实验名称

Lab 4: Forwarding Packets

实验目的

模拟互联网网络中链路层ARP协议的工作过程，模拟路由对数据包的转发过程，加强对互联网通信连接的过程的理解

实验内容

1.Handle ARP Request

- 根据包头判断是否是ARP包，若不是则抛弃
- 判断目的Ip是否在路由器端口中，若不在则抛弃
- 构造对应的ARP响应包并发送

2.Cached ARP Table

- 构造一个ARP缓存表，键值对 `ip : mac , time`
- 每次收到ARP包时，将其放入ARP缓存表中
- 更新ARP缓存表，删除超时的表项

3.IP Forwarding Table Lookup

- 根据`forwarding_table.txt`和路由器端口来建立路由表
- 遍历路由表项，进行最大前缀匹配，未能匹配则返回空

4.Forwarding the Packet and ARP

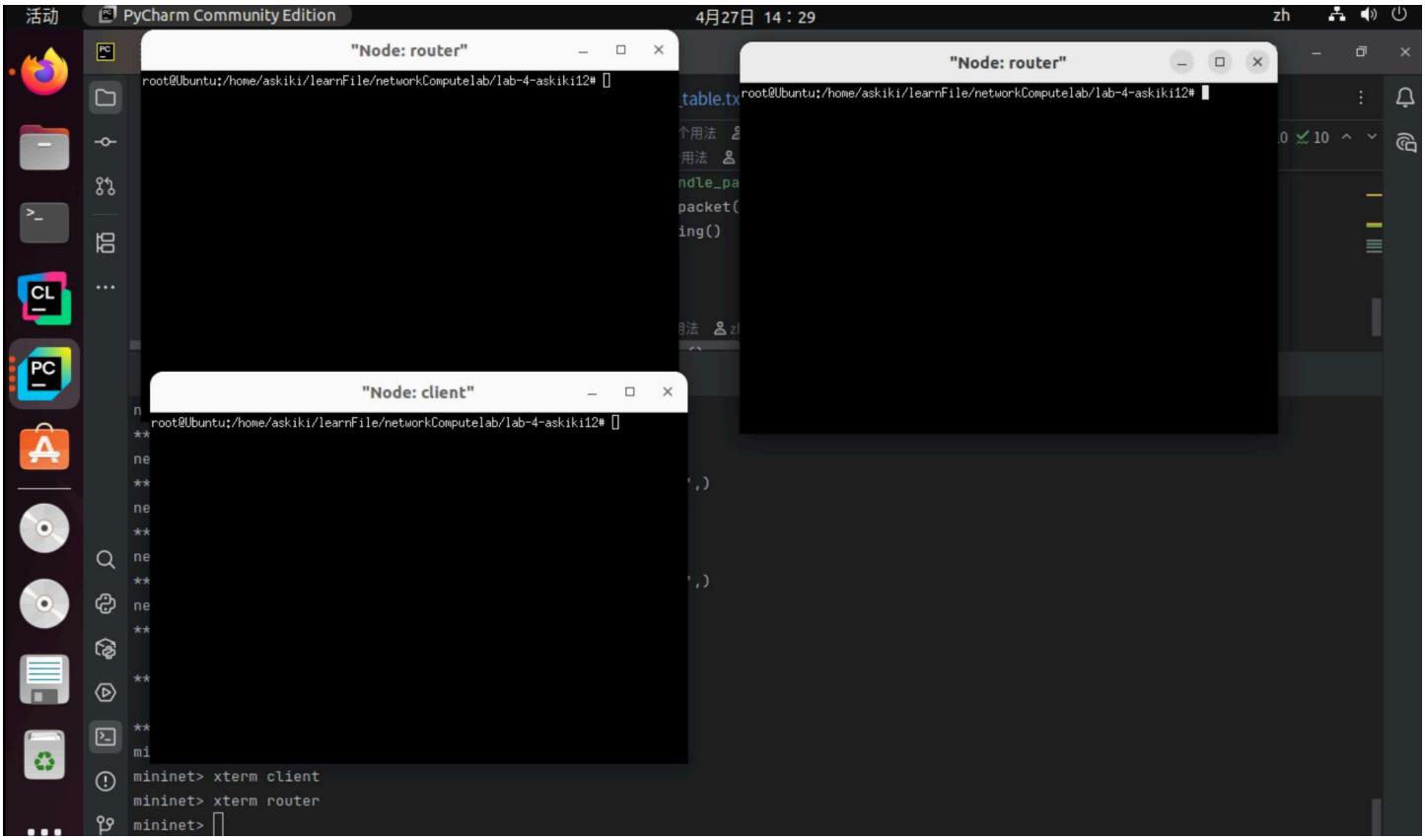
- 收到IPv4包之后，首先判断是否为针对路由器本身的，若是则忽略
- 进行路由表最长匹配，匹配成功则将`ttl`减一
- 根据路由表匹配结果的下一跳地址，决定是否进行转发
- 对下一条地址发送ARP请求，收到ARP响应后对数据包进行封装（这里需要借助ARP Cache Table）
- 如果1s内没有收到ARP响应，则再发送一次ARP请求，至多请求5次

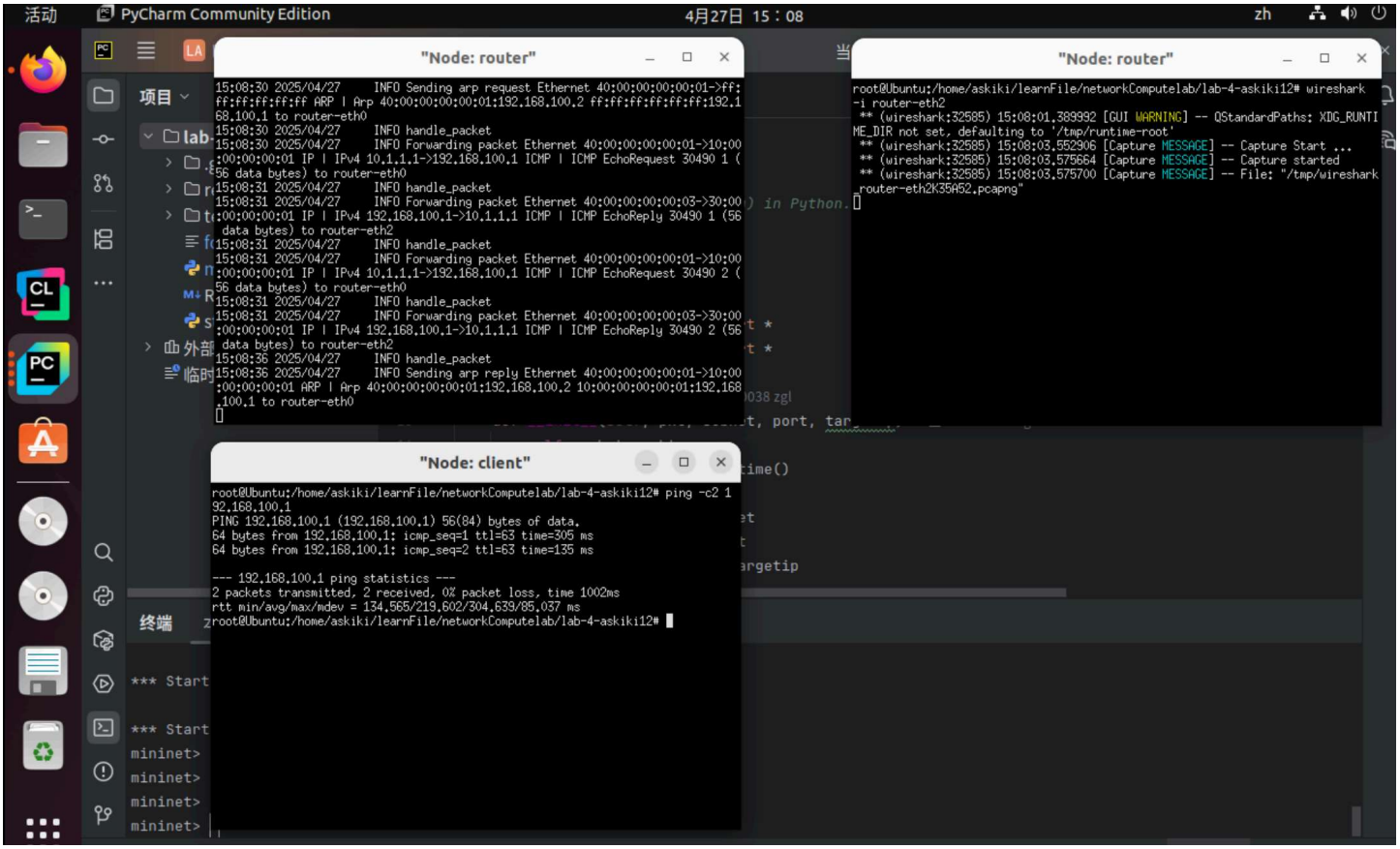
实验结果

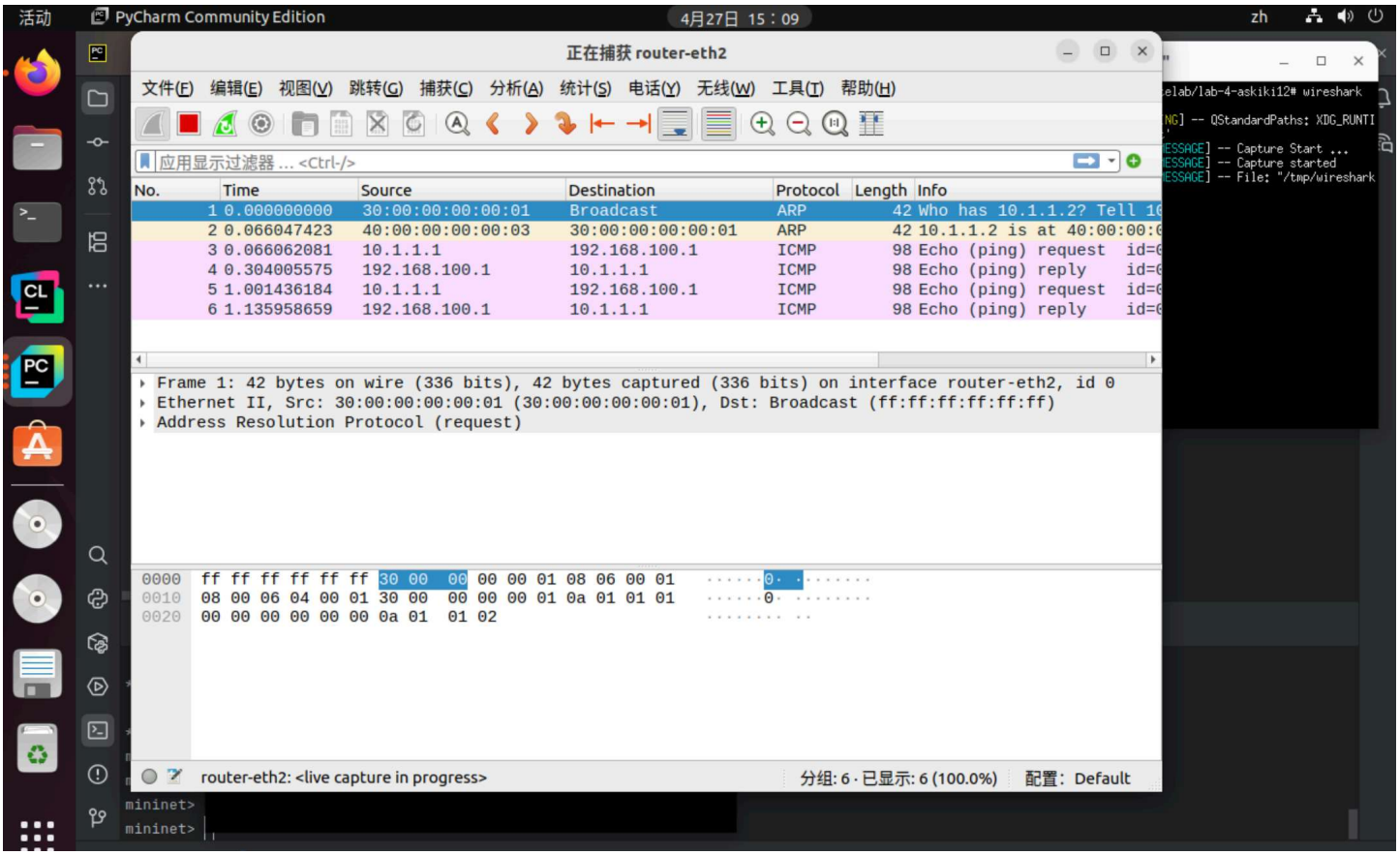
- 输入`swyard -t testcases/testscenario2.srpy myrouter.py`进行测试：

```
终端  本地 ×  +  ⋮ —
26  Router should try to receive a packet (ARP response), but
    then timeout
27  Router should send an ARP request for 10.10.50.250 on
    router-eth1
28  Router should try to receive a packet (ARP response), but
    then timeout
29  Router should send an ARP request for 10.10.50.250 on
    router-eth1
30  Router should try to receive a packet (ARP response), but
    then timeout
31  Router should try to receive a packet (ARP response), but
    then timeout


All tests passed!


(syenv) askiki@Ubuntu:~/learnFile/networkComputelab/lab-4-askiki12$
```

- sudo python3 start_mininet.py
- 在mininet中xterm router并xterm client
- Router中执行 swyard myrouter.py
- Router中同时执行 wireshark -i router-eth2
- Client中执行ping -c2 192.168.100.1




"Node: router"
15:08:30 2025/04/27 INFO Sending arp request Ethernet 40:00:00:00:00:01->ff:ff:ff:ff:ff:ff ARP | Arp 40:00:00:00:00:01:192.168.100.2 ff:ff:ff:ff:ff:ff:192.168.100.1 to router-eth0
15:08:30 2025/04/27 INFO handle_packet
15:08:30 2025/04/27 INFO Forwarding packet Ethernet 40:00:00:00:00:01->10:00:00:00:00:01 IP | IPv4 10.1.1.1->192.168.100.1 ICMP | ICMP EchoRequest 30490 1 (56 data bytes) to router-eth0
15:08:31 2025/04/27 INFO handle_packet
15:08:31 2025/04/27 INFO Forwarding packet Ethernet 40:00:00:00:00:03->30:00:00:00:00:01 IP | IPv4 192.168.100.1->10.1.1.1 ICMP | ICMP EchoReply 30490 1 (56 data bytes) to router-eth2
15:08:31 2025/04/27 INFO handle_packet
15:08:31 2025/04/27 INFO Forwarding packet Ethernet 40:00:00:00:00:01->10:00:00:00:00:01 IP | IPv4 10.1.1.1->192.168.100.1 ICMP | ICMP EchoRequest 30490 2 (56 data bytes) to router-eth0
15:08:31 2025/04/27 INFO handle_packet
15:08:31 2025/04/27 INFO Forwarding packet Ethernet 40:00:00:00:00:03->30:00:00:00:00:01 IP | IPv4 192.168.100.1->10.1.1.1 ICMP | ICMP EchoReply 30490 2 (56 data bytes) to router-eth2
15:08:36 2025/04/27 INFO handle_packet
15:08:36 2025/04/27 INFO Sending arp reply Ethernet 40:00:00:00:00:01->10:00:00:00:00:01 ARP | Arp 40:00:00:00:00:01:192.168.100.2 10:00:00:00:00:01:192.168.100.1 to router-eth0
"Node: router"
root@Ubuntu:/home/askiki/learnFile/networkComputelab/lab-4-askiki12# wireshark -i router-eth2
** (wireshark:32585) 15:08:01.389992 [GUI WARNING] -- QStandardPaths: XDG_RUNTIME_DIR not set, defaulting to '/tmp/runtime-root'
** (wireshark:32585) 15:08:03.552906 [Capture MESSAGE] -- Capture Start ...
** (wireshark:32585) 15:08:03.575664 [Capture MESSAGE] -- Capture started
** (wireshark:32585) 15:08:03.575700 [Capture MESSAGE] -- File: "/tmp/wireshark_router-eth2K35H52.pcapng"
"Node: client"
root@Ubuntu:/home/askiki/learnFile/networkComputelab/lab-4-askiki12# ping -c2 192.168.100.1
PING 192.168.100.1 (192.168.100.1) 56(84) bytes of data.
64 bytes from 192.168.100.1: icmp_seq=1 ttl=63 time=305 ms
64 bytes from 192.168.100.1: icmp_seq=2 ttl=63 time=135 ms
--- 192.168.100.1 ping statistics ---
2 packets transmitted, 2 received, 0% packet loss, time 1002ms
rtt min/avg/max/mdev = 134.565/219.602/304.639/85.037 ms
root@Ubuntu:/home/askiki/learnFile/networkComputelab/lab-4-askiki12#
终端
*** Start
mininet>


正在捕获 router-eth2
文件(F) 编辑(E) 视图(V) 跳转(G) 捕获(C) 分析(A) 统计(S) 电话(Y) 无线(W) 工具(T) 帮助(H)
应用显示过滤器 ... <Ctrl-/>
No. Time Source Destination Protocol Length Info
1 0.000000000 30:00:00:00:00:01 Broadcast ARP 42 Who has 10.1.1.2? Tell 10
2 0.066047423 40:00:00:00:00:03 30:00:00:00:00:01 ARP 42 10.1.1.2 is at 40:00:00:0
3 0.066062081 10.1.1.1 192.168.100.1 ICMP 98 Echo (ping) request id=0
4 0.304005575 192.168.100.1 10.1.1.1 ICMP 98 Echo (ping) reply id=0
5 1.001436184 10.1.1.1 192.168.100.1 ICMP 98 Echo (ping) request id=0
6 1.135958659 192.168.100.1 10.1.1.1 ICMP 98 Echo (ping) reply id=0
Frame 1: 42 bytes on wire (336 bits), 42 bytes captured (336 bits) on interface router-eth2, id 0
Ethernet II, Src: 30:00:00:00:00:01 (30:00:00:00:00:01), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
Address Resolution Protocol (request)
0000 ff ff ff ff ff ff 30 00 00 00 00 01 08 06 00 01
0010 08 00 06 04 00 01 30 00 00 00 00 01 0a 01 01 01
0020 00 00 00 00 00 00 0a 01 01 02
router-eth2: <live capture in progress>
分组: 6 · 已显示: 6 (100.0%)
配置: Default
mininet>

核心代码

```
#!/usr/bin/env python3

'''
Basic IPv4 router (static routing) in Python.
'''

import time
import switchyard
from switchyard.lib.userlib import *
from switchyard.lib.logging import *

class RebuildPkt:
    def __init__(self, pkt, subnet, port, targetip):
        self.packet = pkt
        self.recent_time = time.time()
        self.num_of_retries = 0
        self.match_subnet = subnet
        self.send_out_port = port
        self.targetipaddress = targetip

    def get_targetipaddress(self):
        return self.targetipaddress

    def get_send_out_port(self):
        return self.send_out_port

    def get_packet(self):
        return self.packet

    def get_num_of_retries(self):
        return self.num_of_retries

    def try_to_send(self):
        self.num_of_retries += 1

    def update_time(self):
        self.recent_time = time.time()

    def get_recent_time(self):
        return self.recent_time


class Router(object):
    def __init__(self, net: switchyard.llnetbase.LLNetBase):
        self.net = net
        # other initialization stuff here
        self.interfaces = net.interfaces()
        dir(self.interfaces[0])
        self.arp_table = {}
        self.ip_list = []
        self.eth_list = []
        for i in self.interfaces:
            self.ip_list.append(i.ipaddr)
            self.eth_list.append(i.ethaddr)
        self.forwarding_table = {}
        for i in self.interfaces:
```

```
            sub_network_address = IPv4Address(ip_address((int(i.ipaddr) & int(i.netmask))))
            self.forwarding_table[sub_network_address] = [i.netmask, '0.0.0.0', i.name]

        with open('forwarding_table.txt') as f:
            while True:
                line = f.readline()
                if not line:
                    break
                else:
                    table_info = line.split()
                    self.forwarding_table[IPv4Address(table_info[0])] = [IPv4Address(table_info[1]),
                                                                         IPv4Address(table_info[2]), table_info[3]]
        self.packet_queue = []
        self.arp_timeout = 20*60


    def handle_packet(self, recv: switchyard.llnetbase.ReceivedPacket):
        timestamp, ifaceName, packet = recv
        # TODO: your logic here
        arp = packet.get_header(Arp)
        ipv4 = packet.get_header(IPv4)
        input_port = self.net.interface_by_name(ifaceName)

        if arp is not None:
            self.update_arp_table()
            self.arp_table[arp.senderprotoaddr] = [arp.senderhwaddr, time.time()]
            if arp.operation == ArpOperation.Request:
                for i in self.ip_list:
                    if i == arp.targetprotoaddr:
                        arp_reply_pkt = create_ip_arp_reply(input_port.ethaddr, arp.senderhwaddr, arp.targetprotoaddr,
                                                            arp.senderprotoaddr)
                        self.net.send_packet(ifaceName, arp_reply_pkt)
                        log_info(f"Sending arp reply {arp_reply_pkt} to {ifaceName}")
                        return
            else:
                self.forwarding()
                return
        elif ipv4 is not None:
            if ipv4.dst in self.ip_list:
                return
            match_subnet, next_hop_ip, out_port = self.longest_prefix_match(ipv4.dst)
            if match_subnet:
                ipv4.ttl -= 1
                if ipv4.ttl <= 0:
                    return
                if next_hop_ip == '0.0.0.0':
                    dstip = ipv4.dst
                else:
                    dstip = next_hop_ip
                pkt = RebuildPkt(packet, match_subnet, out_port, dstip)
                self.packet_queue.append(pkt)
                self.forwarding()

    def update_arp_table(self):
        current_time = time.time()
        for ip in list(self.arp_table.keys()):
            mac, last_update_time = self.arp_table[ip]
            if current_time - last_update_time > self.arp_timeout:
                del self.arp_table[ip]
```

```
def longest_prefix_match(self, dst_ip):
    best_match = None
    best_prefix_len = 0
    next_hop_ip = None
    out_port = None
    for prefix, (netmask, next_hop, port) in self.forwarding_table.items():
        net = IPv4Network(str(prefix) + '/' + str(netmask))
        if dst_ip in net:
            if net.prefixlen > best_prefix_len:
                best_prefix_len = net.prefixlen
                best_match = prefix
                next_hop_ip = next_hop
                out_port = port
    return best_match, next_hop_ip, out_port

def forwarding(self):
    if len(self.packet_queue) == 0:
        return
    handle_pkt = self.packet_queue[0]
    targetipaddr = handle_pkt.get_targetipaddress()
    router_send_to_host_port_name = handle_pkt.get_send_out_port()
    my_packet = handle_pkt.get_packet()
    router_forwarding_port_info = self.net.interface_by_name(router_send_to_host_port_name)
    if targetipaddr in self.arp_table.keys():
        self.forwarding_packet(my_packet, router_send_to_host_port_name, targetipaddr, router_forwarding_port_info)
    elif handle_pkt.get_num_of_retries() < 5:
        self.send_arp_request(handle_pkt, router_forwarding_port_info, targetipaddr, router_send_to_host_port_name)
    elif handle_pkt.get_num_of_retries() >= 5:
        del (self.packet_queue[0])


def forwarding_packet(self, my_packet, router_send_to_host_port_name, targetipaddr, router_forwarding_port_info):
    my_packet[Ethernet].src = router_forwarding_port_info.ethaddr
    my_packet[Ethernet].dst = self.arp_table[targetipaddr][0]
    self.net.send_packet(router_send_to_host_port_name, my_packet)
    log_info(f"Forwarding packet {my_packet} to {router_send_to_host_port_name}")
    del (self.packet_queue[0])

def send_arp_request(self, handle_pkt, router_if, targetip, portname):
    if handle_pkt.get_num_of_retries() == 0 or (time.time() - handle_pkt.get_recent_time()) > 1.0:
        arppacket = create_ip_arp_request(
            router_if.ethaddr, router_if.ipaddr, targetip)
        handle_pkt.try_to_send()
        handle_pkt.update_time()
        self.net.send_packet(portname, arppacket)
        log_info(f"Sending arp request {arppacket} to {portname}")

def start(self):
    '''A running daemon of the router.
    Receive packets until the end of time.
    '''
    while True:
        try:
            recv = self.net.recv_packet(timeout=1.0)
        except NoPackets:
            self.forwarding()
            continue
        except Shutdown:
```

```
                break
            log_info("handle_packet")
            self.handle_packet(recv)
            self.forwarding()

        self.stop()

    def stop(self):
        self.net.shutdown()


def main(net):
    '''
    Main entry point for router.  Just create Router
    object and get it going.
    '''
    router = Router(net)
    router.start()
```

根据实验内容和要求实现如上代码，建立并初始化转发表，构建ARP缓存表并适时更新，接收到数据包根据包头按不同逻辑处理

如果是ARP头：判断目标Ip是否是自己的Ip，如果是ARP回应，就直接转发

如果是Ip头：判断自己是否是目标路由，如果不是则按最长前缀匹配转发给下一个路由，如果最长前缀匹配到的下一跳Ip是`'0.0.0.0'`，则目标路由在自己所在的子网中，直接可以发送ARP请求

且ARP请求应该有超时重传的逻辑，最多五次

实验总结

在本次静态路由实验中，我基于 Switchyard 平台完成了以上过程，深入巩固了路由器的核心流程：路由决策、ARP 解析、重试与超时处理，以及队列管理，为理解静态路由器设计奠定了坚实基础。