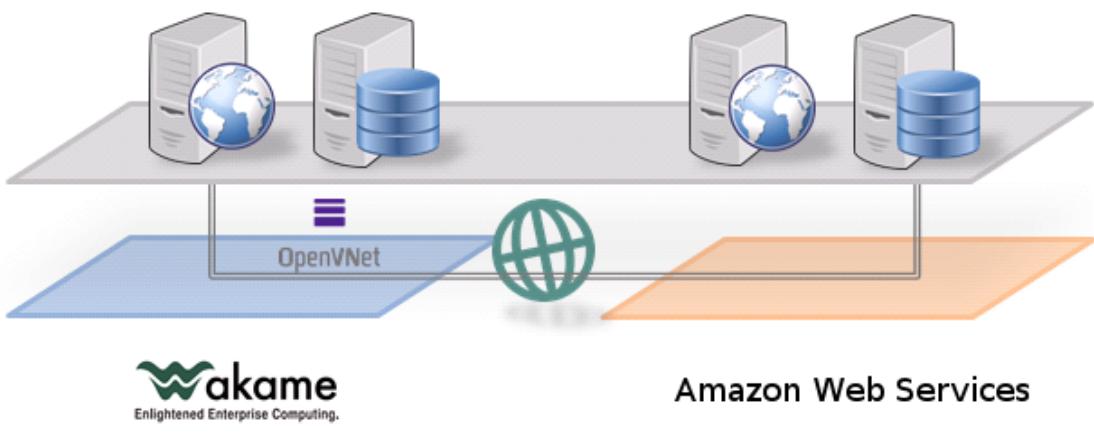
18.11.

#####

#####² #####

18.6.2.

```
#####
#####
```



18.12.

- #####
 - #####
 - #####
 - #####

2 #####://##### #####/##### #####/#####/#####

3 #####://##### #####/##### #####/##### #####/##### #####/##### #####/#####

#####

- #####

18.7. ###

- #####
 - #####
 - #####
 - #####

#. ##### #### # ## #####

3.0:

- #####://##.##.##/#####/#3.0.###