

计算机网络实验报告-08

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一、 实验题目

路由器转发实验。

二、 实验内容

理解路由器转发的内容和原理，构建路由器程序，实现相应的路由转发以及回复。并完成下列实验任务：

- 在给定网络拓扑上，依次 ping r1, h2, h3, 一个不可达的终端，一个不可达的网络，路由器能够正确完成对应处理。
- 构建一个新的有多个路由器的拓扑网络，各个终端节点之间能够 ping 通，并且能够通过 traceroute 程序获取正确的路径信息。

三、 实验过程

本次代码较多，顺序叫乱，不再一一展示，选出几个较为核心的程序片段稍加说明。

程序运行从处理 ip 和 arp 的 packet 开始。

```
// handle ip packet
//
// If the packet is ICMP echo request and the destination IP address is equal to
// the IP address of the iface, send ICMP echo reply; otherwise, forward the
// packet.
void handle_ip_packet(iface_info_t *iface, char *packet, int len)
{
    struct iphdr * ip = packet_to_ip_hdr(packet);

    u32 dst = ntohl(ip->daddr);
    rt_entry_t *entry = longest_prefix_match(dst);
    if (!entry) {
```

处理 ip 的 packet，首先检测是否对应的 ip 地址存在于转发表中，如果不在，回复 ICMP 网络不可达信息。

```

//if out of ttl
if(--ip->ttl <= 0){
    //make up IP Header info of ICMP packet
    char * packet_buf = (char *)malloc(ETHER_HDR_SIZE + ntohs(ip->tot_len) + 40);
    memset(packet_buf, 0, ETHER_HDR_SIZE*sizeof(char));
    memcpy(packet_buf + ETHER_HDR_SIZE*sizeof(char), packet + ETHER_HDR_SIZE, ntohs(ip->tot_len));
    memcpy(packet_buf + ETHER_HDR_SIZE*sizeof(char) + ip->ihl*4 + 8, packet + ETHER_HDR_SIZE,
    ip = packet_to_ip_hdr(packet_buf);
    ip->daddr = ip->saddr;
    ip->saddr = iface->ip;
    ip->protocol = 1;
    ip->tot_len = htons(ip->ihl*4 + 8 + ip->ihl*4 + 8);
    ip->checksum = ip_checksum(ip);

    //send
    icmp_send_packet(packet_buf, ntohs(ip->tot_len) + ETHER_HDR_SIZE, ICMP_TIME_EXCEEDED, ICMP
    return ;
}

```

减 ttl，并判断是否超时，如超时便回复 ICMP 信息。中间的程序段由于最初设计的缘故，和几个发送 ICMP 信息的部分高度重复。所以看一个就好啦。这里我的架构是将 ip 部分构建好以及 icmp 的 data 部分构建好后送入 icmp_send_packet 函数，由它负责填充 icmp 头部已经对应的 checksum，再交由 ip_send_packet 添加本跳的 mac 并利用函数 iface_send_packet_by_arp 最终填充对端的 mac 完成包的发送。由于最后一个函数中的 lookup 函数需要锁，所以在调用发送包的地方都会释放 arp 的锁。

```

//if it is ICMP packet
if(ntohl(ip->daddr) == iface->ip){
    struct icmphdr * ich = (struct icmphdr *) (ip + 1);
    //log(DEBUG,"ICMP message &ip %x, ip ihl * 4 %d, &ich %x ", ip, ip->ihl * 4, ich);

    u8 type = ich->type;
    if(type == 0){
        log(DEBUG,"ICMP received, type : 0, echo reply received \n ");
    }
    else if(type == 3){
        if(ich->code == 0){
            log(DEBUG,"ICMP received, type : 3, NET Unreachable \n ");
        }
        else{
            log(DEBUG,"ICMP received, type : 3, HOST Unreachable \n ");
        }
    }
    else if(type == 11){
        log(DEBUG,"ICMP received, type : 11,Time Exceeded \n ");
    }
    else if(type == 8){
        log(DEBUG,"ICMP received, type : 8, echo received \n ");
    }
}

```

检查是否为 ICMP 包，如是的话做对应处理。如果不是的话，调用 ip_forward_packet 转发即可。

```

void handle_arp_packet(iface_info_t *iface, char *packet, int len)
{
    log(DEBUG, "arp packet received");
    struct ether_arp * arp = (struct ether_arp *) (packet + ETHER_HDR_SIZE);

    //if it is request
    if(arp->arp_op == htons(0x0001) && arp->arp_tpa == htonl(iface->ip)){
        log(DEBUG, "it is echo to %x", iface->ip);
        struct ether_arp buf;
        memcpy(&buf, arp, 6);
        buf.arp_op = htons(0x0002);
        memcpy(buf.arp_sha, iface->mac, ETH_ALEN);
        buf.arp_spa = htonl(iface->ip);
        memcpy(buf.arp_tha, arp->arp_sha, 10);
        arpcache_insert(ntohl(arp->arp_spa), arp->arp_sha);
        arp_send_reply(iface, &buf);
    }
    else{
        arpcache_insert(ntohl(arp->arp_spa), arp->arp_sha);
    }
}
}

```

对于 arp 包的处理就简洁很多，收到一个 arp 包时判断是请求还是回应，是请求的话回应对应的 arp 包，并将新的 mac 条目插入映射表。如果是回应的话，那就将 mac 条目插入映射表。在插入动作中会取出对应等待列表中的 packet 并将它们发送出去。

在 cache 部分，sweep 函数要做的事比之前的 sweep 要多不少，主要体现在对于等待队列的 arp 请求重发以及超过发送次数后的 ICMP 包回复。

运行 router，开始完成对应实验条目，结果见下节。

四、实验结果

运行脚本

```

ruan@ruan-VirtualBox:/mnt/08-router$ sudo python router_topo.py
mininet> xterm h1 h2 h3 r1

```

Ping r1

"Node: h1"	"Node: r1"
<pre> root@ruan-VirtualBox:/mnt/08-router# ping 10.0.1.1 PING 10.0.1.1 (10.0.1.1) 56(84) bytes of data. 64 bytes from 10.0.1.1: icmp_seq=1 ttl=63 time=0.107 ms 64 bytes from 10.0.1.1: icmp_seq=2 ttl=63 time=0.260 ms 64 bytes from 10.0.1.1: icmp_seq=3 ttl=63 time=0.119 ms ^C --- 10.0.1.1 ping statistics --- 3 packets transmitted, 3 received, 0% packet loss, time 2048ms rtt min/avg/max/mdev = 0.107/0.162/0.260/0.069 ms root@ruan-VirtualBox:/mnt/08-router# </pre>	<pre> root@ruan-VirtualBox:/mnt/08-router# ./router DEBUG: find the following interfaces: r1-eth0 r1-eth1 r1-eth2. DEBUG: arp packet received DEBUG: it is echo to a000101 DEBUG: handling ip packet, dad ip 10.0.1.1, sad 10.0.1.11 ERROR: the ttl is 64 DEBUG: ICMP received, type : 8, echo received DEBUG: sending IP (dst:10.0.1.11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: handling ip packet, dad ip 10.0.1.1, sad 10.0.1.11 ERROR: the ttl is 64 DEBUG: ICMP received, type : 8, echo received DEBUG: sending IP (dst:10.0.1.11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: handling ip packet, dad ip 10.0.1.1, sad 10.0.1.11 ERROR: the ttl is 64 DEBUG: ICMP received, type : 8, echo received DEBUG: sending IP (dst:10.0.1.11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 </pre>

成功

Ping h2 h3

"Node: h1"	"Node: r1"
<pre> rtt min/avg/max/mdev = 0.107/0.162/0.260/0.069 ms root@ruan-VirtualBox:/mnt/08-router# ping 10.0,2,22 PING 10.0,2,22 (10.0,2,22) 56(84) bytes of data. 64 bytes from 10.0,2,22: icmp_seq=1 ttl=63 time=0.126 ms 64 bytes from 10.0,2,22: icmp_seq=2 ttl=63 time=0.165 ms 64 bytes from 10.0,2,22: icmp_seq=3 ttl=63 time=0.170 ms 64 bytes from 10.0,2,22: icmp_seq=4 ttl=63 time=0.173 ms 64 bytes from 10.0,2,22: icmp_seq=5 ttl=63 time=0.163 ms ^C --- 10.0,2,22 ping statistics --- 5 packets transmitted, 5 received, 0% packet loss, time 4081ms rtt min/avg/max/mdev = 0.126/0.169/0.173/0.020 ms root@ruan-VirtualBox:/mnt/08-router# ping 10.0,3,33 PING 10.0,3,33 (10.0,3,33) 56(84) bytes of data. 64 bytes from 10.0,3,33: icmp_seq=1 ttl=63 time=0.123 ms 64 bytes from 10.0,3,33: icmp_seq=2 ttl=63 time=0.125 ms 64 bytes from 10.0,3,33: icmp_seq=3 ttl=63 time=0.161 ms 64 bytes from 10.0,3,33: icmp_seq=4 ttl=63 time=0.159 ms 64 bytes from 10.0,3,33: icmp_seq=5 ttl=63 time=0.122 ms ^C --- 10.0,3,33 ping statistics --- 5 packets transmitted, 5 received, 0% packet loss, time 4088ms rtt min/avg/max/mdev = 0.122/0.138/0.161/0.018 ms root@ruan-VirtualBox:/mnt/08-router# </pre>	<pre> DEBUG: finded: 1 ,the correspondding mac is 194 211 117 222 82 19 DEBUG: handling ip packet, dad ip 10.0,1,11, sad 10.0,3,33 ERROR: the ttl is 64 DEBUG: sending IP (dst:10.0,1,11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: handling ip packet, dad ip 10.0,3,33, sad 10.0,1,11 ERROR: the ttl is 64 DEBUG: sending IP (dst:10.0,3,33) packet. DEBUG: finded: 1 ,the correspondding mac is 194 211 117 222 82 19 DEBUG: handling ip packet, dad ip 10.0,1,11, sad 10.0,3,33 ERROR: the ttl is 64 DEBUG: sending IP (dst:10.0,1,11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: handling ip packet, dad ip 10.0,3,33, sad 10.0,1,11 ERROR: the ttl is 64 DEBUG: sending IP (dst:10.0,3,33) packet. DEBUG: finded: 1 ,the correspondding mac is 194 211 117 222 82 19 DEBUG: handling ip packet, dad ip 10.0,1,11, sad 10.0,3,33 ERROR: the ttl is 64 DEBUG: sending IP (dst:10.0,1,11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: arp packet recived DEBUG: it is echo to a000301 </pre>

"Node: h1"	"Node: r1"
<pre> root@ruan-VirtualBox:/mnt/08-router# ping 10.0,1,1 PING 10.0,1,1 (10.0,1,1) 56(84) bytes of data. 64 bytes from 10.0,1,1: icmp_seq=1 ttl=63 time=0.107 ms 64 bytes from 10.0,1,1: icmp_seq=2 ttl=63 time=0.260 ms 64 bytes from 10.0,1,1: icmp_seq=3 ttl=63 time=0.119 ms ^C --- 10.0,1,1 ping statistics --- 3 packets transmitted, 3 received, 0% packet loss, time 2048ms rtt min/avg/max/mdev = 0.107/0.162/0.260/0.069 ms root@ruan-VirtualBox:/mnt/08-router# ping 10.0,2,22 PING 10.0,2,22 (10.0,2,22) 56(84) bytes of data. 64 bytes from 10.0,2,22: icmp_seq=1 ttl=63 time=0.126 ms 64 bytes from 10.0,2,22: icmp_seq=2 ttl=63 time=0.165 ms 64 bytes from 10.0,2,22: icmp_seq=3 ttl=63 time=0.170 ms 64 bytes from 10.0,2,22: icmp_seq=4 ttl=63 time=0.173 ms 64 bytes from 10.0,2,22: icmp_seq=5 ttl=63 time=0.163 ms ^C --- 10.0,2,22 ping statistics --- 5 packets transmitted, 5 received, 0% packet loss, time 4081ms rtt min/avg/max/mdev = 0.126/0.169/0.173/0.020 ms root@ruan-VirtualBox:/mnt/08-router# </pre>	<pre> DEBUG: finded: 1 ,the correspondding mac is 182 112 26 127 35 64 DEBUG: handling ip packet, dad ip 10.0,1,11, sad 10.0,2,22 ERROR: the ttl is 64 DEBUG: sending IP (dst:10.0,1,11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: handling ip packet, dad ip 10.0,2,22, sad 10.0,1,11 ERROR: the ttl is 64 DEBUG: sending IP (dst:10.0,2,22) packet. DEBUG: finded: 1 ,the correspondding mac is 182 112 26 127 35 64 DEBUG: handling ip packet, dad ip 10.0,1,11, sad 10.0,2,22 ERROR: the ttl is 64 DEBUG: sending IP (dst:10.0,1,11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: handling ip packet, dad ip 10.0,2,22, sad 10.0,1,11 ERROR: the ttl is 64 DEBUG: sending IP (dst:10.0,2,22) packet. DEBUG: finded: 1 ,the correspondding mac is 182 112 26 127 35 64 DEBUG: handling ip packet, dad ip 10.0,1,11, sad 10.0,2,22 ERROR: the ttl is 64 DEBUG: sending IP (dst:10.0,1,11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: arp packet recived DEBUG: it is echo to a000201 </pre>

成功

Ping unreachable host

"Node: h1"	"Node: r1"
<pre> 5 packets transmitted, 5 received, 0% packet loss, time 4081ms rtt min/avg/max/mdev = 0.126/0.169/0.173/0.020 ms root@ruan-VirtualBox:/mnt/08-router# ping 10.0,3,33 PING 10.0,3,33 (10.0,3,33) 56(84) bytes of data. 64 bytes from 10.0,3,33: icmp_seq=1 ttl=63 time=0.123 ms 64 bytes from 10.0,3,33: icmp_seq=2 ttl=63 time=0.125 ms 64 bytes from 10.0,3,33: icmp_seq=3 ttl=63 time=0.161 ms 64 bytes from 10.0,3,33: icmp_seq=4 ttl=63 time=0.159 ms 64 bytes from 10.0,3,33: icmp_seq=5 ttl=63 time=0.122 ms ^C --- 10.0,3,33 ping statistics --- 5 packets transmitted, 5 received, 0% packet loss, time 4088ms rtt min/avg/max/mdev = 0.122/0.138/0.161/0.018 ms root@ruan-VirtualBox:/mnt/08-router# ping 10.0,3,22 PING 10.0,3,22 (10.0,3,22) 56(84) bytes of data. From 10.0,3,22 icmp_seq=1 Destination Host Unreachable From 10.0,3,22 icmp_seq=2 Destination Host Unreachable From 10.0,3,22 icmp_seq=3 Destination Host Unreachable From 10.0,3,22 icmp_seq=4 Destination Host Unreachable ^C --- 10.0,3,22 ping statistics --- 5 packets transmitted, 0 received, +4 errors, 100% packet loss, time 4073ms pipe 4 root@ruan-VirtualBox:/mnt/08-router# </pre>	<pre> DEBUG: iface matched DEBUG: append and sent arp request, dest ip : a000316 DEBUG: sending IP (dst:10.0,1,11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: sending IP (dst:10.0,1,11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: sending IP (dst:10.0,1,11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: sending IP (dst:10.0,1,11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: sending IP (dst:10.0,1,11) packet. DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83 DEBUG: req for ip 10.0,3,22 is going to be deleted DEBUG: handling ip packet, dad ip 10.0,3,22, sad 10.0,1,11 ERROR: the ttl is 64 DEBUG: sending IP (dst:10.0,3,22) packet. DEBUG: finded: 0 ,the correspondding mac is 64 119 96 0 0 0 DEBUG: ip packet try pending a000316 DEBUG: new ip packet pending DEBUG: new req ip is a000316 DEBUG: append and sent arp request, dest ip : a000316 DEBUG: arp packet recived DEBUG: it is echo to a000101 DEBUG: sent arp request, dest ip : a000316 , retries 2 DEBUG: sent arp request, dest ip : a000316 , retries 3 </pre>

成功

Ping unreachable net

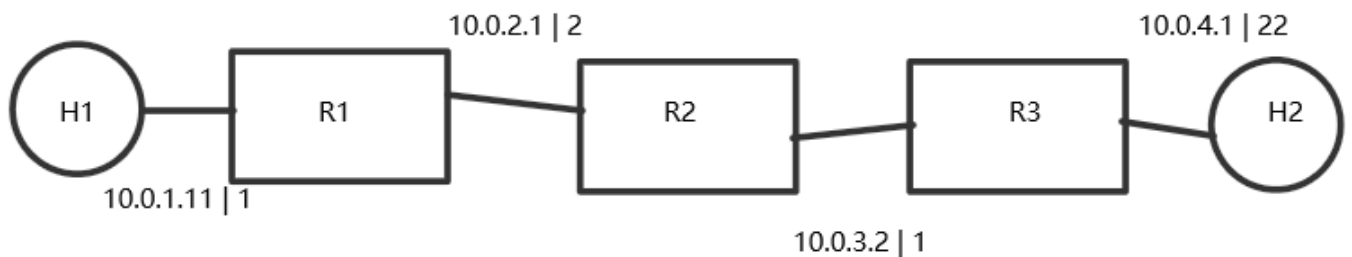
```
"Node: h1"
5 packets transmitted, 5 received, 0% packet loss, time 4088ms
rtt min/avg/max/mdev = 0.122/0.138/0.161/0.018 ms
root@ruan-VirtualBox:/mnt/08-router# ping 10.0.3.22
PING 10.0.3.22 (10.0.3.22) 56(84) bytes of data.
From 10.0.3.22 icmp_seq=1 Destination Host Unreachable
From 10.0.3.22 icmp_seq=2 Destination Host Unreachable
From 10.0.3.22 icmp_seq=3 Destination Host Unreachable
From 10.0.3.22 icmp_seq=4 Destination Host Unreachable
^C
--- 10.0.3.22 ping statistics ---
5 packets transmitted, 0 received, +4 errors, 100% packet loss, time 4073ms
pipe 4
root@ruan-VirtualBox:/mnt/08-router# ping 10.0.4.22
PING 10.0.4.22 (10.0.4.22) 56(84) bytes of data.
From 10.0.4.22 icmp_seq=1 Destination Protocol Unreachable
From 10.0.4.22 icmp_seq=2 Destination Protocol Unreachable
From 10.0.4.22 icmp_seq=3 Destination Protocol Unreachable
From 10.0.4.22 icmp_seq=4 Destination Protocol Unreachable
From 10.0.4.22 icmp_seq=5 Destination Protocol Unreachable
^C
--- 10.0.4.22 ping statistics ---
5 packets transmitted, 0 received, +5 errors, 100% packet loss, time 4097ms
root@ruan-VirtualBox:/mnt/08-router#

"Node: r1"
DEBUG: req for ip 10.0.3.22 is going to be deleted
DEBUG: arp cache (ip) 10.0.1.11 is out of time and swept.
DEBUG: handling ip packet, dad ip 10.0.4.22, sad 10.0.1.11
ERROR: Could not find forwarding rule for IP (dst:10.0.4.22) packet.
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83
DEBUG: handling ip packet, dad ip 10.0.4.22, sad 10.0.1.11
ERROR: Could not find forwarding rule for IP (dst:10.0.4.22) packet.
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83
DEBUG: handling ip packet, dad ip 10.0.4.22, sad 10.0.1.11
ERROR: Could not find forwarding rule for IP (dst:10.0.4.22) packet.
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83
DEBUG: handling ip packet, dad ip 10.0.4.22, sad 10.0.1.11
ERROR: Could not find forwarding rule for IP (dst:10.0.4.22) packet.
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: finded: 1 ,the correspondding mac is 210 95 125 26 155 83
```

成功

运行新的拓扑脚本

拓扑关系见下图



运行脚本

```
ruan@ruan-VirtualBox:/mnt/08-router$ sudo python 3router_topo.py
[sudo] ruan 的密码:
mininet> xterm r1 r2 r3 h1
```

在各端口配置好转发发表后，直接用 h1 ping r1，得如下结果

```
"Node: r2"
DEBUG: new req ip is a000301
DEBUG: append and sent arp request, dest ip : a000301
DEBUG: arp packet received
DEBUG: it is reply from a000301, op is 2, arp->tpa is a000302, iface->ip is a000302
DEBUG: finded: 1 ,the correspondding mac is 245 147 121 60 185 115
DEBUG: pending packet has been sent, dst ip 10.0.3.1
DEBUG: req for ip 10.0.3.1 is going to be deleted
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.22
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: finded: 0 ,the correspondding mac is 64 119 96 0 0 0
DEBUG: ip packet try pending a000201
DEBUG: new ip packet pending
DEBUG: new req ip is a000201
DEBUG: append and sent arp request, dest ip : a000201
DEBUG: arp packet received
DEBUG: it is reply from a000201, op is 2, arp->tpa is a000202, iface->ip is a000202
DEBUG: finded: 1 ,the correspondding mac is 10 173 209 85 17 6
DEBUG: pending packet has been sent, dst ip 10.0.2.1
DEBUG: req for ip 10.0.2.1 is going to be deleted
DEBUG: arp cache (ip) 10.0.2.1 is out of time and swept.

"Node: r1"
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: finded: 1 ,the correspondding mac is 182 104 43 89 212 95
DEBUG: handling ip packet, dad ip 10.0.1.1, sad 10.0.1.11
DEBUG: ICMP received, type : 8, echo received
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: finded: 1 ,the correspondding mac is 182 104 43 89 212 95
DEBUG: handling ip packet, dad ip 10.0.1.1, sad 10.0.1.11
DEBUG: ICMP received, type : 8, echo received
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: finded: 1 ,the correspondding mac is 182 104 43 89 212 95
DEBUG: handling ip packet, dad ip 10.0.1.1, sad 10.0.1.11
DEBUG: ICMP received, type : 8, echo received
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: finded: 1 ,the correspondding mac is 182 104 43 89 212 95

"Node: r3"
DEBUG: finded: 1 ,the correspondding mac is 254 215 149 113 4 245
DEBUG: arp packet received
DEBUG: it is echo to a000301
DEBUG: handling ip packet, dad ip 10.0.4.22, sad 10.0.1.11
DEBUG: sending IP (dst:10.0.4.22) packet.
DEBUG: finded: 1 ,the correspondding mac is 62 32 0 60 63 86
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.22
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: finded: 1 ,the correspondding mac is 254 215 149 113 4 245
DEBUG: arp packet received
DEBUG: it is echo to a000301
DEBUG: handling ip packet, dad ip 10.0.4.22, sad 10.0.1.11
DEBUG: sending IP (dst:10.0.4.22) packet.
DEBUG: finded: 1 ,the correspondding mac is 62 32 0 60 63 86
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.22
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: finded: 1 ,the correspondding mac is 254 215 149 113 4 245
DEBUG: arp packet received
DEBUG: it is echo to a000401
DEBUG: arp cache (ip) 10.0.3.2 is out of time and swept.
DEBUG: arp cache (ip) 10.0.4.22 is out of time and swept.

"Node: h1"
root@ruan-VirtualBox:/mnt/08-router# ping 10.0.4.22
fPING 10.0.4.22 (10.0.4.22) 56(84) bytes of data.
f64 bytes from 10.0.4.22: icmp_seq=1 ttl=61 time=0.643 ms
f64 bytes from 10.0.4.22: icmp_seq=2 ttl=61 time=1.38 ms
f64 bytes from 10.0.4.22: icmp_seq=3 ttl=61 time=1.22 ms
f64 bytes from 10.0.4.22: icmp_seq=4 ttl=61 time=1.16 ms
f64 bytes from 10.0.4.22: icmp_seq=5 ttl=61 time=0.459 ms
f64 bytes from 10.0.4.22: icmp_seq=6 ttl=61 time=1.23 ms
^C
r--- 10.0.4.22 ping statistics ---
f6 packets transmitted, 6 received, 0% packet loss, time 5041ms
frrt min/avg/max/mdev = 0.459/1.018/1.384/0.340 ms
froot@ruan-VirtualBox:/mnt/08-router# ping 10.0.1.1
fPING 10.0.1.1 (10.0.1.1) 56(84) bytes of data.
f64 bytes from 10.0.1.1: icmp_seq=1 ttl=63 time=0.081 ms
f64 bytes from 10.0.1.1: icmp_seq=2 ttl=63 time=0.129 ms
f64 bytes from 10.0.1.1: icmp_seq=3 ttl=63 time=0.133 ms
f64 bytes from 10.0.1.1: icmp_seq=4 ttl=63 time=0.128 ms
f64 bytes from 10.0.1.1: icmp_seq=5 ttl=63 time=0.129 ms
r^C
r--- 10.0.1.1 ping statistics ---
5 packets transmitted, 5 received, 0% packet loss, time 4089ms
rtrt min/avg/max/mdev = 0.081/0.120/0.133/0.019 ms
root@ruan-VirtualBox:/mnt/08-router#
```

用 h1 ping h2，得如下结果，可以证明各个端口之间正常连通。

```

"Node: r2"
DEBUG: ip packet try pending a000301
DEBUG: new ip packet pending
DEBUG: new req ip is a000301
DEBUG: append and sent arp request, dest ip : a000301
DEBUG: arp packet received
DEBUG: it is reply from a000301, op is 2, arp->tpa is a000302, iface->ip is a000302
DEBUG: found: 1 ,the corresponding mac is 246 147 121 60 185 115
DEBUG: pending packet has been sent, dst ip10.0.3.1
DEBUG: req for ip 10.0.3.1 is going to be deleted
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.22
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 0 ,the corresponding mac is 64 119 96 0 0 0
DEBUG: ip packet try pending a000201
DEBUG: new ip packet pending
DEBUG: new req ip is a000201
DEBUG: append and sent arp request, dest ip : a000201
DEBUG: arp packet received
DEBUG: it is reply from a000201, op is 2, arp->tpa is a000202, iface->ip is a000202
DEBUG: found: 1 ,the corresponding mac is 10 173 209 85 17 6
DEBUG: pending packet has been sent, dst ip10.0.2.1
DEBUG: req for ip 10.0.2.1 is going to be deleted
[]

"Node: r1"
DEBUG: sending IP (dst:10.0.4.22) packet.
DEBUG: found: 1 ,the corresponding mac is 174 113 238 65 61 138
DEBUG: arp packet received
DEBUG: it is echo to a000201
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.22
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 182 104 43 89 212 95
DEBUG: handling ip packet, dad ip 10.0.4.22, sad 10.0.1.11
DEBUG: sending IP (dst:10.0.4.22) packet.
DEBUG: found: 1 ,the corresponding mac is 174 113 238 65 61 138
DEBUG: arp packet received
DEBUG: it is echo to a000201
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.22
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 182 104 43 89 212 95
DEBUG: handling ip packet, dad ip 10.0.4.22, sad 10.0.1.11
DEBUG: sending IP (dst:10.0.4.22) packet.
DEBUG: found: 1 ,the corresponding mac is 174 113 238 65 61 138
DEBUG: arp packet received
DEBUG: it is echo to a000201
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.22
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 182 104 43 89 212 95
[]

"Node: r3"
DEBUG: sending IP (dst:10.0.4.22) packet.
DEBUG: found: 1 ,the corresponding mac is 62 32 0 60 63 86
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.22
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 254 215 149 113 4 245
DEBUG: arp packet received
DEBUG: it is echo to a000301
DEBUG: handling ip packet, dad ip 10.0.4.22, sad 10.0.1.11
DEBUG: sending IP (dst:10.0.4.22) packet.
DEBUG: found: 1 ,the corresponding mac is 62 32 0 60 63 86
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.22
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 254 215 149 113 4 245
DEBUG: arp packet received
DEBUG: it is echo to a000301
DEBUG: handling ip packet, dad ip 10.0.4.22, sad 10.0.1.11
DEBUG: sending IP (dst:10.0.4.22) packet.
DEBUG: found: 1 ,the corresponding mac is 62 32 0 60 63 86
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.22
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 254 215 149 113 4 245
DEBUG: arp packet received
DEBUG: it is echo to a000401
[]

"Node: h1"
root@ruan-VirtualBox:/mnt/08-router# ping 10.0.4.22
PING 10.0.4.22 (10.0.4.22) 56(84) bytes of data.
64 bytes from 10.0.4.22: icmp_seq=1 ttl=61 time=0.643 ms
64 bytes from 10.0.4.22: icmp_seq=2 ttl=61 time=1.38 ms
64 bytes from 10.0.4.22: icmp_seq=3 ttl=61 time=1.22 ms
64 bytes from 10.0.4.22: icmp_seq=4 ttl=61 time=1.16 ms
64 bytes from 10.0.4.22: icmp_seq=5 ttl=61 time=0.459 ms
64 bytes from 10.0.4.22: icmp_seq=6 ttl=61 time=1.23 ms
^C
--- 10.0.4.22 ping statistics ---
6 packets transmitted, 6 received, 0% packet loss, time 5041ms
rtt min/avg/max/ndev = 0.469/1.018/1.384/0.340 ms
root@ruan-VirtualBox:/mnt/08-router#
```

Ping unreachable host/net 也得到了对应的正确回应

```

"Node: r2"
DEBUG: req for ip 10.0.2.1 is going to be deleted
DEBUG: arp packet received
DEBUG: it is reply from a000201, op is 2, arp->tpa is a000202, iface->ip is a000202
DEBUG: arp packet received
DEBUG: it is reply from a000201, op is 2, arp->tpa is a000202, iface->ip is a000202
DEBUG: arp packet received
DEBUG: it is reply from a000201, op is 2, arp->tpa is a000202, iface->ip is a000202
DEBUG: handling ip packet, dad ip 10.0.4.33, sad 10.0.1.11
DEBUG: sending IP (dst:10.0.4.33) packet.
DEBUG: found: 0 ,the corresponding mac is 64 119 96 0 0 0
DEBUG: ip packet try pending a000301
DEBUG: new ip packet pending
DEBUG: new req ip is a000301
DEBUG: append and sent arp request, dest ip : a000301
DEBUG: arp packet received
DEBUG: it is reply from a000301, op is 2, arp->tpa is a000302, iface->ip is a000302
DEBUG: found: 1 ,the corresponding mac is 246 147 121 60 185 115
DEBUG: pending packet has been sent, dst ip10.0.3.1
DEBUG: req for ip 10.0.3.1 is going to be deleted
[]

"Node: r1"
DEBUG: arp packet received
DEBUG: it is echo to a000201
DEBUG: arp packet received
DEBUG: it is echo to a000201
DEBUG: arp packet received
DEBUG: it is echo to a000201
DEBUG: arp packet received
DEBUG: it is echo to a000201
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.33
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 182 104 43 89 212 95
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.33
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 182 104 43 89 212 95
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.33
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 182 104 43 89 212 95
DEBUG: handling ip packet, dad ip 10.0.1.11, sad 10.0.4.33
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 182 104 43 89 212 95
DEBUG: handling ip packet, dad ip 10.0.4.33, sad 10.0.1.11
DEBUG: sending IP (dst:10.0.4.33) packet.
DEBUG: found: 1 ,the corresponding mac is 174 113 238 65 61 138
[]

"Node: r3"
DEBUG: append and sent arp request, dest ip : a000421
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 254 215 149 113 4 245
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 254 215 149 113 4 245
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 254 215 149 113 4 245
DEBUG: sending IP (dst:10.0.1.11) packet.
DEBUG: found: 1 ,the corresponding mac is 254 215 149 113 4 245
DEBUG: req for ip 10.0.4.33 is going to be deleted
DEBUG: arp packet received
DEBUG: it is echo to a000301
DEBUG: handling ip packet, dad ip 10.0.4.33, sad 10.0.1.11
DEBUG: sending IP (dst:10.0.4.33) packet.
DEBUG: found: 0 ,the corresponding mac is 64 119 96 0 0 0
DEBUG: ip packet try pending a000421
DEBUG: new ip packet pending
DEBUG: new req ip is a000421
DEBUG: append and sent arp request, dest ip : a000421
DEBUG: sent arp request, dest ip : a000421 , retries 2
DEBUG: sent arp request, dest ip : a000421 , retries 3
DEBUG: sent arp request, dest ip : a000421 , retries 4
DEBUG: sent arp request, dest ip : a000421 , retries 5
[]

"Node: h1"
r64 bytes from 10.0.1.1: icmp_seq=1 ttl=63 time=0.081 ms
r64 bytes from 10.0.1.1: icmp_seq=2 ttl=63 time=0.129 ms
r64 bytes from 10.0.1.1: icmp_seq=3 ttl=63 time=0.133 ms
r64 bytes from 10.0.1.1: icmp_seq=4 ttl=63 time=0.128 ms
r64 bytes from 10.0.1.1: icmp_seq=5 ttl=63 time=0.129 ms
^C
--- 10.0.1.1 ping statistics ---
5 packets transmitted, 5 received, 0% packet loss, time 4089ms
rtt min/avg/max/ndev = 0.081/0.129/0.133/0.019 ms
root@ruan-VirtualBox:/mnt/08-router# ping 10.0.4.33
PING 10.0.4.33 (10.0.4.33) 56(84) bytes of data.
rFrom 10.0.4.33 icmp_seq=1 Destination Host Unreachable
rFrom 10.0.4.33 icmp_seq=2 Destination Host Unreachable
rFrom 10.0.4.33 icmp_seq=3 Destination Host Unreachable
rFrom 10.0.4.33 icmp_seq=4 Destination Host Unreachable
rFrom 10.0.4.33 icmp_seq=5 Destination Host Unreachable
rFrom 10.0.4.33 icmp_seq=6 Destination Host Unreachable
rFrom 10.0.4.33 icmp_seq=7 Destination Host Unreachable
rFrom 10.0.4.33 icmp_seq=8 Destination Host Unreachable
^C
--- 10.0.4.33 ping statistics ---
9 packets transmitted, 0 received, +0 errors, 100% packet loss, time 8119ms
pipe 4
root@ruan-VirtualBox:/mnt/08-router#
```


一天调试，这样长度的调试时间其实也很能说明我之前对实验的架构掌握得不够好，对各个时候应该做什么并没有了然于心，导致走了不少弯路；另一个问题是网络序和本地序的转化，确实是太容易忘记了，而且在初期时，也不大确定各个函数输入的东西究竟是怎样的，导致了不少问题，另外这个确实是很容易出错，不管是类型还是是否需要转换，而且往往影响挺大，好在有 **wireshark** 的帮助，调试的压力小了不少。