Lab 3

ONOS Application Development:
SDN-enabled Learning Bridge and Proxy ARP

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Deadline: 2024/10/16 23:59

Outline

- Build ONOS Application Project
  - Environment Setup
  - Create an ONOS Application
  - Build, Install, Activate, and Reinstall ONOS Application
- ARP
  - Introduction
  - ARP Request/Reply Format
- Learning Bridge Function
  - Introduction
  - Workflow
- Proxy APR
  - Introduction
  - Workflow
- Lab 3 Requirements

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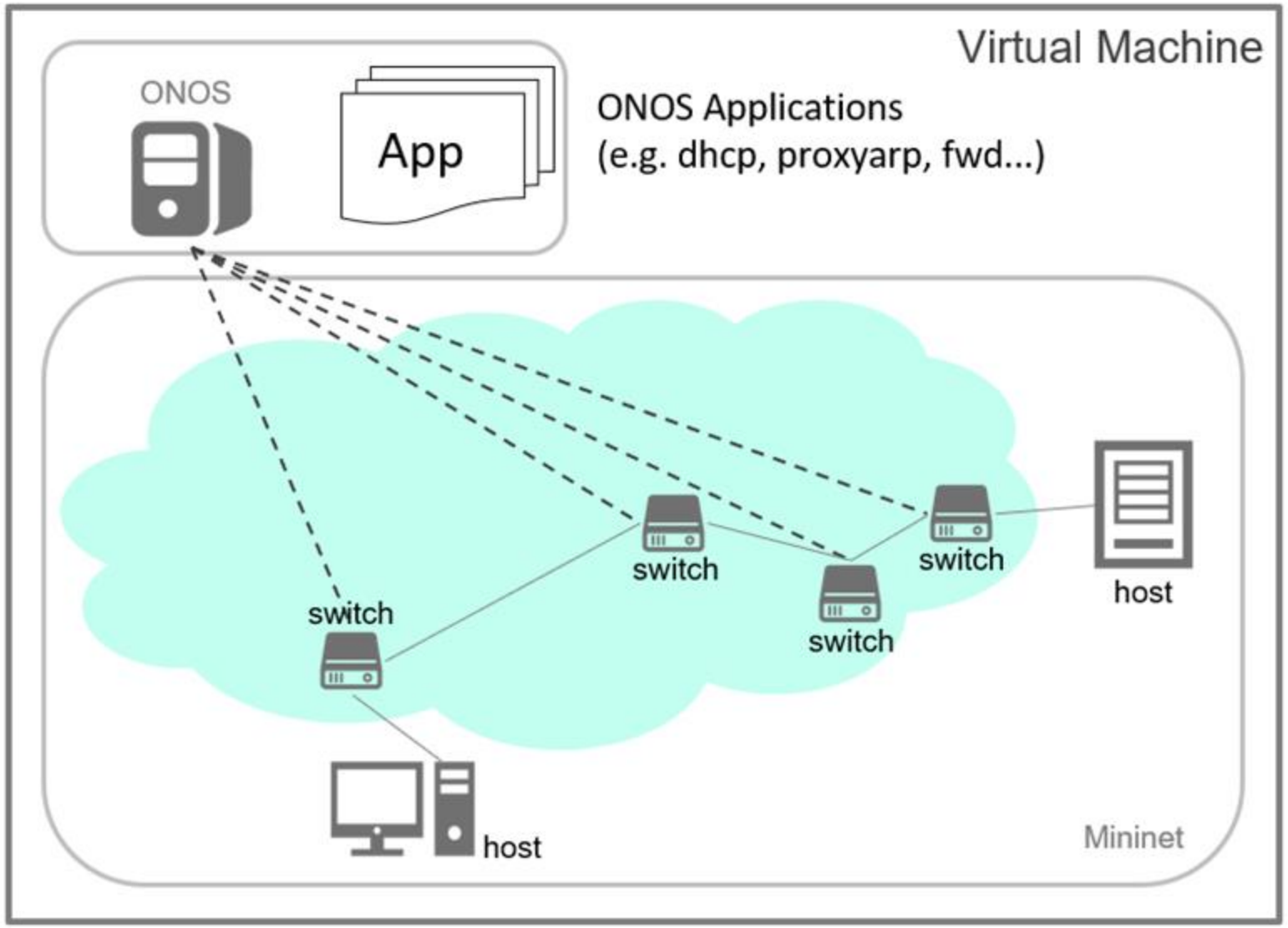
Overview


Virtual Machine
ONOS
App
ONOS Applications
(e.g. dhcp, proxyarp, fwd...)
switch
switch
switch
switch
host
host
Mininet

JDK Installation

1. Download the “install_jdk” script from E3.
2. Add execution permission to the script:

```
$ chmod +x install_jdk
```

3. Execute the script:

```
$ ./install_jdk
```

4. Once the installation finishes, you will see a success message:

```
Setting up zulu11-jdk (11.0.16.1-1) ...
************************************************************
* Installation of Azul Zulu JDK 11 finished successfully! *
************************************************************
```

5. Check the installed JDK version:

```
$ java -version
```

```
demo@SDN-NFV:~$ java -version
openjdk version "11.0.16.1" 2022-07-19 LTS
OpenJDK Runtime Environment Zulu11.58+23-CA (build 11.0.16.1+1-LTS)
OpenJDK 64-Bit Server VM Zulu11.58+23-CA (build 11.0.16.1+1-LTS, mixed mode)
```

Apache Maven

- A software project management and comprehension tool.
- Based on the concept of a Project Object Model (POM).
- Manage a project's build, reporting and documentation from a **central piece** of information.
- It has been intalled in your VM by the “env_setup” script in Lab 1.
- Official website: https://maven.apache.org/

Build ONOS Application Archetypes

- We will use ***onos-create-app*** command to generate an ONOS application template.
- ***onos-create-app*** command relies on the ONOS archetypes.
- We need to build ONOS archetypes first.
- Steps:
  - Specify ONOS version:

```
$ export ONOS_POM_VERSION=2.7.0
```

  - Build archetypes:

```
$ cd $ONOS_ROOT/tools/package/archetypes
$ mvn clean install -DskipTests
```

    - ***-DskipTests***: Skip running tests of the project.

Build ONOS Application Template

- Run ***onos-create-app***.

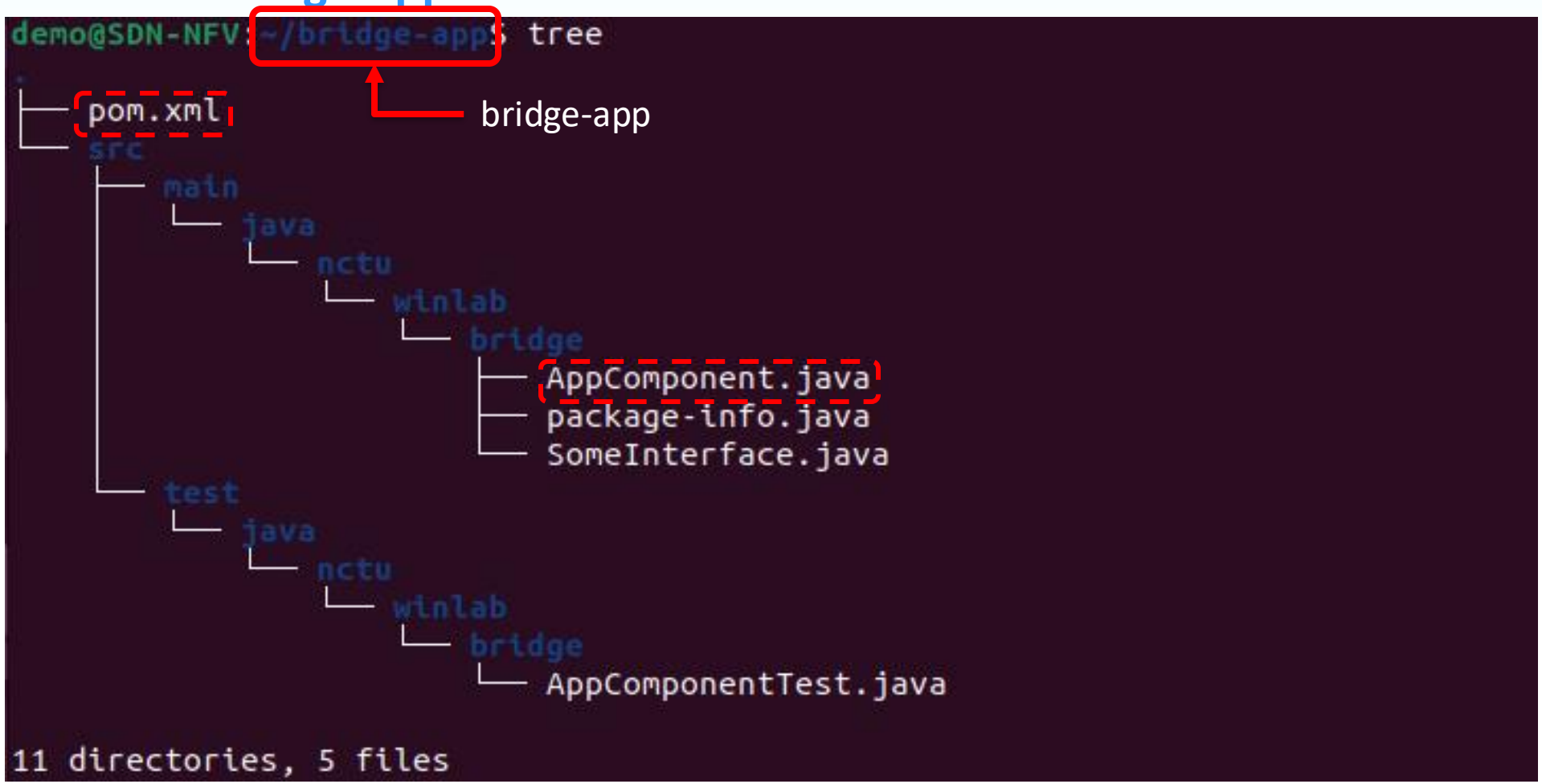
```
$ onos-create-app
...
[INFO] ...
Define value for property 'groupId': nycu.winlab
Define value for property 'artifactId': bridge-app
Define value for property 'version' 1.0-SNAPSHOT: : <enter>
Define value for property 'package' nycu.winlab: : nycu.winlab.bridge

Confirm properties configuration:
onosVersion: 2.7.0
groupId: nycu.winlab
artifactId: bridge-app
version: 1.0-SNAPSHOT
package: nycu.winlab.bridge
 Y: : <enter>
[INFO] ...
...
[INFO] BUILD SUCCESS
```

Archive ID for the created ONOS application.

Folder Structure of Created ONOS Application

- ***onos-create-app*** command creates a folder named **bridge-app** (artifactId).
- Structure of **bridge-app** folder:



Modify ONOS Application Properties

- Modify Project Object Model file pom.xml to describe your project.

pom.xml
Before

```
34      <properties>
35          <!-- Uncomment to generate ONOS app from this module.
36          <onos.app.name>org.foo.app</onos.app.name>
37          <onos.app.title>Foo App</onos.app.title>
38          <onos.app.origin>Foo, Inc.</onos.app.origin>
39          <onos.app.category>default</onos.app.category>
40          <onos.app.url>http://onosproject.org</onos.app.url>
41          <onos.app.readme>ONOS OSGi bundle archetype.</onos.app.readme>
42          -->
43      </properties>
```

pom.xml
After

```
34      <properties>
35          <onos.app.name>nctu.winlab.bridge</onos.app.name>
36          <onos.app.title>Learning Bridge App</onos.app.title>
37          <onos.app.origin>Winlab, NCTU</onos.app.origin>
38          <onos.app.category>default</onos.app.category>
39          <onos.app.url>http://onosproject.org</onos.app.url>
40          <onos.app.readme>ONOS OSGi bundle archetype.</onos.app.readme>
41      </properties>
```

Overview of AppComponent.java

- AppComponent.java code template.

```java
public class AppComponent implements SomeInterface {

    private final Logger log = LoggerFactory.getLogger(getClass());

    /** Some configurable property. */
    private String someProperty;

    @Reference(cardinality = ReferenceCardinality.MANDATORY)
    protected ComponentConfigService cfgService;

    @Activate
    protected void activate() {
        cfgService.registerProperties(getClass());
        log.info("Started");
    }

    @Deactivate
    protected void deactivate() {
        cfgService.unregisterProperties(getClass(), clear: false);
        log.info("Stopped");
    }

    @Modified
    public void modified(ComponentContext context) {
        Dictionary<?, ?> properties = context != null ? context.getProperties()
        if (context != null) {
            someProperty = get(properties, propertyName: "someProperty");
        }
        log.info("Reconfigured");
    }

    @Override
    public void someMethod() { log.info("Invoked"); }

}
```

Inject a dependent service in ONOS Core.

```java
@Reference(cardinality = ReferenceCardinality.MANDATORY)
protected ComponentConfigService cfgService;
```

Executed when app activated.

```java
@Activate
protected void activate() {
    cfgService.registerProperties(getClass());
    log.info("Started");
}
```

Executed when app deactivated.

```java
@Deactivate
protected void deactivate() {
    cfgService.unregisterProperties(getClass(), clear: false);
    log.info("Stopped");
}
```

Build, Install and Activate ONOS Application

- Build ONOS application:

```
# In the root of your application folder.
$ mvn clean install -DskipTests
```

```
demo@SDN-NFV:~/bridge-app$ ls target
bridge-app-1.0-SNAPSHOT.jar        checkstyle-header.txt        generated-test-sources
bridge-app-1.0-SNAPSHOT.oar        checkstyle-result.xml        maven-archiver
bridge-app-1.0-SNAPSHOT-tests.jar  checkstyle-suppressions.xml  maven-status
checkstyle-cachefile               classes                      oar
checkstyle-checker.xml             generated-sources            test-classes
```

built results

- Run ONOS:

```
$ cd $ONOS_ROOT
$ bazel run onos-local -- clean debug
```

- Install and activate ONOS application:

```
# In the root of your application folder.
$ onos-app localhost install! target/<artifactId>-<version>.oar
```

(bridge-app-1.0-SNAPSHOT.oar)

  - ***install!***: Install and activate application immediately.

Reinstall ONOS Application

If you modify your application, you need to rebuild and reinstall it on ONOS.

1. Rebuild application of new version:

```
# In the root of your application folder.
$ mvn clean install -DskipTests
```

2. Deactivate application of old version on ONOS:

```
$ onos-app localhost deactivate <onos.app.name>
```

- ***<onos.app.name>*** is set in your pom.xml. e.g. nycu.winlab.bridge

3. Uninstall application of old version:

```
$ onos-app localhost uninstall <onos.app.name>
```

4. Install and activate application of new version:

```
# In the root of your application folder.
$ onos-app localhost install! target/<artifactId>-<version>.oar
```

References

- Install Azul Zulu on Debian-based Linux
- ONOS Wiki – Template Application Tutorial
- ONOS Application Subsystem
- ONOS Java API (2.7.0)

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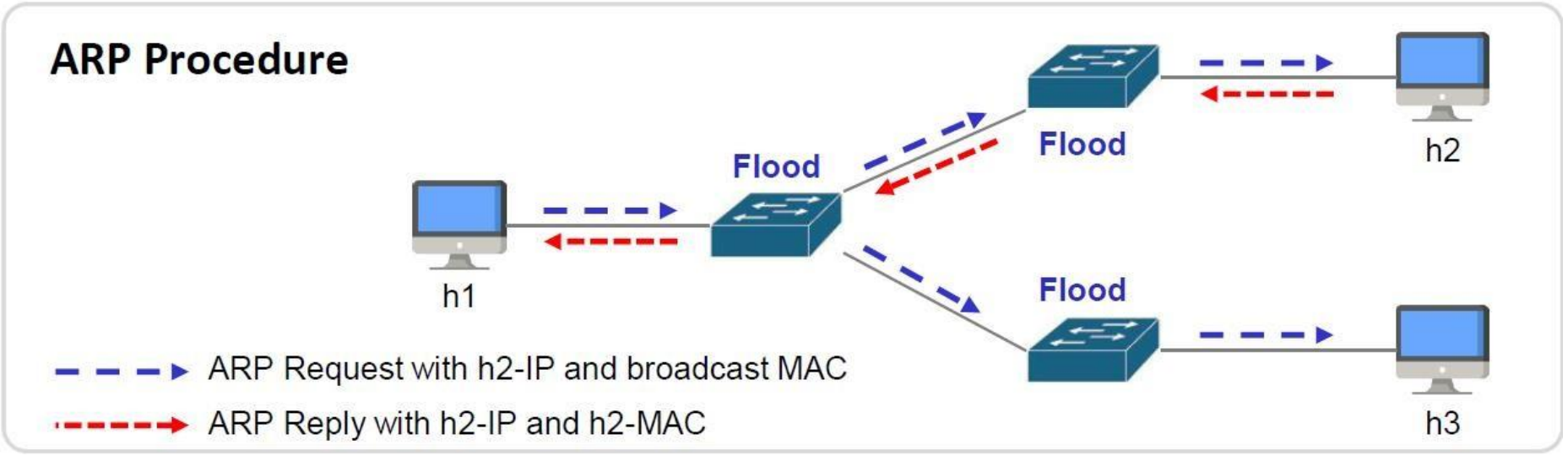
What is Address Resolution Protocol (ARP)

- Used to discover Link Layer address (e.g. MAC) with the given Network Layer address (e.g. IPv4)
- Use flooding to discover devices
  - Destination Ethernet address of ARP Request is broadcast address
- Hosts maintain an ARP table for mapping IP address to MAC



ARP Request Packet Format

- e.g. h1 sends ARP request to h2

Hardware Type (Ethernet = 1)		Protocol Type (IPv4 = 0x0800)
Hardware Length (Ethernet = 6)	Protocol Length (IPv4 = 4)	Operation Code (Request = 0x1)
Sender Hardware Address (h1-MAC)		
Sender Protocol Address (h1-IP)		
Target Hardware Address (**00:00:00:00:00:00**)		
Target Protocol Address (h2-IP)		

ARP Reply Packet Format

- e.g. h2 sends ARP reply to h1

Hardware Type (Ethernet = 1)		Protocol Type (IPv4 = 0x0800)
Hardware Length (Ethernet = 6)	Protocol Length (IPv4 = 4)	Operation Code (Reply = 0x2)
Sender Hardware Address (**h2-MAC**)		
Sender Protocol Address (h2-IP)		
Target Hardware Address (h1-MAC)		
Target Protocol Address (h1-IP)		

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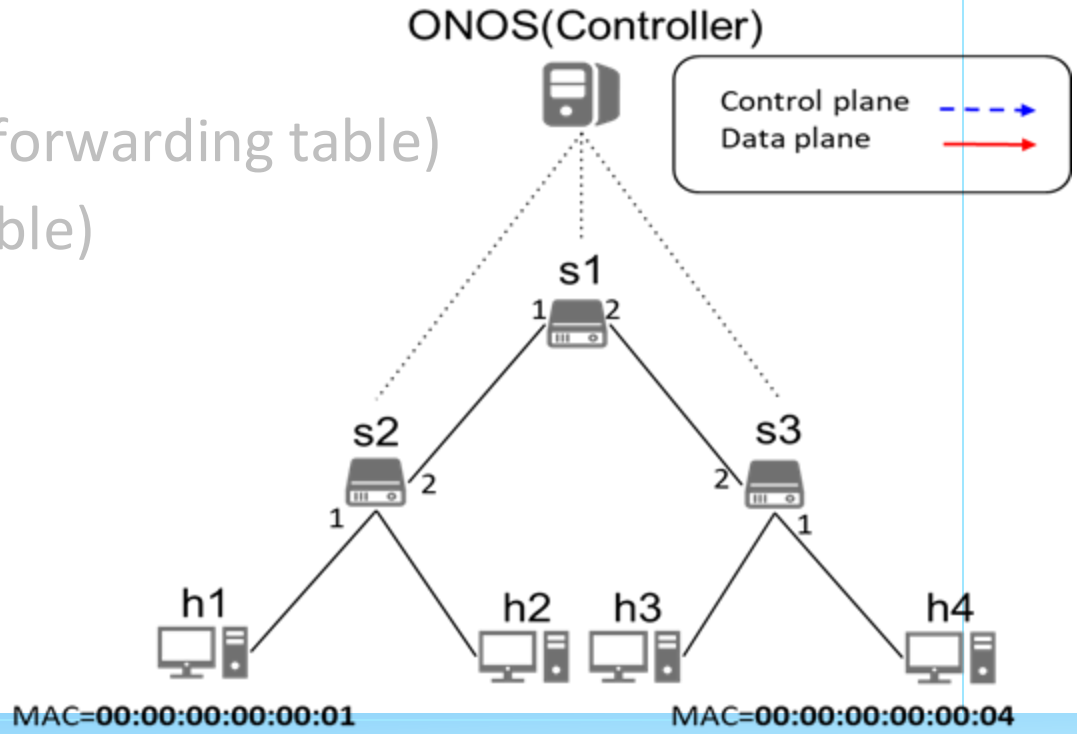
Learning Bridge Functionality

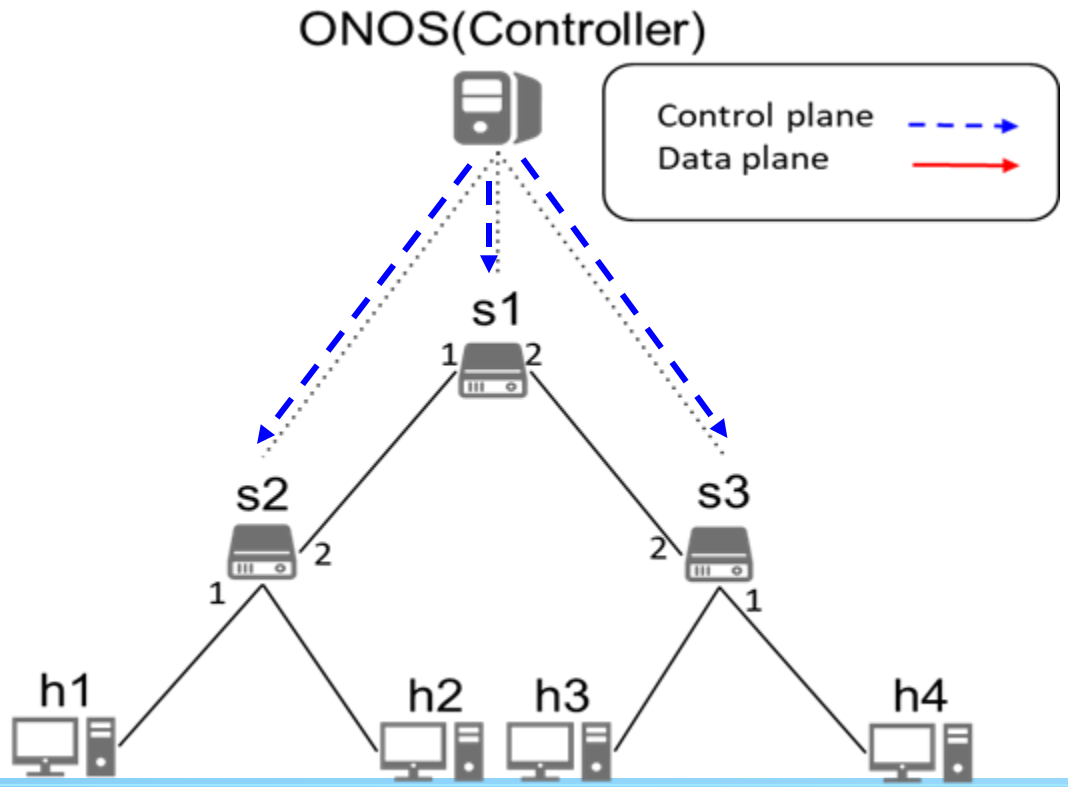
- Switch functionality:
  - When receives a packet, matches Destination MAC
    - Matched: Forwards packet via specified port
    - Not matched: Packet-in
- ONOS App functionality:
  - When receives a Packet-in
    - Records Source MAC and incoming port (in forwarding table)
    - Looks up Destination MAC (in forwarding table)
      a. Not found:
      Floods Packet-out.
      b. Found:
      Sends Packet-out via designated port.
      Installs flow rule on switch.

s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port



Request for Packet-in

- When App is activated, it installs a rule on each switch.
  - To request Packet-in for IPv4 packets.
  - With very low priority.
- Don’t forget to cancel the request for Packet-in when your App is deactivated.



Workflow (h1 -> h4)

1. h1 pings h4.
2. Switch sends Packet-in to Controller.
3. Controller updates MAC address table with source MAC and incoming port.
4. Controller looks up MAC address table for destination MAC:
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5. h4 receives packet from h1.

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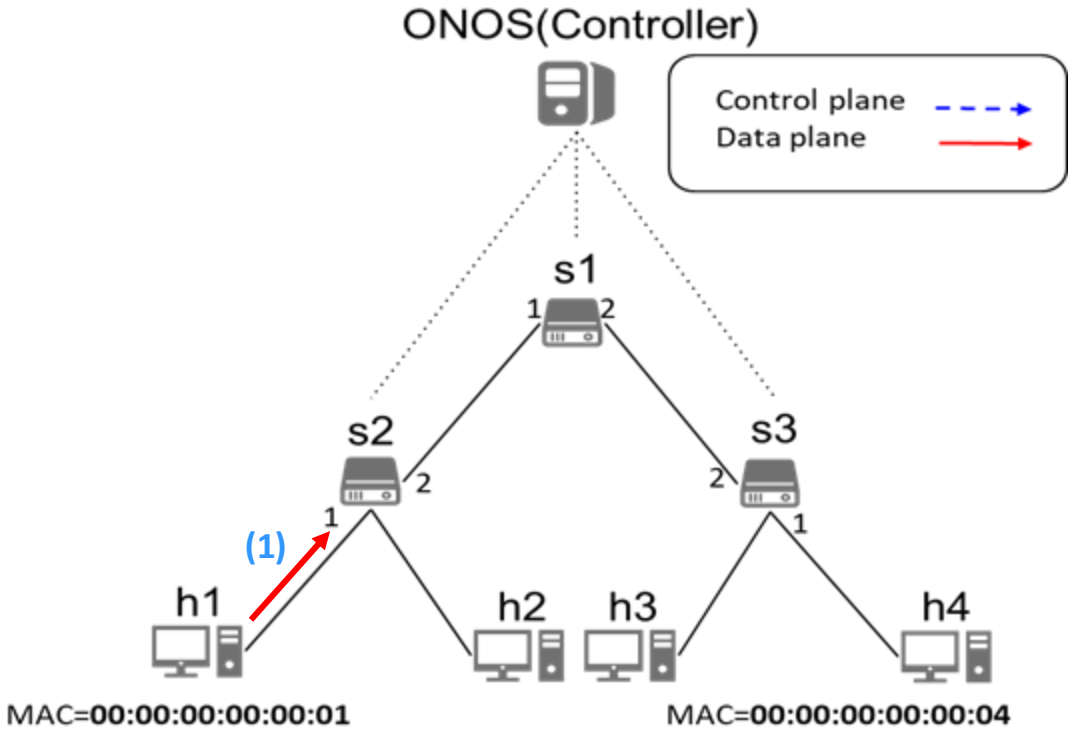

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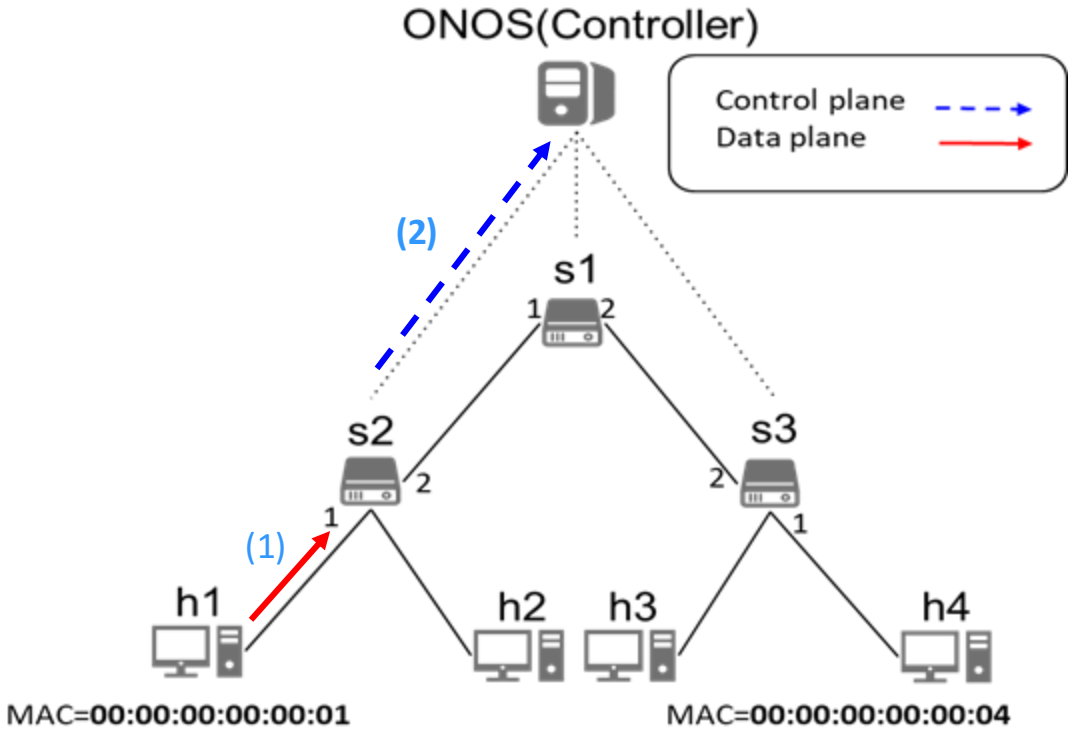

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      - Installs flow rule on switch.
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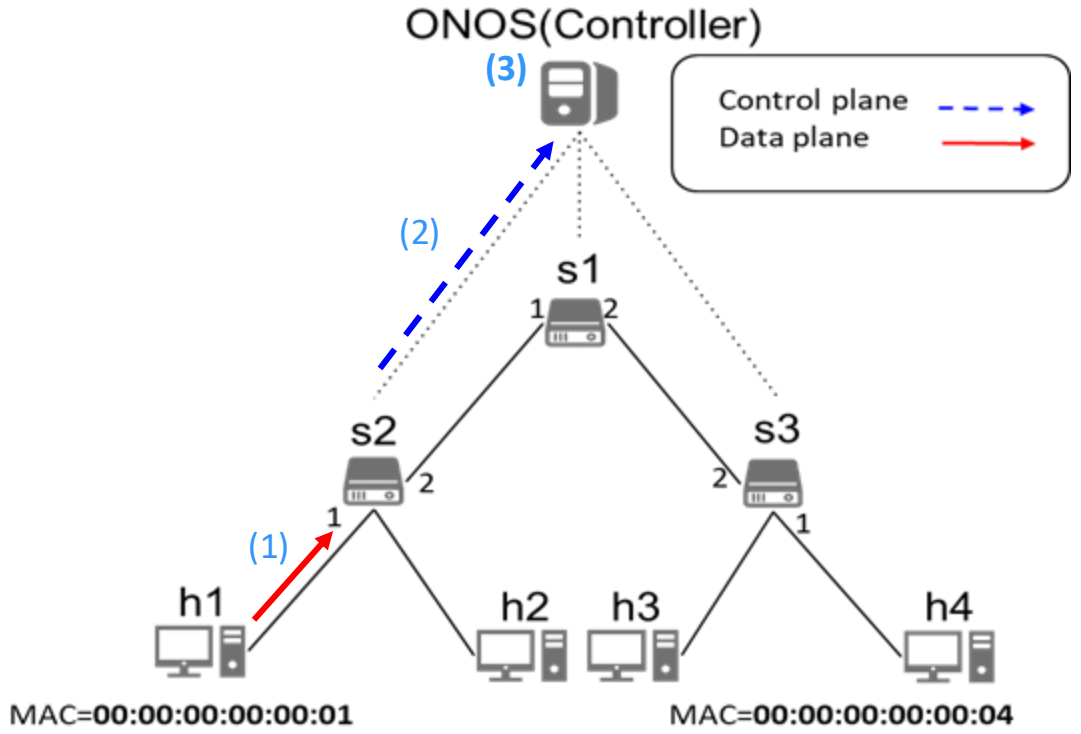
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
		00:.....:01	**1**		



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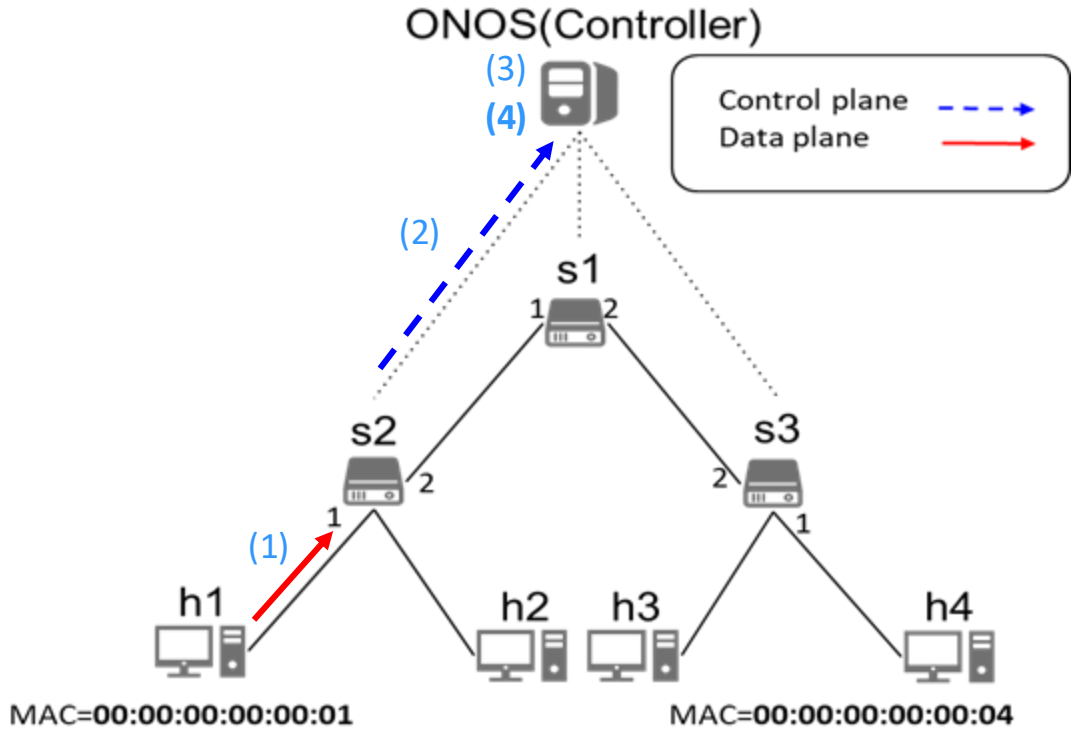
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
		00:.....:01	1		



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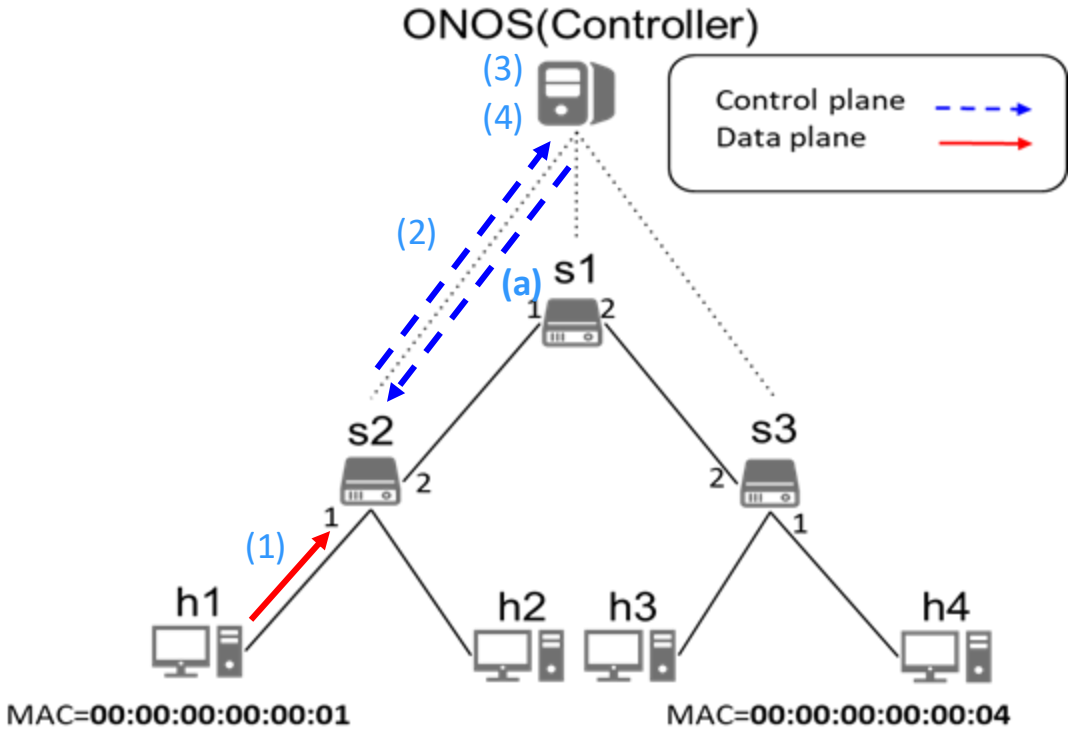
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
		00:.....:01	1		



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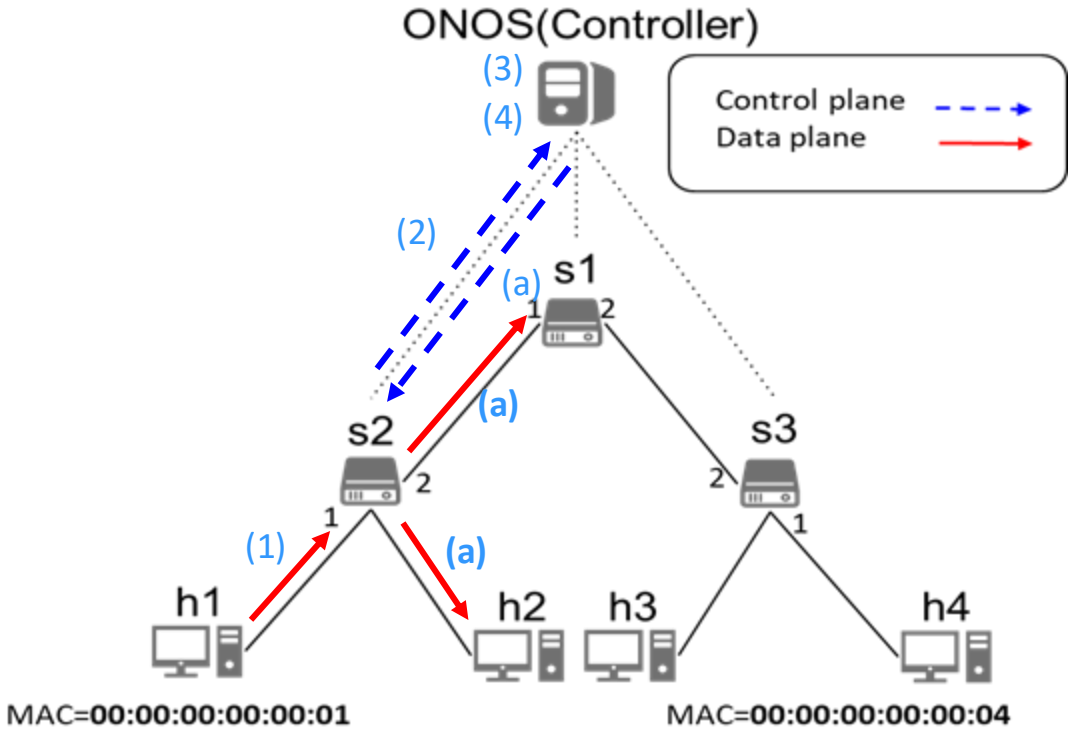
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
		00:.....:01	1		



Workflow (h1 -> h4)

1. h1 pings h4.
2. Switch (s1) sends Packet-in to Controller.
3. Controller updates MAC address table with source MAC and incoming port.
4. Controller looks up MAC address table for destination MAC:
   a. Destination MAC not found:
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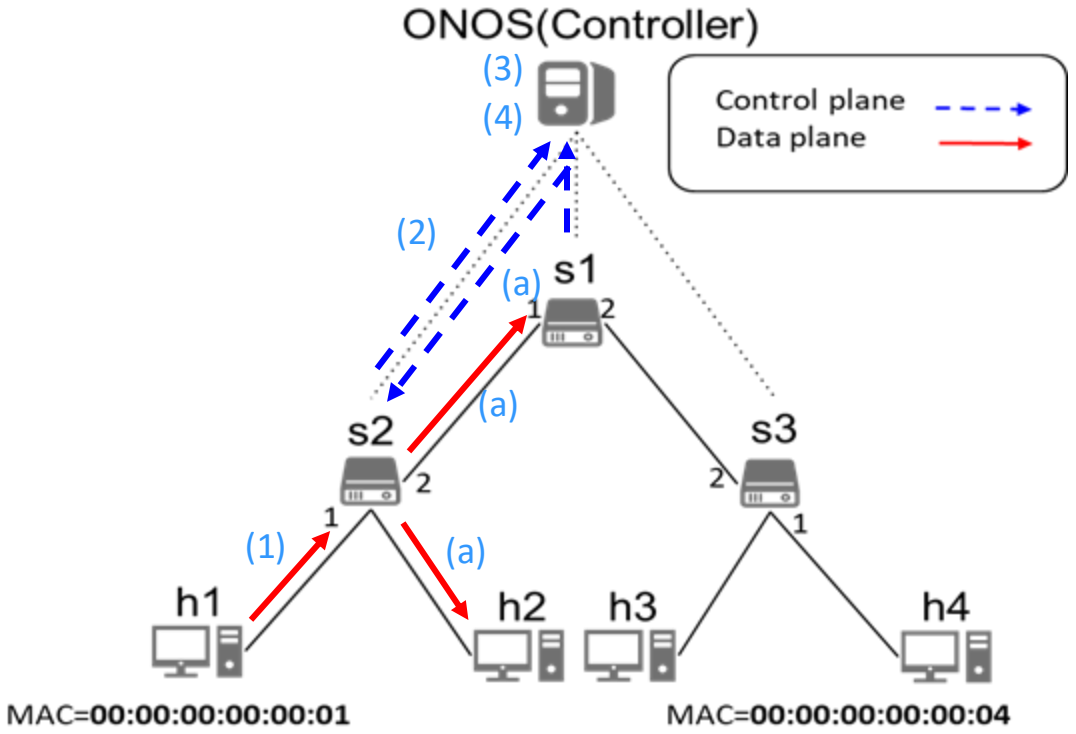
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
		00:.....:01	1		



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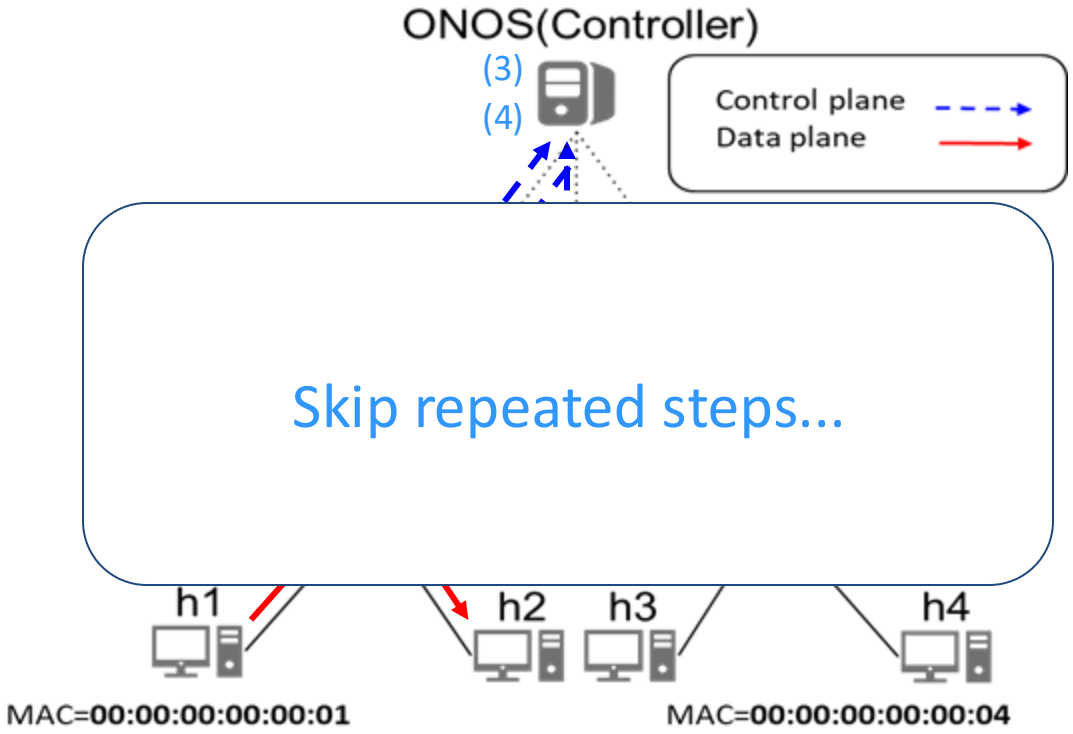
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
		00:.....:01	1		



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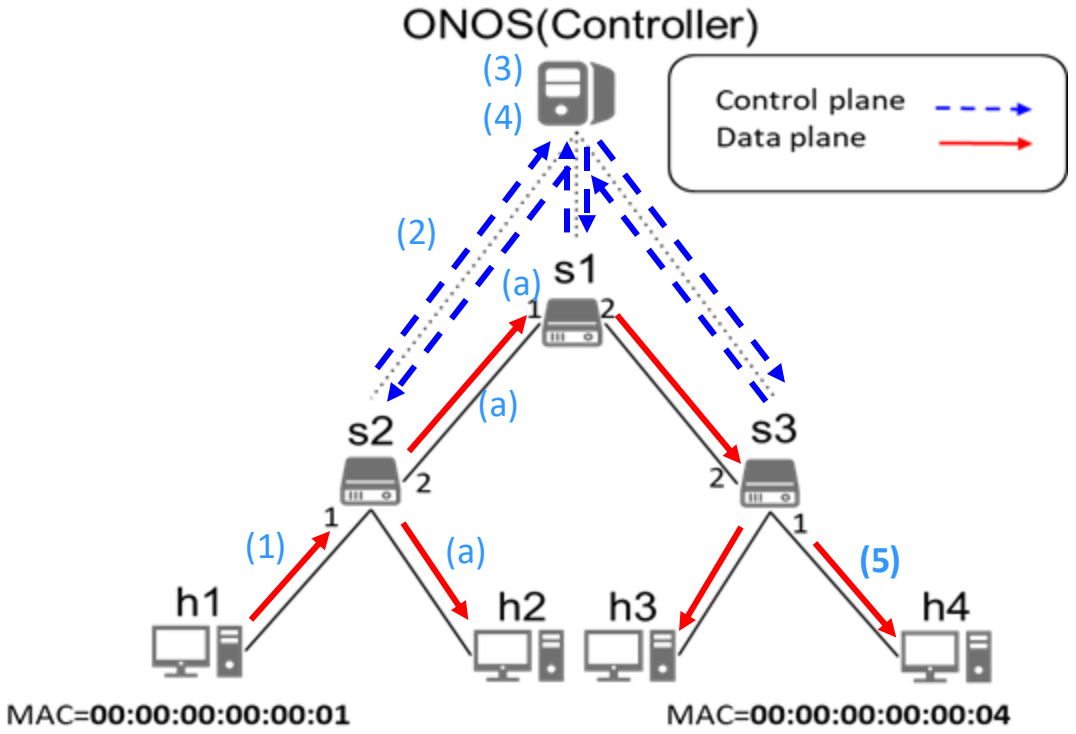
   b. Destination MAC found:
      - Sends Packet-out via designated port.
      - Installs flow rule on switch.
5. h4 receives packet from h1.

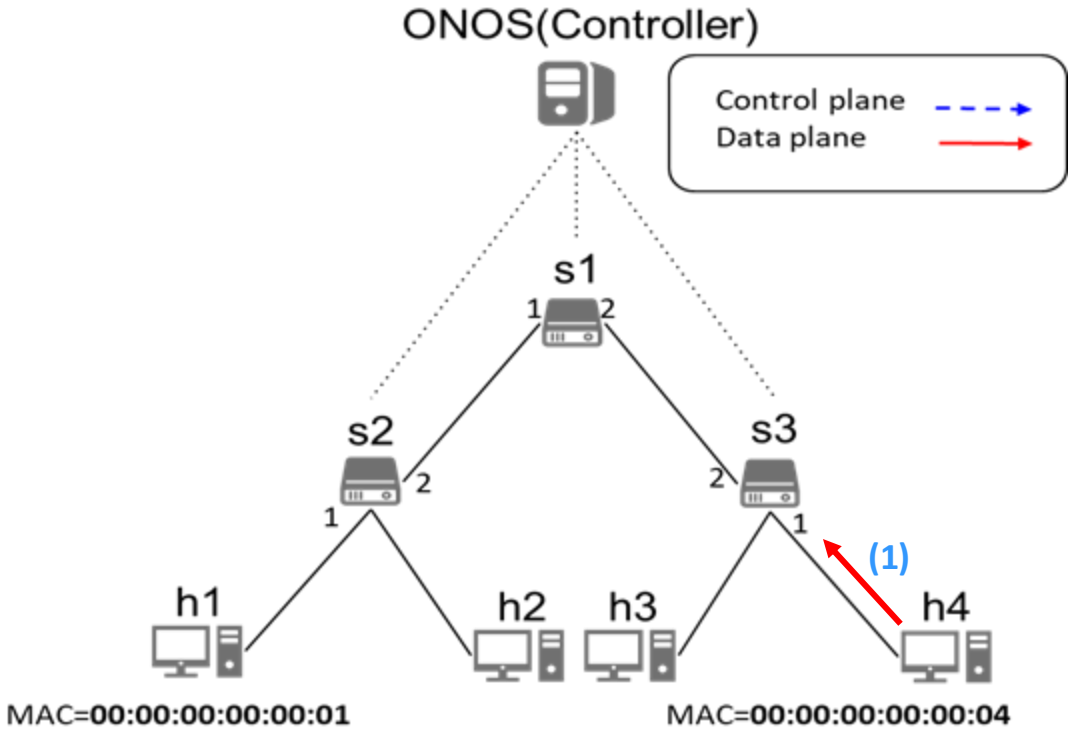
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
00:.....:01	1	00:.....:01	1	00:.....:01	2



Workflow (h4 -> h1)

1. h4 replies to h1.
2. Switch sends Packet-in to Controller.
3. Controller updates MAC address table with source MAC and incoming port.
4. Controller looks up MAC address table for destination MAC:
   a. Destination MAC not found:
      - Floods Packet-out.
   b. Destination MAC found:
      - Sends Packet-out via designated port.
      - Installs flow rule on switch.
5. h1 receives packet from h4.

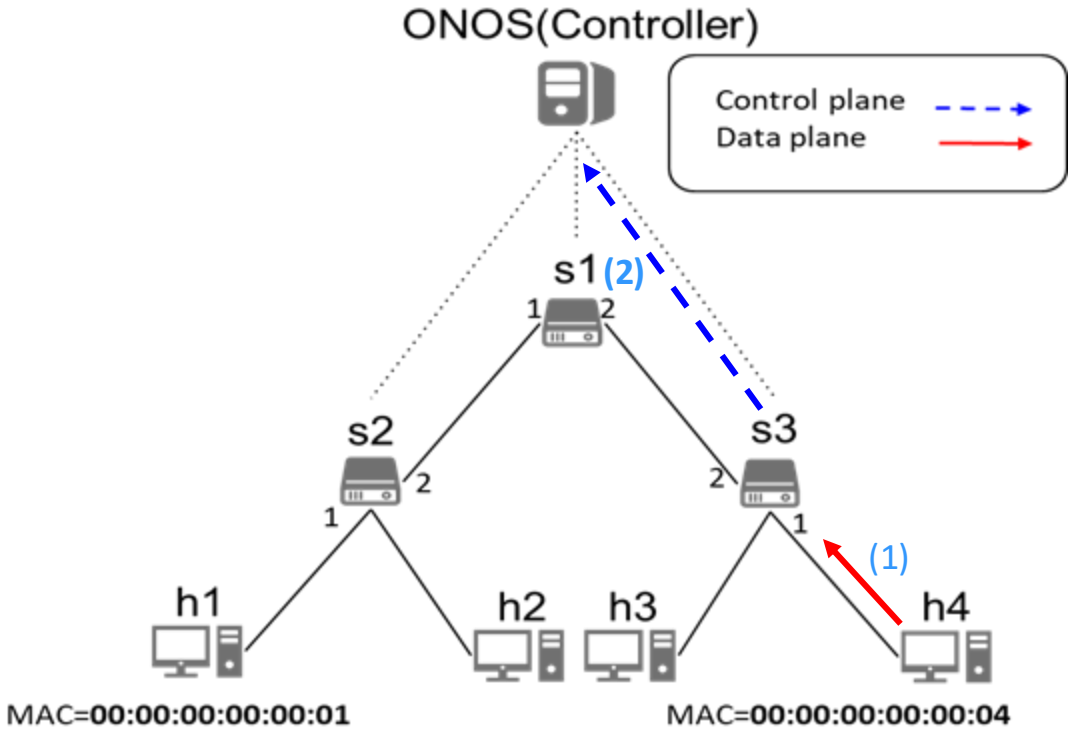
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
00:.....:01	1	00:.....:01	1	00:.....:01	2



Workflow (h4 -> h1)

1. h4 replies to h1.
2. Switch (s3) sends Packet-in to Controller.
3. Controller updates MAC address table with source MAC and incoming port.
4. Controller looks up MAC address table for destination MAC:
   a. Destination MAC not found:
      - Floods Packet-out.
   b. Destination MAC found:
      - Sends Packet-out via designated port.
      - Installs flow rule on switch.
5. h1 receives packet from h4.

s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
00:.....:01	1	00:.....:01	1	00:.....:01	2



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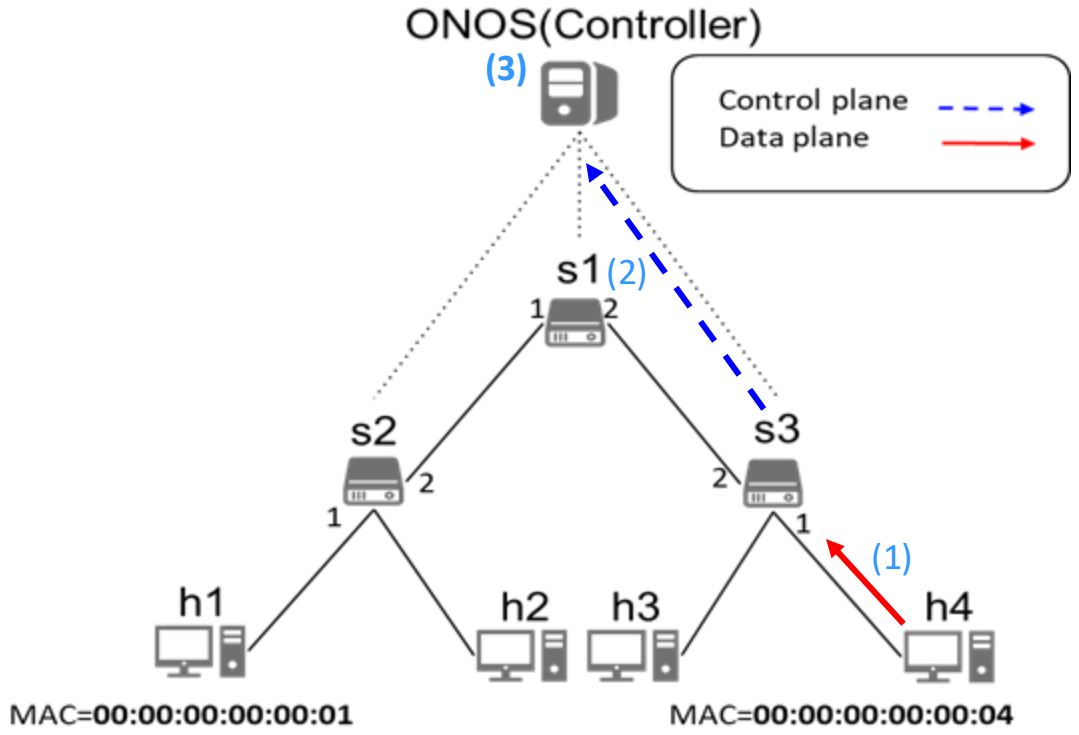
      - Installs flow rule on switch.
5. h1 receives packet from h4.

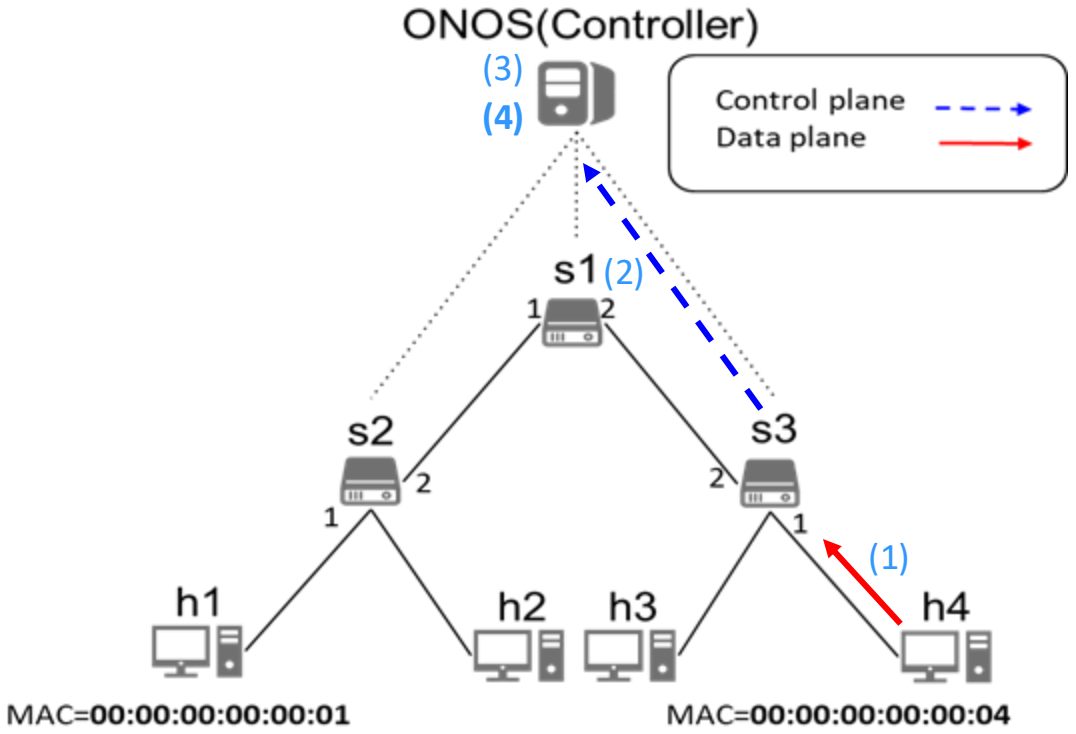
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
00:.....:01	1	00:.....:01	1	00:.....:01	2
				00:.....:04	**1**



Workflow (h4 -> h1)

1. h4 replies to h1.
2. Switch sends Packet-in to Controller.
3. Controller updates MAC address table with source MAC and incoming port.
4. Controller looks up MAC address table for destination MAC:
   a. Destination MAC not found:
      - Floods Packet-out.
   b. Destination MAC found:
      - Sends Packet-out via designated port.
      - Installs flow rule on switch.
5. h1 receives packet from h4.

s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
00:.....:01	1	00:.....:01	1	00:.....:01	2
				00:.....:04	1



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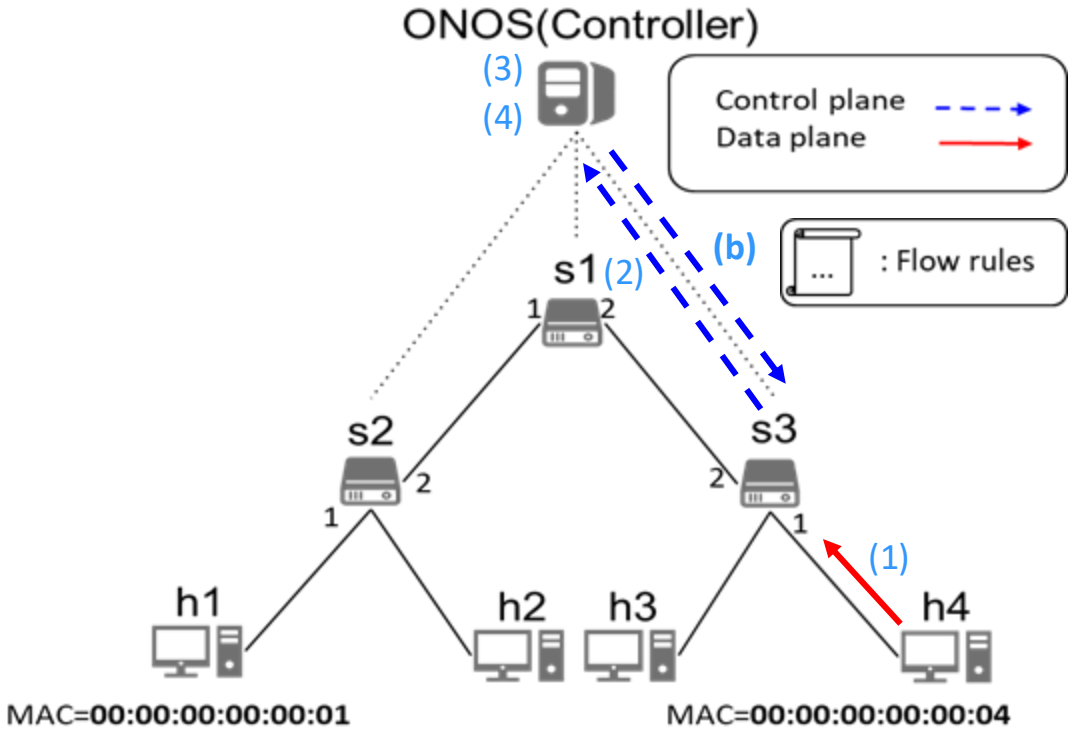
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
00:.....:01	1	00:.....:01	1	00:.....:01	2
				00:.....:04	1



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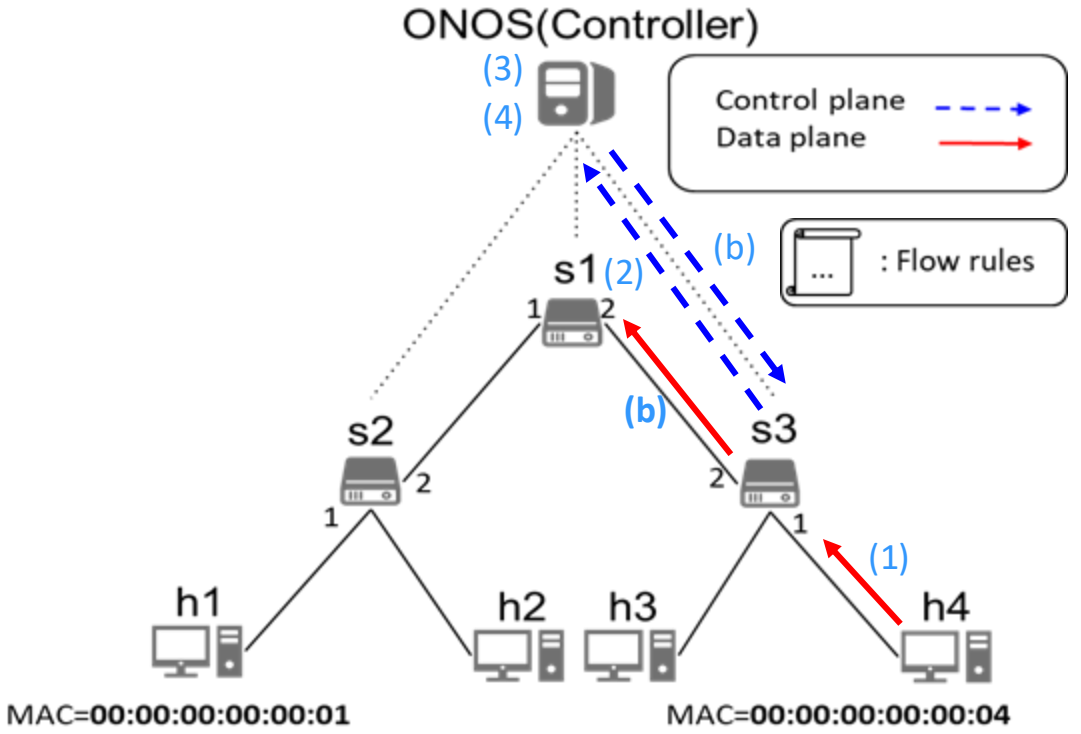
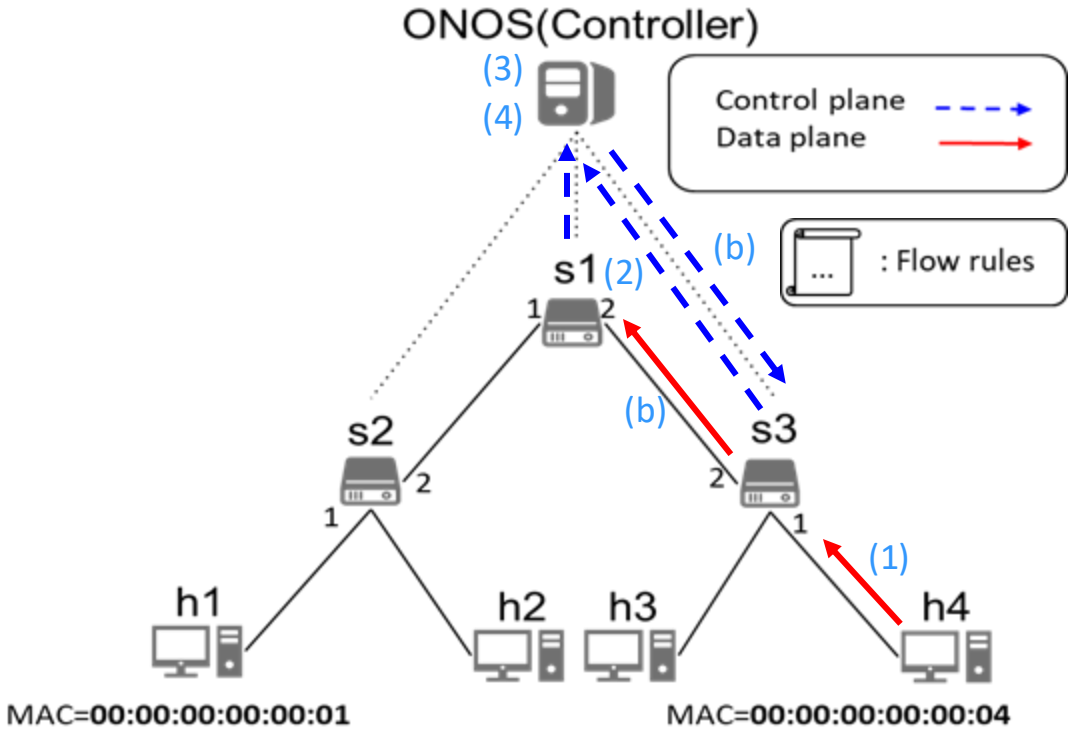
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
00:.....:01	1	00:.....:01	1	00:.....:01	2
				00:.....:04	1



Workflow (h4 -> h1)

1. h4 replies to h1.
2. Switch (s1) sends Packet-in to Controller.
3. Controller updates MAC address table with source MAC and incoming port.
4. Controller looks up MAC address table for destination MAC:
   a. Destination MAC not found:
      - Floods Packet-out.
   b. Destination MAC found:
      - Sends Packet-out via designated port.
      - Installs flow rule on switch.
5. h1 receives packet from h4.

s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
00:.....:01	1	00:.....:01	1	00:.....:01	2
				00:.....:04	1



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1. h4 replies to h1.
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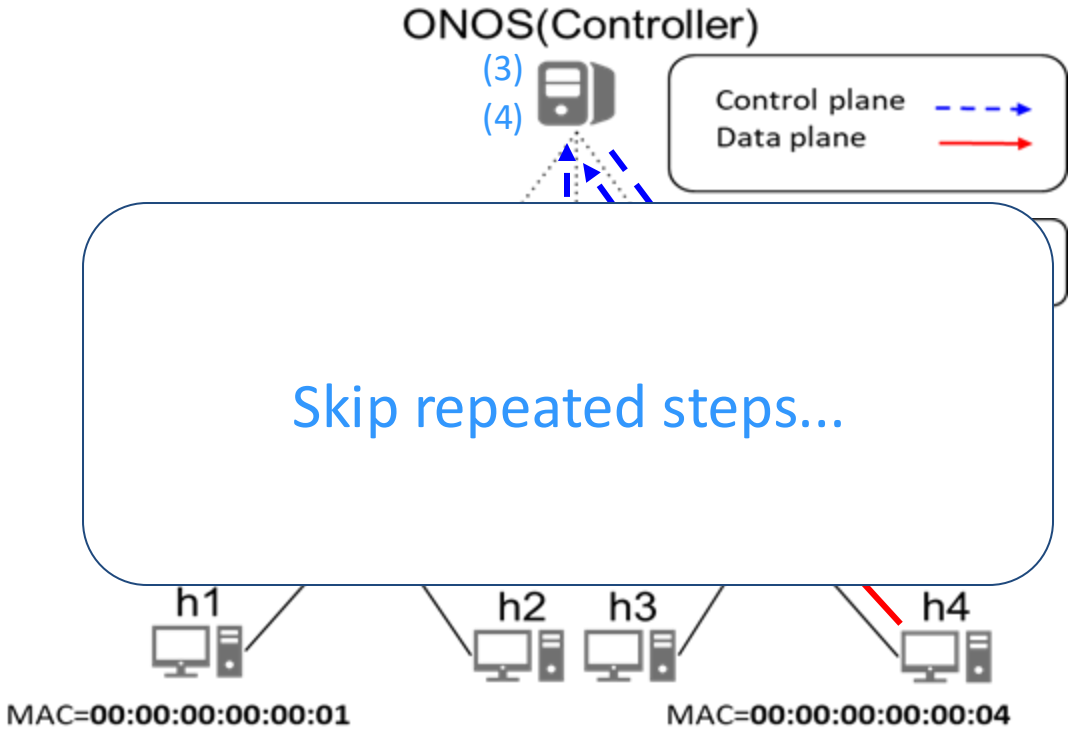
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
00:.....:01	1	00:.....:01	1	00:.....:01	2
				00:.....:04	1



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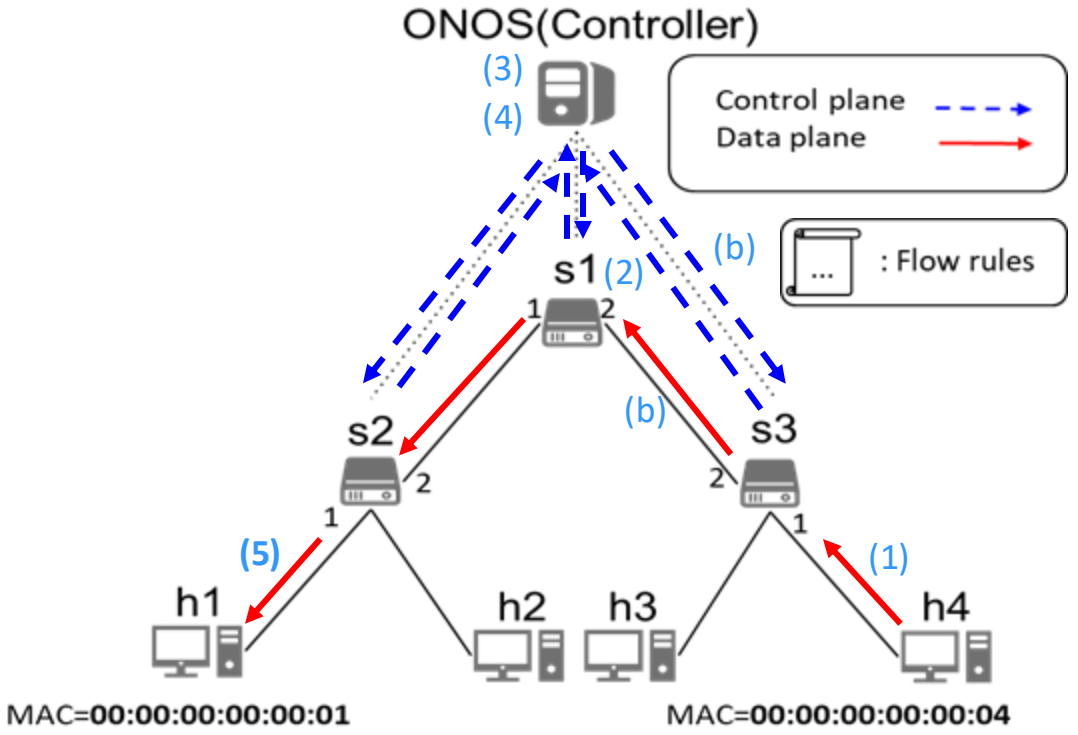
s1		s2		s3	
MAC	Port	MAC	Port	MAC	Port
00:.....:01	1	00:.....:01	1	00:.....:01	2
00:.....:04	2	00:.....:04	2	00:.....:04	1



Outline

- Build ONOS Application Project
  - Environment Setup
  - Create an ONOS Application
  - Build, Install, Activate, and Reinstall ONOS Application
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  - Introduction
  - ARP Request/Reply Format
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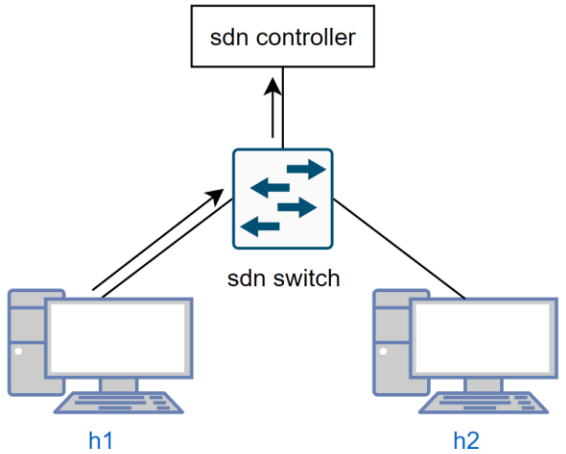
  - Introduction
  - Workflow
- Proxy APR
  - Introduction
  - Workflow
- Lab 3 Requirements

What is Proxy ARP

- A Proxy device answers ARP Requests for IP address on behalf of other devices
  - The Proxy device could be router, firewall, etc.
  - The replied MAC belongs to the **Proxy device**
- In SDNs, controller can serve as Proxy device
  - However, the replied MAC belongs to the **target host**
  - Benefits:
    - Decreases workload of network devices
    - Prevent issues like broadcast storm



h1 send ARP Request

Workflow of Proxy ARP in SDN

1. Sender sends ARP Request
2. Edge switch Packet-Ins the Request to controller
3. Proxy ARP learns IP-MAC mappings of the sender
4. Proxy ARP looks up ARP table (For target IP-MAC mapping)
   - If mapping exist:
     - Fetch target MAC

     5a. Packet-Outs ARP Reply (with target MAC) to the sender
   - Else (mapping not exist):

     5b. Floods ARP Request to edge ports except the port receiving ARP Request

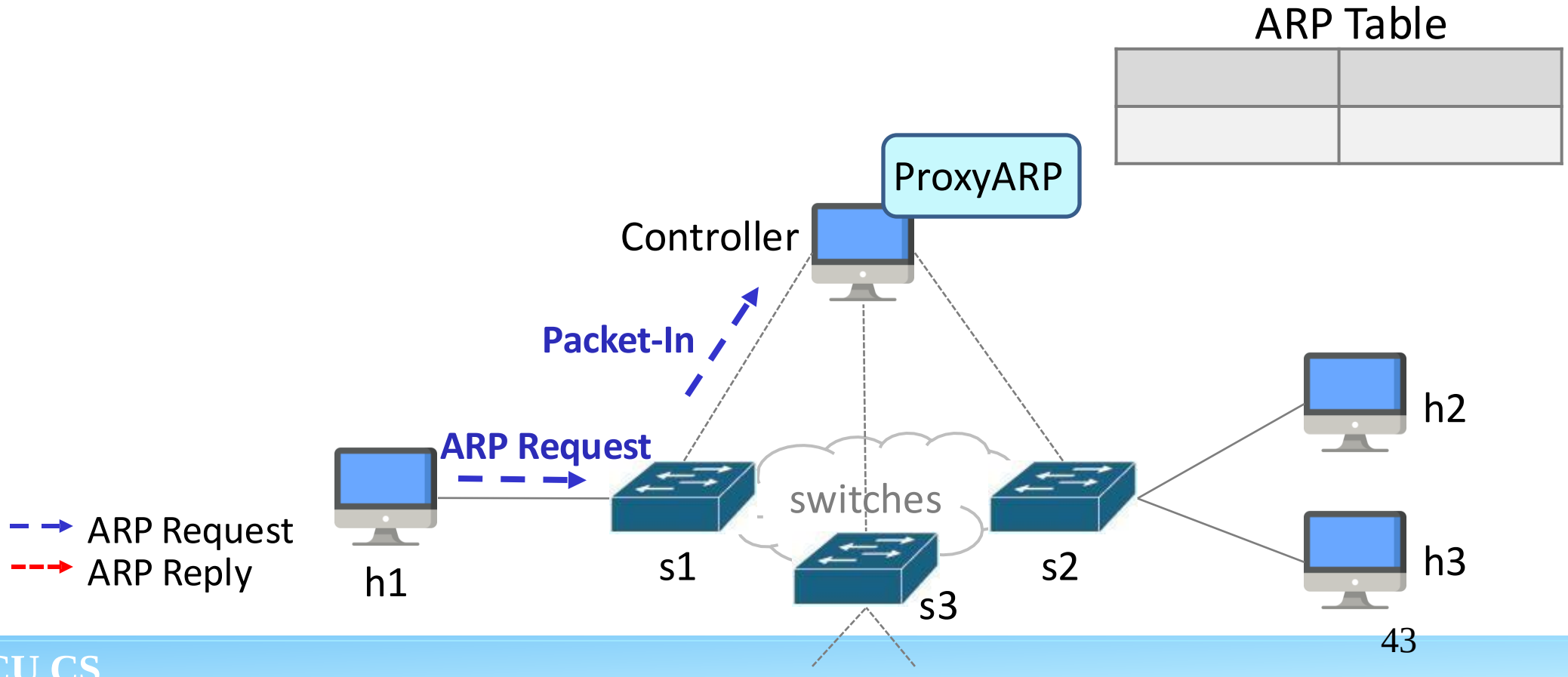
     6. When h2 receives ARP Request, h2 will Reply ARP packet.

     7. Edge switch Packet-Ins the Reply to controller

     8. Proxy ARP learns IP-MAC mapping from h2

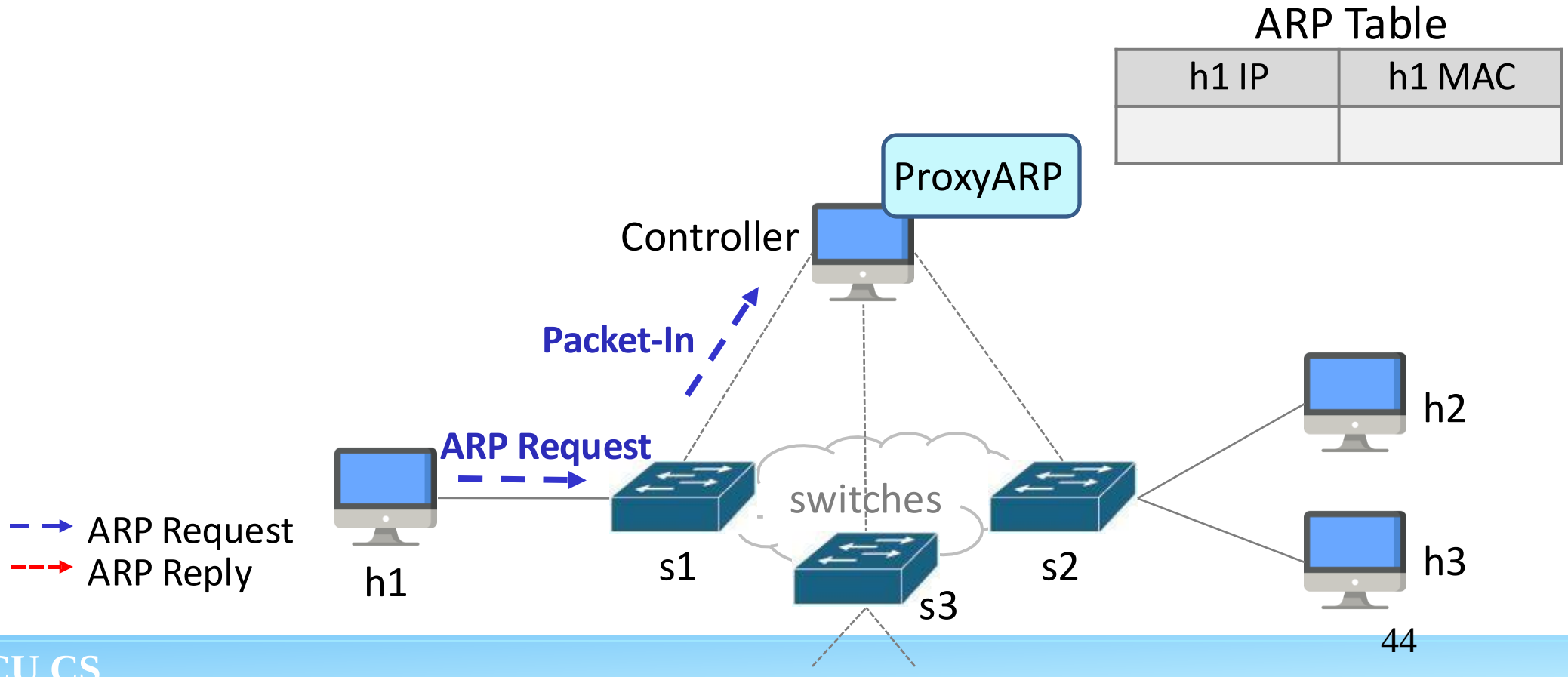
First ARP Request

1. h1 sends ARP Request
2. Edge switch Packet-Ins the Request to controller



Proxy ARP learns IP-MAC

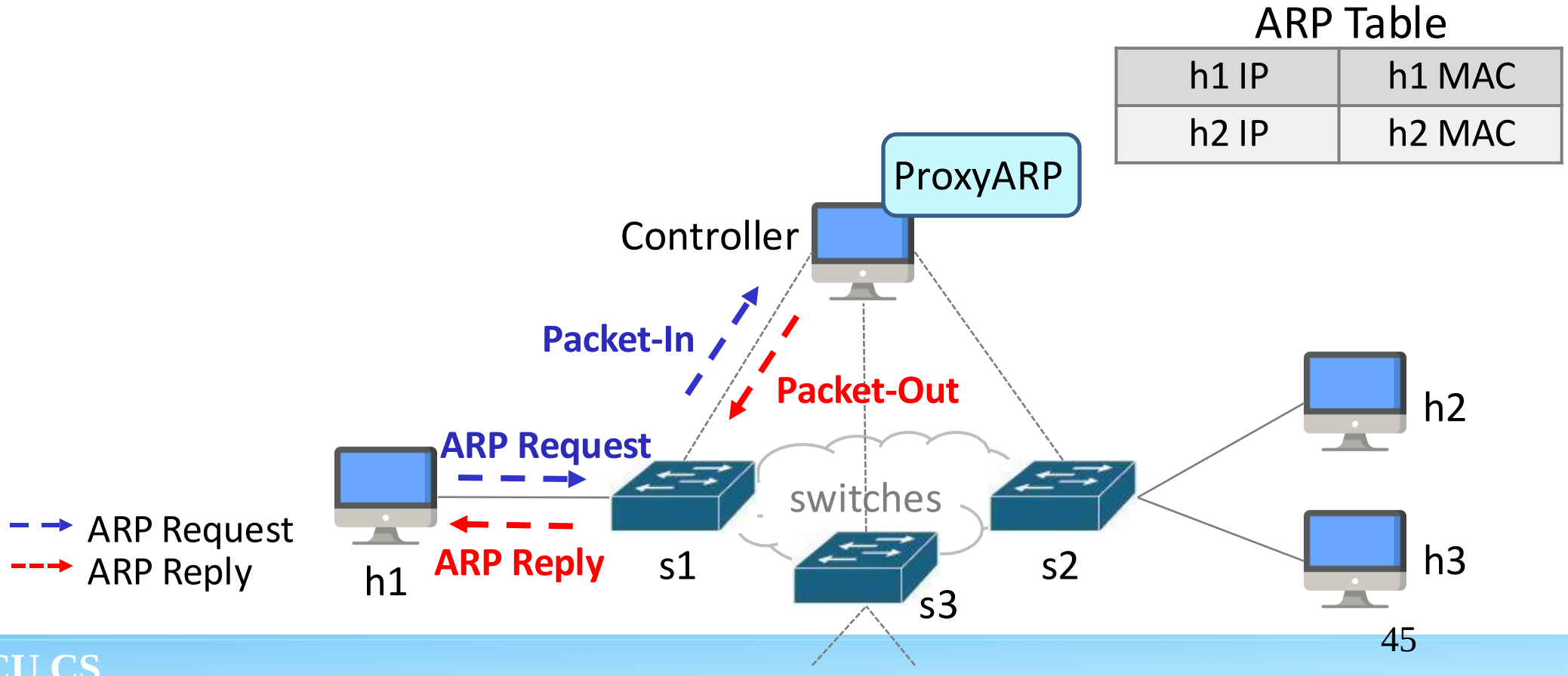
3. Controller learns mapping of IP to MAC of h1
4. Proxy ARP looks up ARP table (For target IP-MAC mapping)



If mapping exist

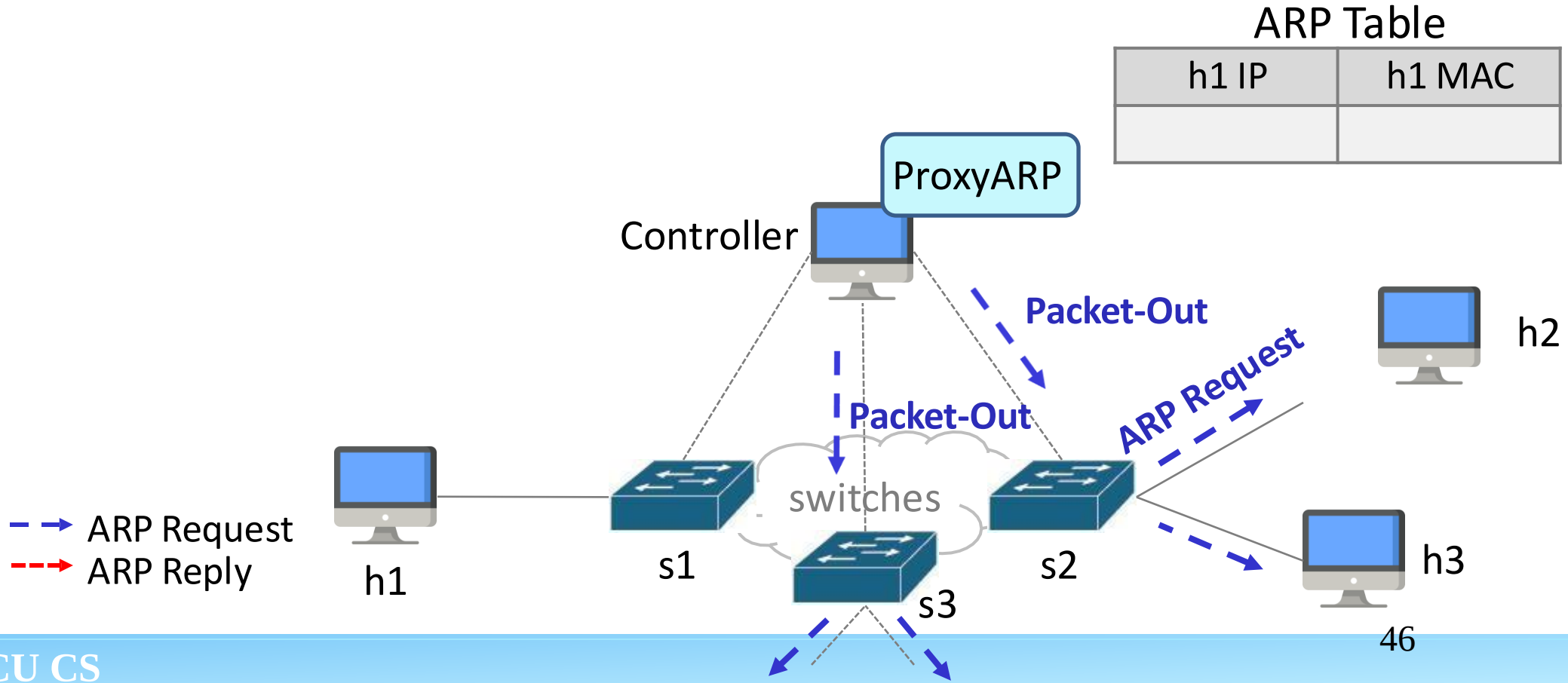
- Fetch target MAC

5a. Proxy ARP simply generates and Packet-Outs ARP Reply (with target MAC) to the sender



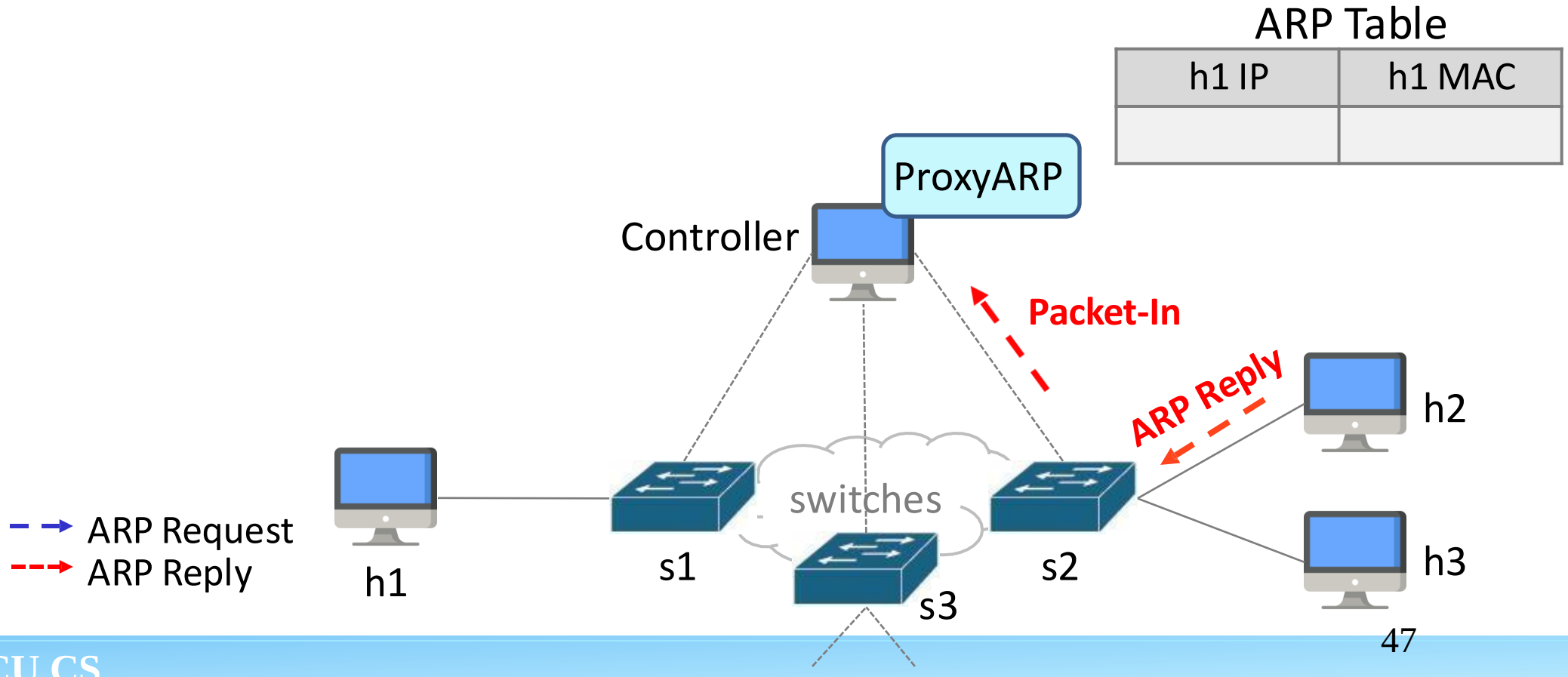
If mapping not exist

- 5b. Floods ARP Request to edge ports except the port receiving ARP Request via Packet-Outs ARP Request



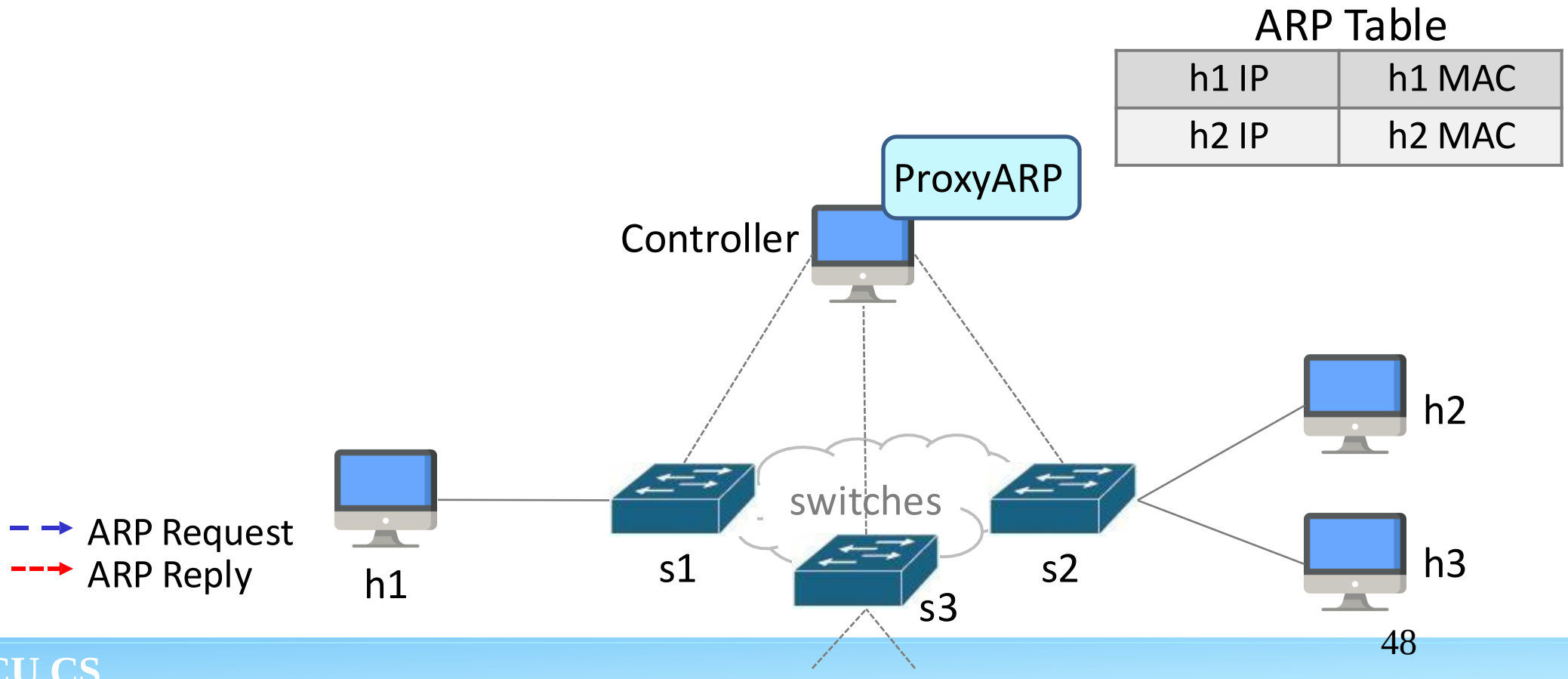
Reply ARP packet

6. When h2 receives ARP Request, h2 will Reply ARP packet.
7. Edge switch Packet-Ins the Reply to controller



Proxy ARP learns IP-MAC

8. Proxy ARP learns IP-MAC from h2



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Lab 3 Descriptions

- **Complete the given code for learning bridge function (40%)**
  - Correct naming convention in pom (5%)
  - Learning bridge function is available (20%)
  - Logs are in the correct format (10%)
  - Flow rules in hosts are comply with the regulations (5%)
- **Create an ONOS application for Proxy ARP (60%)**
  - Correct naming convention in pom (10%)
  - Proxy ARP is available (40%)
  - Logs are in the correct format (10%)
- The two apps will be tested separately
- If there's a difference between the image and the text, just go with the text.
- We'll be providing a template for the learning bridge app at E3

Learning Bridge Function

- You must set values in the pom.xml file as the following: **(5%)**
  - <groupId>: nycu.winlab
  - <artifactId>: bridge-app
  - <version>: (default)
  - <onos.app.name>: nycu.winlab.bridge
- You earn credits only if all settings are correct.

```
26      <groupId>nctu.winlab</groupId>
27      <artifactId>bridge-app</artifactId>
28      <version>1.0-SNAPSHOT</version>
29      <packaging>bundle</packaging>
30
31      <description>ONOS OSGi bundle archetype</description>
32      <url>http://onosproject.org</url>
33
34      <properties>
35          <onos.app.name>nctu.winlab.bridge</onos.app.name>
36          <onos.app.title>Learning Bridge App</onos.app.title>
37          <onos.app.origin>Winlab, NCTU</onos.app.origin>
38          <onos.app.category>default</onos.app.category>
39          <onos.app.url>http://onosproject.org</onos.app.url>
40          <onos.app.readme>ONOS OSGi bundle archetype.</onos.app.readme>
41      </properties>
```

Learning Bridge Function

- Ping should work for all host pairs.

```
mininet> pingall
```

```
mininet> pingall
*** Ping: testing ping reachability
h1 -> h2 h3 h4
h2 -> h1 h3 h4
h3 -> h1 h2 h4
h4 -> h1 h2 h3
*** Results: 0% dropped (12/12 received)
mininet>
```

- Learning Bridge Function with tree (depth=2) topology. **(10%)**

```
$ sudo mn --controller=remote,127.0.0.1:6653 \
      --topo=tree,depth=2 \
      --switch=ovs,protocols=OpenFlow14
```

- Learning Bridge Function with tree (depth=3~5) topology. **(10%)**
  - You earn credits only if your application works for all depths.

Learning Bridge Function

- We will test your application with only the following applications activated:

```
demo@root > apps -a -s                                                    23:
*   12 org.onosproject.optical-model          2.7.0    Optical Network Model
*   13 org.onosproject.drivers                2.7.0    Default Drivers
*   52 org.onosproject.openflow-base          2.7.0    OpenFlow Base Provider
*   72 org.onosproject.hostprovider           2.7.0    Host Location Provider
*   73 org.onosproject.lldpprovider           2.7.0    LLDP Link Provider
*   74 org.onosproject.openflow               2.7.0    OpenFlow Provider Suite
*   81 org.onosproject.gui2                   2.7.0    ONOS GUI2
```

- You must only use classes under **org.onosproject.net.flowobjective** or **org.onosproject.net.flow** package to install flow rules on network devices.
  - If you don't follow this, you won't get any points.
  - **Everyone should really understand how to use both packages to install flow rules.**

Learning Bridge Function

- Use ***log.info()*** to record actions done by your application. **(10%)**
  1. New entry is added into the forwarding table.
  2. Destination MAC address is missed. Flood the packet.
  3. Destination MAC address is matched. Install a flow rule.
- You earn credits only if each log pattern is exactly the same as the given one.

1.
```
2022-09-29T01:58:41,115 | INFO  | onos-of-dispatcher-127.0.0.1:53644 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| Add an entry to the port table of `of:0000000000000002`. MAC address: `2E:D1:D4:8A:B1:90` => Port: `1`.
2022-09-29T01:58:41,116 | INFO  | onos-of-dispatcher-127.0.0.1:53624 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| Add an entry to the port table of `of:0000000000000001`. MAC address: `2E:D1:D4:8A:B1:90` => Port: `1`.
```

2.
```
2022-09-29T01:58:41,116 | INFO  | onos-of-dispatcher-127.0.0.1:53644 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| MAC address `FF:FF:FF:FF:FF:FF` is missed on `of:0000000000000002`. Flood the packet.
2022-09-29T01:58:41,116 | INFO  | onos-of-dispatcher-127.0.0.1:53624 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| MAC address `FF:FF:FF:FF:FF:FF` is missed on `of:0000000000000001`. Flood the packet.
2022-09-29T01:58:41,117 | INFO  | onos-of-dispatcher-127.0.0.1:53632 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| Add an entry to the port table of `of:0000000000000003`. MAC address: `2E:D1:D4:8A:B1:90` => Port: `3`.
2022-09-29T01:58:41,117 | INFO  | onos-of-dispatcher-127.0.0.1:53644 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| Add an entry to the port table of `of:0000000000000002`. MAC address: `A2:66:19:A6:1D:0F` => Port: `2`.
2022-09-29T01:58:41,117 | INFO  | onos-of-dispatcher-127.0.0.1:53632 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| MAC address `FF:FF:FF:FF:FF:FF` is missed on `of:0000000000000003`. Flood the packet.
```

3.
```
2022-09-29T01:58:41,121 | INFO  | onos-of-dispatcher-127.0.0.1:53644 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| MAC address `2E:D1:D4:8A:B1:90` is matched on `of:0000000000000002`. Install a flow rule.
2022-09-29T01:58:41,122 | INFO  | onos-of-dispatcher-127.0.0.1:53644 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| Add an entry to the port table of `of:0000000000000002`. MAC address: `2E:D1:D4:8A:B1:90` => Port: `1`.
2022-09-29T01:58:41,123 | INFO  | onos-of-dispatcher-127.0.0.1:53644 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| MAC address `A2:66:19:A6:1D:0F` is matched on `of:0000000000000002`. Install a flow rule.
2022-09-29T01:58:41,128 | INFO  | onos-of-dispatcher-127.0.0.1:53644 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| Add an entry to the port table of `of:0000000000000002`. MAC address: `2E:D1:D4:8A:B1:90` => Port: `1`.
2022-09-29T01:58:41,129 | INFO  | onos-of-dispatcher-127.0.0.1:53644 | LearningBridge                   | 215 - nctu.winlab.bridge-app - 1.0.0.SNAPSHOT
| MAC address `FF:FF:FF:FF:FF:FF` is missed on `of:0000000000000002`. Flood the packet.
```

Learning Bridge Function

1. New entry is added into the MAC address table.
   - Pattern: "**Add an entry to the port table of `{device ID}`. MAC address: `{MAC}` => Port: `{port}`.**"
   - Example: "Add an entry to the port table of `of:0000000000000002`. MAC address: `2E:D1:D4:8A:B1:90` => Port: `1`."
2. Destination MAC address is missed. Flood the packet.
   - Pattern: "**MAC address `{MAC}` is missed on `{device ID}`. Flood the packet.**"
   - Example: "MAC address `FF:FF:FF:FF:FF:FF` is missed on `of:0000000000000002`. Flood the packet."
3. Destination MAC address is matched. Install a flow rule.
   - Pattern: "**MAC address `{MAC}` is matched on `{device ID}`. Install a flow rule.**"
   - Example: "MAC address `2E:D1:D4:8A:B1:90` is matched on `of:0000000000000002`. Install a flow rule."

Learning Bridge Function

- Here are examples of how to use ***log.info()*** to print log information.

```
log.info("Add an entry to the port table of `" + inDevice +
    "`. MAC address: `" + srcMac + "` => Port: `" + inPort + "`.");
```

```
log.info("MAC address `" + dstMac + "` is missed on `" + inDevice + "`. Flood the packet.");
```

```
log.info("MAC address `" + dstMac + "` is matched on `" + inDevice + "`. Install a flow rule.");
```

```
log.info("MAC address `{}` is matched on `{}`. Install a flow rule.",
        dstMac, recDevId);
```

Learning Bridge Function

- Rule requirements: **(5%)**
  - Match field (selector): ETH_SRC, ETH_DST
  - Action field (treatment): OUTPUT
  - Flow priority: 30
  - Flow timeout: 30
  - You earn credits only if all flow rules are correct.

STATE ▾	PACKETS	DURATION	FLOW PRIORITY	TABLE NAME	SELECTOR	TREATMENT	APP NAME
Added	0	2,945	1	0	ETH_TYPE:ipv4	imm[OUTPUT:CONTROLLER], cleared:true	*core
Added	1	7	30	0	ETH_DST:A2:66:19:A6:1D:0F, ETH_SRC:3E:0B:9F:F9:EF:D9	imm[OUTPUT:1], cleared:false	nctu.winlab.bridge
Added	1	8	30	0	ETH_DST:A2:66:19:A6:1D:0F, ETH_SRC:9A:E8:EA:DF:AD:88	imm[OUTPUT:1], cleared:false	nctu.winlab.bridge
Added	1	8	30	0	ETH_DST:2E:D1:D4:8A:B1:90, ETH_SRC:3E:0B:9F:F9:EF:D9	imm[OUTPUT:1], cleared:false	nctu.winlab.bridge
Added	1	7	30	0	ETH_DST:3E:0B:9F:F9:EF:D9, ETH_SRC:A2:66:19:A6:1D:0F	imm[OUTPUT:2], cleared:false	nctu.winlab.bridge
Added	1	8	30	0	ETH_DST:3E:0B:9F:F9:EF:D9, ETH_SRC:2E:D1:D4:8A:B1:90	imm[OUTPUT:2], cleared:false	nctu.winlab.bridge
Added	1	8	30	0	ETH_DST:9A:E8:EA:DF:AD:88, ETH_SRC:A2:66:19:A6:1D:0F	imm[OUTPUT:2], cleared:false	nctu.winlab.bridge
Added	1	8	30	0	ETH_DST:2E:D1:D4:8A:B1:90, ETH_SRC:9A:E8:EA:DF:AD:88	imm[OUTPUT:1], cleared:false	nctu.winlab.bridge
Added	1	8	30	0	ETH_DST:9A:E8:EA:DF:AD:88, ETH_SRC:2E:D1:D4:8A:B1:90	imm[OUTPUT:2], cleared:false	nctu.winlab.bridge

Learning Bridge Function

- You can trace ReactiveForwarding.java to figure out how to install flow rules.
- When receives Packet-in, your application need to send Packet-out to switch, in addition to installing flow rule.
- How to debug:
  - Use Logger to print runtime information.
  - Use Wireshark to capture your packets.

ARP Proxy

- You must set values in the pom.xml file as the following: **(10%)**
  - <groupId>: nycu.winlab
  - <artifactId>: ProxyArp
  - <version>: (default)
  - <onos.app.name>: nycu.winlab.ProxyArp
- You earn credits only if all settings are correct.

ARP Proxy

- Work properly at least in tree (depth=3, fanout=3) topology **(40%)**
  - - All hosts are able to **arping** to each other
- Once you activate your application and Mininet, execute **`arping`** in Mininet to check ARP functionality

```
mininet> h1 arping h2
```

- Correct result would look like:

```
mininet> h1 arping h2 -c 3
ARPING 10.0.0.2 from 10.0.0.1 h1-eth0
Unicast reply from 10.0.0.2 [D6:B5:82:B5:23:0E]  15.850ms
Unicast reply from 10.0.0.2 [D6:B5:82:B5:23:0E]  4.267ms
Unicast reply from 10.0.0.2 [D6:B5:82:B5:23:0E]  4.370ms
Sent 3 probes (1 broadcast(s))
Received 3 response(s)
mininet>
```

ARP Proxy

- Print messages in following events: **(10%)**

  - ARP table miss

```
| 209 - nctu.winlab.ProxyArp - 1.0.0.SNAPSHOT | TABLE MISS. Send request to edge ports
```

  - ONOS receives ARP Reply from host

```
| 209 - nctu.winlab.ProxyArp - 1.0.0.SNAPSHOT | RECV REPLY. Requested MAC = 06:4F:F1:84:A5:EA
```

  - ARP table hit

```
| 209 - nctu.winlab.ProxyArp - 1.0.0.SNAPSHOT | TABLE HIT.  Requested MAC = 06:4F:F1:84:A5:EA
```

- You earn credits only if each log pattern is exactly the same as the given one.
- We also use ***log.info()*** to print messages.

ARP Proxy

- ONOS application activation
  - You are only allowed to activate **your *ProxyARP*** and the following ONOS applications:

```
brian@root > apps -a -s
*   6 org.onosproject.drivers                2.2.0    Default Drivers
*   7 org.onosproject.optical-model          2.2.0    Optical Network Model
*  39 org.onosproject.gui2                   2.2.0    ONOS GUI2
*  52 org.onosproject.openflow-base          2.2.0    OpenFlow Base Provider
*  84 org.onosproject.hostprovider           2.2.0    Host Location Provider
*  85 org.onosproject.lldpprovider           2.2.0    LLDP Link Provider
*  86 org.onosproject.openflow               2.2.0    OpenFlow Provider Suite
* 192 nctu.winlab.ProxyArp                   1.0.SNAPSHOT ONOS OSGi bundle archetype
```

Submission Naming Convention

- Move your bridge-app and Proxy ARP into directory lab3_<student ID>
- Compress the directory into zip file named as lab3_<student ID>
- Wrong file name or format will result in 10 points deduction
- 20% deduction for late submission in one week
  - Won't accept submissions over one week

```
sdn@sdn-virtual-machine:~/lab3_313552034$ tree
.
├── bridge-app
│   ├── pom.xml
│   └── src
│       ├── main
│       │   └── java
│       │       └── nycu
│       │           └── winlab
│       │               └── bridge
│       │                   ├── AppComponent.java
│       │                   ├── package-info.java
│       │                   └── SomeInterface.java
│       └── test
│           └── java
│               └── nycu
│                   └── winlab
│                       └── bridge
│                           └── AppComponentTest.java
└── ProxyArp
    ├── pom.xml
    └── src
        ├── main
        │   └── java
        │       └── nycu
        │           └── winlab
        │               └── ProxyArp
        │                   ├── AppComponent.java
        │                   ├── package-info.java
        │                   └── SomeInterface.java
        └── test
            └── java
                └── nycu
                    └── winlab
                        └── ProxyArp
                            └── AppComponentTest.java

24 directories, 10 files
```

Lab 3 Demo

- TA has opened a demo time-reserved table.
  - Lab 3 Demo Time-reserved Table
    - Open Period: 9/26 ~ 10/16 23:59
  - The demo dates will be in the week after Lab 3 deadline.
- Demo questions will show when demo starts.
- The demo score will be **40%** of total score.
  - e.g. If your earn 100% credits for submission and 80% credits for demo, then your total score of Lab3 will be **100 x 60% + 80 x 40% = 92**.

About help!

- For lab problem, ask at e3 forum
  - Ask at the e3 forum
  - TAs will help to clarify Lab contents instead of giving answers!
  - Please describe your questions with sufficient context,
    - e.g. Environment setup, Input/Output, Screenshots, …
- For personal problem mail to **sdnta@win.cs.nycu.edu.tw**
  - You have special problem and you can't meet the deadline
  - You got weird score with lab
- No Fixed TA hours