CAN 201

CW2 Report

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Abstract—**This project develops a Software-Defined Networking (SDN) management system using the Ryu controller and Mininet. It enables dynamic topology construction, efficient packet forwarding, and traffic redirection. The system supports applications like load balancing and failover while optimizing network latency and reliability. It highlights SDN's value in network management and lays the groundwork for future enhancements in scalability and efficiency.**

I. Introduction

A. *Project Background and Task Description*

Software-Defined Networking (SDN) separates the network control plane from the data plane, enabling centralized network management and programmability. This project implements an intelligent network management system using the Ryu controller, featuring network topology construction, packet forwarding, and traffic redirection capabilities.

B. *Technical Challenges*

During the project development, we encountered the following main challenges:

1) **Network Topology Construction and Management:** Design and implementation of a scalable network topology; configuration of multiple hosts and switches; ensuring stable communication between components.
2) **TCP Connection Tracking:** Implementation of TCP state machine; handling of TCP three-way handshake process; managing concurrent TCP connections.
3) **Traffic Redirection Mechanism:** Transparent modification of packet headers; maintaining session consistency during redirection; managing bidirectional traffic flow.
4) **Performance and Reliability:** Minimizing packet processing overhead; ensuring proper flow table management; maintaining system stability under load.

C. *Practice Relevance*

The implementation of this project has broad practical applications:

1) **Load Balancing:** Through traffic redirection functionality, traffic destined for one server can be dynamically redirected to other servers, achieving load distribution.
2) **Service Migration:** Enable smooth service migration from one server to another without affecting client access.
3) **Failover:** Seamlessly redirect traffic to backup servers when the primary server experiences failures.

D. *Main Contributions*

The main contributions of this project include:

1) Implementation of network topology construction based on Mininet, supporting connection configuration between clients and multiple servers.
2) Development of a packet forwarding mechanism based on the Ryu controller, supporting TCP connection establishment and maintenance.
3) Design and implementation of TCP traffic redirection functionality, capable of transparently redirecting traffic intended for Server1 to Server2.
4) Implementation of ARP request handling mechanism, ensuring proper address resolution within the network.

These implementations provide a crucial foundation for building reliable SDN network management systems.

II. Related Work

Software-Defined Networking (SDN) has introduced programmability and central control, enabling efficient traffic redirection through separation of the control and data planes. This capability has been extensively studied to optimize network operations and facilitate dynamic path adjustments.

A. SDN Traffic Redirection Mechanisms

Several studies have explored SDN's potential for traffic redirection. Chen et al. proposed a dynamic routing framework leveraging SDN controllers to reroute traffic flows in real-time, optimizing for load balancing and minimizing congestion. Similarly, Zhang and Wang investigated intelligent routing algorithms based on SDN to enhance network latency and bandwidth utilization. These studies highlight SDN's advantages in addressing traffic management challenges in dynamic network environments.

B. Ryu Controller and Traffic Management

The Ryu controller, an OpenFlow-based SDN framework, has been demonstrated to enable advanced traffic control policies. Kumar et al. explored Ryu's capabilities in dynamically modifying flow tables for real-time path optimization. Its RESTful API and modularity allow developers to implement custom traffic monitoring and redirection strategies, making it a preferred choice for academic and industrial use.

C. Network Simulation and Validation

Mininet is a widely used network emulation platform for validating SDN implementations. Rodriguez et al. emphasized its suitability for testing traffic redirection algorithms, highlighting its ability to emulate complex network topologies efficiently. By integrating Mininet with SDN controllers like Ryu, researchers can prototype and evaluate various traffic management strategies.

Challenges in Traffic Redirection

Traffic redirection in SDN faces several challenges. Ibrahim and Singh identified key issues such as scalability in large-scale networks, ensuring security during redirection, and minimizing the overhead caused by frequent flow updates. Additionally, the need for compatibility with heterogeneous network devices adds complexity to implementation.

D. Research Gaps and Project Contribution

While existing literature provides valuable insights into SDN traffic redirection, there remains a critical need for practical implementations that seamlessly integrate intelligent traffic monitoring with dynamic path selection. This project addresses this gap by developing a Ryu-based traffic redirection mechanism that can:

- Dynamically adjust network paths based on real-time network conditions
- Implement intelligent routing strategies with minimal performance overhead
- Provide a flexible and reproducible approach to network traffic management

III. Design

A. Description of diagram

This solution is based on the SDN architecture. Through OpenFlow communication between the controller and the switch, the corresponding flow table entries are dynamically created and installed to flexibly manage data forwarding and redirection. In this way, in a topology consisting of an SDN switch, a client, and two servers, the client traffic can be directly forwarded to Server1, and the traffic originally sent to Server1 can be transparently redirected to Server2 and the return traffic can be disguised, ultimately ensuring dynamic flow table management, forwarding efficiency, and transparency.

B. Work flow

The data packet is first sent from the host Client in the network to the switch s_1, where the switch checks its internal flow table rules. If a matching rule is found, the packet will be processed according to the existing rule. If no matching rule exists, a Packet_In event is

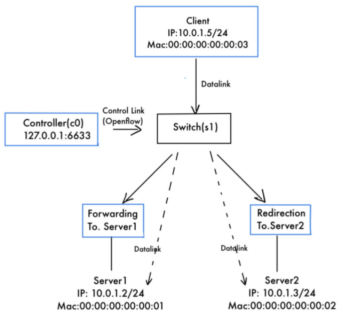
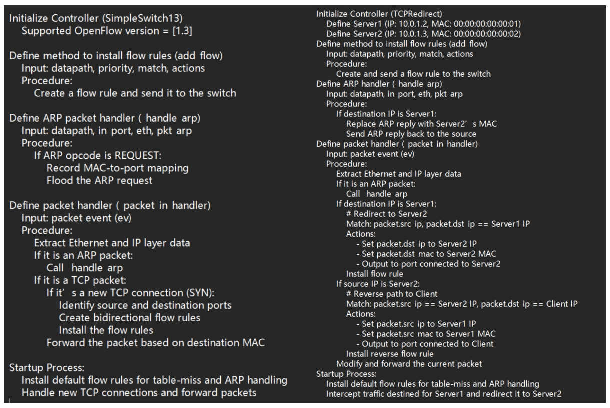


Fig. 1: Design Diagram

triggered, and the unmatched packet is sent to the controller c_0 via the OpenFlow protocol. The relevant information of the packet, including source IP address, destination IP address, and protocol type, is encapsulated in the Packet_In message. During this process, if the packet is an ARP request (e.g., Client requests the MAC address of Server1), the controller processes it based on the specific scenario: in a normal forwarding scenario, the controller broadcasts the ARP request to the network, allowing the target device to respond directly. In Task 5's traffic redirection scenario, the controller intercepts the ARP request and responds with a spoofed MAC address of Server2, pretending it is Server1, to enable subsequent traffic redirection to Server2.

Upon receipt of the packet at the controller, the Packet_In event is triggered, prompting the controller to analyze the packet's source information. This analysis yields details such as the source IP address, destination IP address, and protocol type. Subsequently, the controller determines the requisite rules based on the identified traffic type. During the flow rule creation process, the controller calls the `add_flow` method to generate rules, including matching conditions, priority levels, and an idle timeout of 5 seconds. Simultaneously, the controller evaluates the traffic characteristics to decide the rule's content: for normal traffic in Task 4, it creates a forwarding rule from Client to Server1; for redirection traffic in Task 5, it modifies the destination address to Server2 and creates a rule from Client to Server2. Based on these rules, the controller handles the traffic accordingly, either transmitting it to Server1 or modifying the destination IP and MAC addresses to redirect the traffic to Server2.

During the flow rule installation process, the controller uses the FlowMod message in the OpenFlow protocol, containing all the relevant rule information, to send the flow rule to the switch. Upon receiving the FlowMod message, the switch parses its content and installs the flow rule in its local flow table, where rules with different priorities are placed in the appropriate positions. Once the flow rule takes effect, the first packet may be directly forwarded by the controller via a Packet_Out message, while subsequent packets matching the rule will be processed directly by the switch's flow table without triggering another Packet_In.



```
Initialize Controller (SimpleSwitch13)
    Supported OpenFlow version = [1.3]

Define method to install flow rules (add flow)
    Input: datapath, priority, match, actions
    Procedure:
        Create a flow rule and send it to the switch

Define ARP packet handler ( handle arp)
    Input: datapath, in port, eth, pkt arp
    Procedure:
        If ARP opcode is REQUEST:
            Record MAC-to-port mapping
            Flood the ARP request

Define packet handler ( packet in handler)
    Input: packet event (ev)
    Procedure:
        Extract Ethernet and IP layer data
        If it is an ARP packet:
            Call  handle arp
        If it is a TCP packet:
            If it'  s a new TCP connection (SYN):
                Identify source and destination ports
                Create bidirectional flow rules
                Install the flow rules
            Forward the packet based on destination MAC

Startup Process:
    Install default flow rules for table-miss and ARP handling
    Handle new TCP connections and forward packets
```

```
Initialize Controller (TCPRedirect)
    Define Server1 (IP: 10.0.1.2, MAC: 00:00:00:00:00:01)
    Define Server2 (IP: 10.0.1.3, MAC: 00:00:00:00:00:02)
Define method to install flow rules (add flow)
    Input: datapath, priority, match, actions
    Procedure:
        Create and send a flow rule to the switch
Define ARP handler ( handle arp)
    Input: datapath, in port, eth, pkt arp
    Procedure:
        If destination IP is Server1:
            Replace ARP reply with Server2'  s MAC
            Send ARP reply back to the source
Define packet handler ( packet in handler)
    Input: packet event (ev)
    Procedure:
        Extract Ethernet and IP layer data
        If it is an ARP packet:
            Call  handle arp
        If destination IP is Server1:
            # Redirect to Server2
            Match: packet.src ip, packet.dst ip == Server1 IP
            Actions:
                - Set packet.dst ip to Server2 IP
                - Set packet.dst mac to Server2 MAC
                - Output to port connected to Server2
            Install flow rule
        If source IP is Server2:
            # Reverse path to Client
            Match: packet.src ip == Server2 IP, packet.dst ip == Client IP
            Actions:
                - Set packet.src ip to Server1 IP
                - Set packet.src mac to Server1 MAC
                - Output to port connected to Client
            Install reverse flow rule
        Modify and forward the current packet
Startup Process:
    Install default flow rules for table-miss and ARP handling
    Intercept traffic destined for Server1 and redirect it to Server2
```

Fig. 2: Pseudo-code for the functionality of forward and redirect

IV. Implementation details

The implementation environment consists of a Linux-based system (Ubuntu) required for running Mininet and OpenFlow. The development tools include Python as the primary programming language, Ryu SDN Framework as the controller platform, and Mininet for network emulation. Key Python libraries used include ryu for SDN controller implementation, mininet for network topology creation, socket for TCP communication, and various packet processing libraries for handling network protocols. The system first uses Mininet to create a network topology consisting of an OpenFlow controller (c0), a switch (s1), and three hosts (client, server1, server2). After the topology is created, start the Ryu controller to manage the OpenFlow switch.

The basic forward test is for the client to initiate a TCP connection to server1. When a Client sends data to server1, the Ryu controller dynamically installs stream table entries on the switch according to MAC address learning rules. The switch forwards traffic to server1. The flow table entry is deleted after a timeout (5 seconds). To make sure the flow table rules are installed correctly, use the Mininet CLI to view the switch's flow table. Verify the basic forwarding function and see if server 1 receives traffic from the client.

When a client establishes a TCP connection to server 1 in the traffic redirection test, the controller intercepts the SYN packet and reroutes it to server 2.In accordance with the traffic redirection rules, the client's connection request is redirected from server 1 to server 2 by the Ryu controller's traffic redirection logic.The client's SYN packet is changed and sent to server 2 with the new destination MAC and IP address.The time between the client's SYN and the receiving ACK is simultaneously recorded as part of the TCP handshake time tracking.

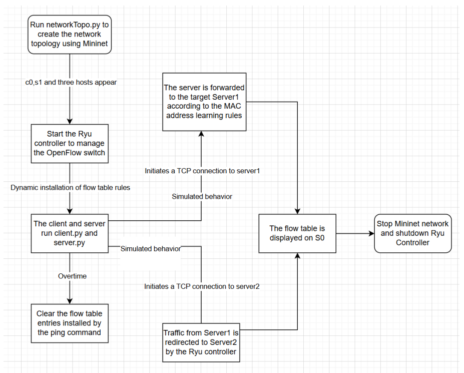

Run networkTopo.py to create the network topology using Mininet
c0,s1 and three hosts appear
Start the Ryu controller to manage the OpenFlow switch
Dynamic installation of flow table rules
The client and server run client.py and server.py
Overtime
Clear the flow table entries installed by the ping command
The server is forwarded to the target Server1 according to the MAC address learning rules
Initiates a TCP connection to server1
Simulated behavior
Simulated behavior
Initiates a TCP connection to server2
Traffic from Server1 is redirected to Server2 by the Ryu controller
The flow table is displayed on S0
Stop Mininet network and shutdown Ryu Controller

Fig. 3: Program flow charts

In terms of programming skills, we made extensive use of object-oriented programming (OOP), the main controller class implemented various event handlers, and implemented event-driven programming for packet processing and state management, while the SDN controller implemented OpenFlow protocol processing. At the same time, we also added appropriate error handling and logging mechanisms.

For the traffic redirection function, we implement packet inspection in the controller to identify TCP SYN packets destined for server1. When such a packet is detected, the controller modifies the packet headers to redirect the traffic to server2, and installs appropriate flow table entries in the switch. The implementation tracks TCP handshake timing by recording timestamps of SYN and ACK packets, allowing us to measure the connection establishment time. During the implementation, we encountered several challenges. One important issue was maintaining the correct state tracking of TCP connections, which we solved by using a state tracking system and flow identifiers. Another challenge was that server2 could not receive the redirected traffic during the redirection, which we solved by re-improving the installation of flow table rules and setting its MAC address correctly. At the same time, we made the flow table more efficient by implementing the deletion of timed flow table entries and setting appropriate flow table entry priorities.

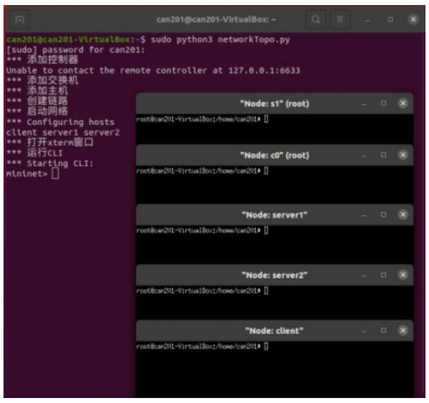
V. Testing and Results

A. Testing Environment

The implementation and testing were conducted in a virtualized environment using VirtualBox with the Mininet SDN emulator and the Ryu SDN framework. The environment was configured with the following specifications: Operating System: Ubuntu 20.04 LTS. Tools: Python 3.8, Mininet, Ryu, and Wireshark for packet analysis.

B. *Testing Steps*

Task 1: Execute the networkTopo.py script to build the topology. Figure 4 shows the terminal output verifying successful topology creation, where the topology is started, and five terminals are opened: Controller c0, Switch s1, Client, Server1, and Server2.



```
can201@can201-VirtualBox:~$ sudo python3 networkTopo.py
[sudo] password for can201:
*** 添加控制器
Unable to contact the remote controller at 127.0.0.1:6633
*** 添加交换机
*** 添加主机
*** 创建链路
*** 启动网络
*** Configuring hosts
client server1 server2
*** 打开xterm窗口
*** 运行CLI
*** Starting CLI:
mininet> 
```

```
"Node: s1" (root)
root@can201-VirtualBox:/home/can201# 
```

```
"Node: c0" (root)
root@can201-VirtualBox:/home/can201# 
```

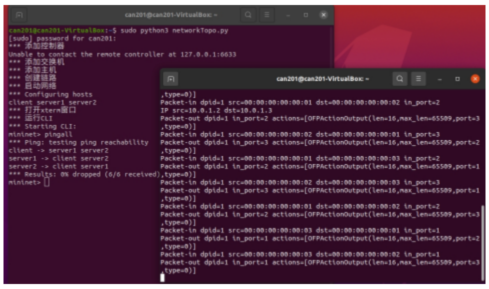
```
"Node: server1"
root@can201-VirtualBox:/home/can201# 
```

```
"Node: server2"
root@can201-VirtualBox:/home/can201# 
```

```
"Node: client"
root@can201-VirtualBox:/home/can201# 
```

Fig. 4

Task 2: Run the Ryu controller scripts `ryu_forward.py` and `ryu_redirect.py`. Perform ICMP ping tests from the client to `Server1` and `Server2` to verify connectivity. Figures 5 and 6 show the terminal output confirming successful packet exchanges between all nodes (0% packet loss), indicating proper reachability among them.

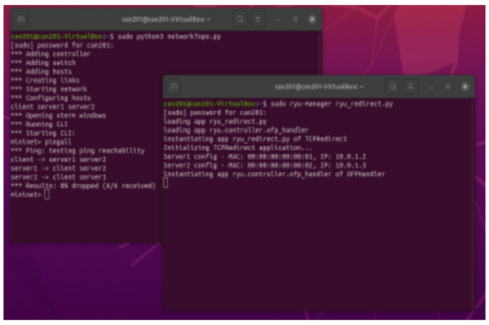


```
can201@can201-VirtualBox:~$ sudo python3 networkTopo.py
[sudo] password for can201:
*** 添加控制器
Unable to contact the remote controller at 127.0.0.1:6633
*** 添加交换机
*** 添加主机
*** 创建链路
*** 启动网络
*** Configuring hosts
client server1 server2
*** 打开xterm窗口
*** 运行CLI
*** Starting CLI:
mininet> pingall
*** Ping: testing ping reachability
client -> server1 server2
server1 -> client server2
server2 -> client server1
*** Results: 0% dropped (6/6 received)
mininet> 
```

```
,type=0)]
Packet-in dpid=1 src=00:00:00:00:00:01 dst=00:00:00:00:00:02 in_port=2
IP src=10.0.1.2 dst=10.0.1.3
Packet-out dpid=1 in_port=2 actions=[OFPActionOutput(len=16,max_len=65509,port=3
,type=0)]
Packet-in dpid=1 src=00:00:00:00:00:02 dst=00:00:00:00:00:01 in_port=3
Packet-out dpid=1 in_port=3 actions=[OFPActionOutput(len=16,max_len=65509,port=2
,type=0)]
Packet-in dpid=1 src=00:00:00:00:00:01 dst=00:00:00:00:00:03 in_port=2
Packet-out dpid=1 in_port=2 actions=[OFPActionOutput(len=16,max_len=65509,port=1
,type=0)]
Packet-in dpid=1 src=00:00:00:00:00:02 dst=00:00:00:00:00:03 in_port=3
Packet-out dpid=1 in_port=3 actions=[OFPActionOutput(len=16,max_len=65509,port=1
,type=0)]
Packet-in dpid=1 src=00:00:00:00:00:01 dst=00:00:00:00:00:02 in_port=2
Packet-out dpid=1 in_port=2 actions=[OFPActionOutput(len=16,max_len=65509,port=3
,type=0)]
Packet-in dpid=1 src=00:00:00:00:00:03 dst=00:00:00:00:00:01 in_port=1
Packet-out dpid=1 in_port=1 actions=[OFPActionOutput(len=16,max_len=65509,port=2
,type=0)]
Packet-in dpid=1 src=00:00:00:00:00:03 dst=00:00:00:00:00:02 in_port=1
Packet-out dpid=1 in_port=1 actions=[OFPActionOutput(len=16,max_len=65509,port=3
,type=0)]
```

Fig. 5

Task 3: Run the server.py script on both Server1 and Server2. Run the client.py script on Client to send traffic to Server1. Figure 7 shows

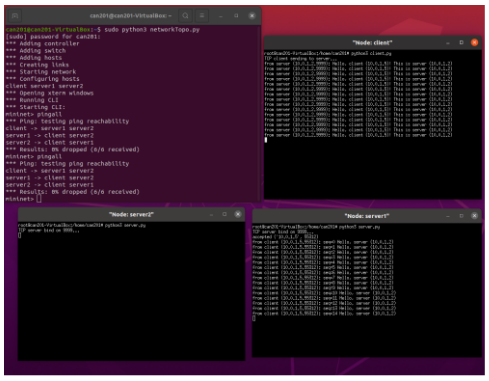


```
can201@can201-VirtualBox:~$ sudo python3 networkTopo.py
[sudo] password for can201:
*** Adding controller
*** Adding switch
*** Adding hosts
*** Creating links
*** Starting network
*** Configuring hosts
client server1 server2
*** Opening xterm windows
*** Running CLI
*** Starting CLI:
mininet> pingall
*** Ping: testing ping reachability
client -> server1 server2
server1 -> client server2
server2 -> client server1
*** Results: 0% dropped (6/6 received)
mininet> 
```

```
can201@can201-VirtualBox:~$ sudo ryu-manager ryu_redirect.py
[sudo] password for can201:
loading app ryu_redirect.py
loading app ryu.controller.ofp_handler
instantiating app ryu_redirect.py of TCPRedirect
Initializing TCPRedirect application...
Server1 config - MAC: 00:00:00:00:00:01, IP: 10.0.1.2
Server2 config - MAC: 00:00:00:00:00:02, IP: 10.0.1.3
instantiating app ryu.controller.ofp_handler of OFPHandler
```

Fig. 6

that Server1 successfully received traffic from the client through captured logs.



```
can201@can201-VirtualBox:~$ sudo python3 networkTopo.py
[sudo] password for can201:
*** Adding controller
*** Adding switch
*** Adding hosts
*** Creating links
*** Starting network
*** Configuring hosts
client server1 server2
*** Opening xterm windows
*** Running CLI
*** Starting CLI:
mininet> pingall
*** Ping: testing ping reachability
client -> server1 server2
server1 -> client server2
server2 -> client server1
*** Results: 0% dropped (6/6 received)
mininet> pingall
*** Ping: testing ping reachability
client -> server1 server2
server1 -> client server2
server2 -> client server1
*** Results: 0% dropped (6/6 received)
mininet> 
```

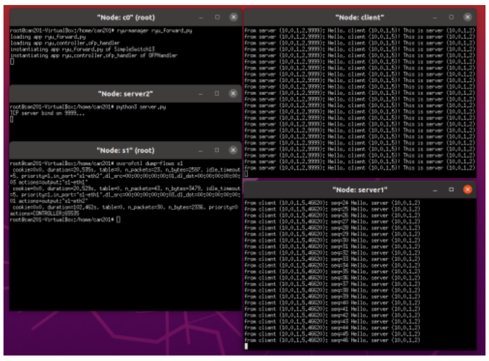
```
"Node: client"
root@can201-VirtualBox:/home/can201# python3 client.py
TCP client sending to server...
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
```

```
"Node: server2"
root@can201-VirtualBox:/home/can201# python3 server.py
TCP server bind on 9999...
```

```
"Node: server1"
root@can201-VirtualBox:/home/can201# python3 server.py
TCP server bind on 9999...
Accepted ('10.0.1.5', 55312)
from client (10.0.1.5,55312): seq=0 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=1 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=2 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=3 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=4 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=5 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=6 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=7 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=8 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=9 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=10 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=11 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=12 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=13 Hello, server (10.0.1.2)
from client (10.0.1.5,55312): seq=14 Hello, server (10.0.1.2)
```

Fig. 7

Task 4: Running the `ryu_forward.py` script on `c0` produces the results shown in Figure 8, where `Server1` successfully receives the client's request. The flow table correctly forwards traffic to `Server1`, enabling normal communication between the `Client` and `Server1`.



```
"Node: c0" (root)
root@can201-VirtualBox:/home/can201# ryu-manager ryu_forward.py
loading app ryu_forward.py
loading app ryu.controller.ofp_handler
instantiating app ryu_forward.py of SimpleSwitch13
instantiating app ryu.controller.ofp_handler of OFPHandler
```

```
"Node: server2"
root@can201-VirtualBox:/home/can201# python3 server.py
TCP server bind on 9999...
```

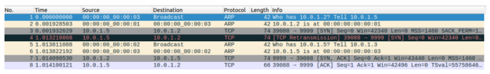
```
"Node: s1" (root)
root@can201-VirtualBox:/home/can201# ovs-ofctl dump-flows s1
 cookie=0x0, duration=20.535s, table=0, n_packets=23, n_bytes=2587, idle_timeout
=5, priority=1,in_port="s1-eth2",dl_src=00:00:00:00:00:01,dl_dst=00:00:00:00:00:
03 actions=output:"s1-eth1"
 cookie=0x0, duration=20.529s, table=0, n_packets=43, n_bytes=3479, idle_timeout
=5, priority=1,in_port="s1-eth1",dl_src=00:00:00:00:00:03,dl_dst=00:00:00:00:00:
01 actions=output:"s1-eth2"
 cookie=0x0, duration=102.462s, table=0, n_packets=30, n_bytes=2336, priority=0
actions=CONTROLLER:65535
root@can201-VirtualBox:/home/can201# 
```

```
"Node: client"
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
from server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.2)
```

```
"Node: server1"
from client (10.0.1.5,46620): seq=24 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=25 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=26 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=27 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=28 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=29 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=30 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=31 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=32 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=33 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=34 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=35 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=36 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=37 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=38 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=39 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=40 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=41 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=42 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=43 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=44 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=45 Hello, server (10.0.1.2)
from client (10.0.1.5,46620): seq=46 Hello, server (10.0.1.2)
```

Fig. 8

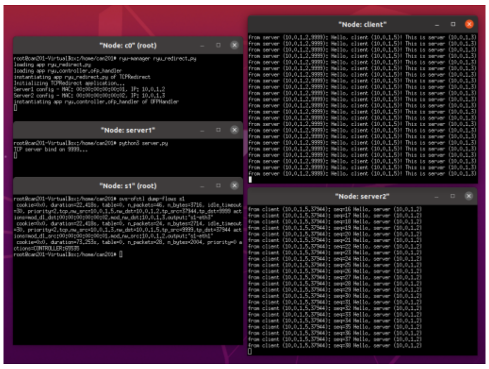
Wireshark was used to capture the data packets shown in Figure 9 on the Client, and a network delay of 1.012167492 seconds was calculated.



```
No.  Time         Source             Destination        Protocol Length Info
   1 0.000000000  00:00:00_00:00:03  Broadcast          ARP      42 Who has 10.0.1.2? Tell 10.0.1.5
   2 0.001928503  00:00:00_00:00:01  00:00:00_00:00:03  ARP      42 10.0.1.2 is at 00:00:00:00:00:01
   3 0.001932629  10.0.1.5           10.0.1.2           TCP      74 39088 → 9999 [SYN] Seq=0 Win=42340 Len=0 MSS=1460 SACK_PERM=1…
   4 1.013210868  10.0.1.5           10.0.1.2           TCP      74 [TCP Retransmission] 39088 → 9999 [SYN] Seq=0 Win=42340 Len=0…
   5 1.013811088  00:00:00_00:00:02  Broadcast          ARP      42 Who has 10.0.1.5? Tell 10.0.1.3
   6 1.013822192  00:00:00_00:00:03  00:00:00_00:00:02  ARP      42 10.0.1.5 is at 00:00:00:00:00:03
   7 1.014090530  10.0.1.2           10.0.1.5           TCP      74 9999 → 39088 [SYN, ACK] Seq=0 Ack=1 Win=43440 Len=0 MSS=1460 …
   8 1.014100121  10.0.1.5           10.0.1.2           TCP      66 39088 → 9999 [ACK] Seq=1 Ack=1 Win=42496 Len=0 TSval=55758646…
```

Fig. 9

Task 5: Running the `ryu_redirect.py` script on `c0` produces the situation shown in Figure 7, where a response on `Server2` indicates successful redirection to `Server2`. The flow table ensures accurate traffic redirection from `Client` to `Server2`



```
"Node: c0" (root)
root@can201-VirtualBox:/home/can201# ryu-manager ryu_redirect.py
loading app ryu_redirect.py
loading app ryu.controller.ofp_handler
instantiating app ryu_redirect.py of TCPRedirect
Initializing TCPRedirect application...
Server1 config - MAC: 00:00:00:00:00:01, IP: 10.0.1.2
Server2 config - MAC: 00:00:00:00:00:02, IP: 10.0.1.3
instantiating app ryu.controller.ofp_handler of OFPHandler
```

```
"Node: server1"
root@can201-VirtualBox:/home/can201# python3 server.py
TCP server bind on 9999...
```

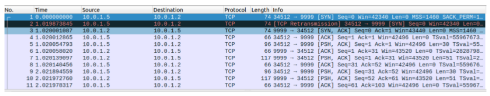
```
"Node: s1" (root)
root@can201-VirtualBox:/home/can201# ovs-ofctl dump-flows s1
 cookie=0x0, duration=22.418s, table=0, n_packets=46, n_bytes=3716, idle_timeout
=30, priority=2,tcp,nw_src=10.0.1.5,nw_dst=10.0.1.2,tp_src=37944,tp_dst=9999 act
ions=mod_dl_dst:00:00:00:00:00:02,mod_nw_dst:10.0.1.3,output:"s1-eth3"
 cookie=0x0, duration=22.418s, table=0, n_packets=24, n_bytes=2714, idle_timeout
=30, priority=2,tcp,nw_src=10.0.1.3,nw_dst=10.0.1.5,tp_src=9999,tp_dst=37944 act
ions=mod_dl_src:00:00:00:00:00:01,mod_nw_src:10.0.1.2,output:"s1-eth1"
 cookie=0x0, duration=73.253s, table=0, n_packets=28, n_bytes=2004, priority=0 a
ctions=CONTROLLER:65535
root@can201-VirtualBox:/home/can201# 
```

```
"Node: client"
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
From server (10.0.1.2,9999): Hello, client (10.0.1.5)! This is server (10.0.1.3)
```

```
"Node: server2"
from client (10.0.1.5,37944): seq=16 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=17 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=18 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=19 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=20 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=21 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=22 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=23 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=24 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=25 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=26 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=27 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=28 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=29 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=30 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=31 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=32 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=33 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=34 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=35 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=36 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=37 Hello, server (10.0.1.2)
from client (10.0.1.5,37944): seq=38 Hello, server (10.0.1.2)
```

Fig. 10

Wireshark was used to capture the data packets shown in Figure 11 on the Client, and a network delay of 1.020 seconds was calculated.



```
No.  Time         Source     Destination  Protocol Length Info
   1 0.000000000  10.0.1.5   10.0.1.2     TCP      74 34512 → 9999 [SYN] Seq=0 Win=42340 Len=0 MSS=1460 SACK_PERM=1…
   2 1.019873845  10.0.1.5   10.0.1.2     TCP      74 [TCP Retransmission] 34512 → 9999 [SYN] Seq=0 Win=42340 Len=0…
   3 1.020001087  10.0.1.2   10.0.1.5     TCP      74 9999 → 34512 [SYN, ACK] Seq=0 Ack=1 Win=43440 Len=0 MSS=1460 …
   4 1.020012865  10.0.1.5   10.0.1.2     TCP      66 34512 → 9999 [ACK] Seq=1 Ack=1 Win=42496 Len=0 TSval=55967673…
   5 1.020054793  10.0.1.5   10.0.1.2     TCP      96 34512 → 9999 [PSH, ACK] Seq=1 Ack=1 Win=42496 Len=30 TSval=55…
   6 1.020058020  10.0.1.2   10.0.1.5     TCP      66 9999 → 34512 [ACK] Seq=1 Ack=31 Win=43520 Len=0 TSval=2828798…
   7 1.020139097  10.0.1.2   10.0.1.5     TCP     117 9999 → 34512 [PSH, ACK] Seq=1 Ack=31 Win=43520 Len=51 TSval=2…
   8 1.020140456  10.0.1.5   10.0.1.2     TCP      66 34512 → 9999 [ACK] Seq=31 Ack=52 Win=42496 Len=0 TSval=559676…
   9 2.021894559  10.0.1.5   10.0.1.2     TCP      96 34512 → 9999 [PSH, ACK] Seq=31 Ack=52 Win=42496 Len=30 TSval=…
  10 2.021972760  10.0.1.2   10.0.1.5     TCP     117 9999 → 34512 [PSH, ACK] Seq=52 Ack=61 Win=43520 Len=51 TSval=…
  11 2.021978317  10.0.1.5   10.0.1.2     TCP      66 34512 → 9999 [ACK] Seq=61 Ack=103 Win=42496 Len=0 TSval=55967…
```

Fig. 11

Testing Results:

As shown in Figure 12 , the comparison demonstrates that the redirection mechanism effectively reduces latency, thereby aligning with the objectives of optimizing traffic flow in SDN-based systems.

VI. Conclusion

This project successfully implemented the intelligent SDN management system by using the Ryu controller and Mininet. Key achievements are network topology construction, dynamic packet forwarding, and transparent traffic redirection, which can effectively support failover and load balancing. Testing has shown that network latency was optimized, enhancing flexibility and performance.

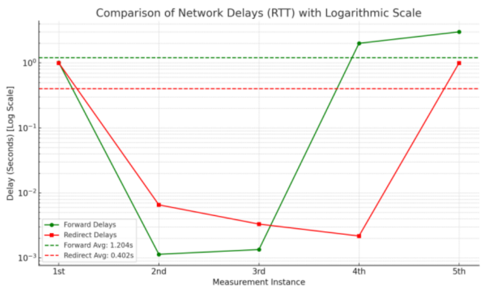


Fig. 12

In the future, the system can be improved in terms of scalability, fault tolerance, and adaptability to larger and more complex networks. Additionally, improvements to SDN itself, including simplifying packet processing, increasing processing speed, optimizing memory usage, and improving efficiency, will further enhance its applicability and performance in real-world applications. The enhancement will consolidate SDN's position as one of the key technologies for the management of modern networks.

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