

## Report 4 — September 26

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## 第一部分 Hub

### 4.1 实验内容

1. 实现节点广播的 broadcast\_packet 函数
2. 验证广播网络能够正常运行(从一个端节点 ping 另一个端节点)
3. 验证广播网络的效率(分两种场景在 three\_nodes\_bw.py 进行 iperf 测量, h1 同时向 h2 和 h3 测量与 h2 和 h3 同时向 h1 测量)
4. 自己动手构建环形拓扑, 验证该拓扑下节点广播会产生数据包环路

### 4.2 实验过程

#### 4.2.1 实现节点广播的 broadcast\_packet 函数

```
// the memory of ``packet`` will be free'd in handle_packet().
void broadcast_packet(iface_info_t *iface, const char *packet, int len)
{
    // TODO: broadcast packet
    // fprintf(stdout, "TODO: broadcast packet.\n");
    iface_info_t *iface_entry;
    list_for_each_entry(iface_entry, &instance->iface_list, list) {
        if (iface_entry->fd != iface->fd)
            iface_send_packet(iface_entry, packet, len);
    }
}
```

在这个函数里,我们遍历所有的接口,如果遍历到的接口不是发送所收到网络包的接口,就调用 `iface_send_packet` 函数广播发送数据包。

#### 4.2.2 验证广播网络能够正常运行

拓扑图如下:

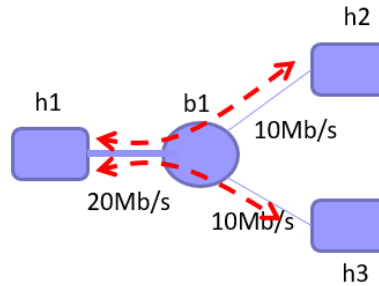


图 4.1. 广播网络拓扑图

h1, h2, h3 分别是三个节点, 它们如果能够相互 ping 通, 说明广播网络能够正常运行。这里 h1 的 IP 地址是 10.0.0.1, h2 的 IP 地址是 10.0.0.2, h3 的 IP 地址是 10.0.0.3。

```
"Node: h1"
root@zhangjiawei-VirtualBox: /home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# ping 10.0.0.2 -c 4
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data:
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=0.091 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.108 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.085 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.058 ms
--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3085ms
rtt min/avg/max/mdev = 0.058/0.085/0.108/0.018 ms
root@zhangjiawei-VirtualBox: /home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# ping 10.0.0.3 -c 4
PING 10.0.0.3 (10.0.0.3) 56(84) bytes of data:
64 bytes from 10.0.0.3: icmp_seq=1 ttl=64 time=0.338 ms
64 bytes from 10.0.0.3: icmp_seq=2 ttl=64 time=0.059 ms
64 bytes from 10.0.0.3: icmp_seq=3 ttl=64 time=0.073 ms
64 bytes from 10.0.0.3: icmp_seq=4 ttl=64 time=0.079 ms
--- 10.0.0.3 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3071ms
rtt min/avg/max/mdev = 0.059/0.137/0.338/0.116 ms
```

图 4.2. h1 ping h2, h3

```
"Node: h2"
root@zhangjiawei-VirtualBox: /home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# ping 10.0.0.1 -c 4
PING 10.0.0.1 (10.0.0.1) 56(84) bytes of data:
64 bytes from 10.0.0.1: icmp_seq=1 ttl=64 time=0.120 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.109 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.086 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.084 ms
--- 10.0.0.1 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3052ms
rtt min/avg/max/mdev = 0.084/0.099/0.120/0.015 ms
root@zhangjiawei-VirtualBox: /home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# ping 10.0.0.3 -c 4
PING 10.0.0.3 (10.0.0.3) 56(84) bytes of data:
64 bytes from 10.0.0.3: icmp_seq=1 ttl=64 time=0.077 ms
64 bytes from 10.0.0.3: icmp_seq=2 ttl=64 time=0.074 ms
64 bytes from 10.0.0.3: icmp_seq=3 ttl=64 time=0.071 ms
64 bytes from 10.0.0.3: icmp_seq=4 ttl=64 time=0.069 ms
--- 10.0.0.3 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3109ms
rtt min/avg/max/mdev = 0.069/0.072/0.077/0.003 ms
```

图 4.3. h2 ping h1, h3

```
"Node: h3"
root@zhangjiawei-VirtualBox: /home/zhangjiawei/EE3/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# ping 10.0.0.1 -c 4
PING 10.0.0.1 (10.0.0.1) 56(84) bytes of data.
64 bytes from 10.0.0.1: icmp_seq=1 ttl=64 time=0.072 ms
64 bytes from 10.0.0.1: icmp_seq=2 ttl=64 time=0.063 ms
64 bytes from 10.0.0.1: icmp_seq=3 ttl=64 time=0.073 ms
64 bytes from 10.0.0.1: icmp_seq=4 ttl=64 time=0.105 ms

--- 10.0.0.1 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3109ms
rtt min/avg/max/mdev = 0.063/0.078/0.105/0.015 ms
root@zhangjiawei-VirtualBox: /home/zhangjiawei/EE3/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# ping 10.0.0.2 -c 4
PING 10.0.0.2 (10.0.0.2) 56(84) bytes of data.
64 bytes from 10.0.0.2: icmp_seq=1 ttl=64 time=0.200 ms
64 bytes from 10.0.0.2: icmp_seq=2 ttl=64 time=0.067 ms
64 bytes from 10.0.0.2: icmp_seq=3 ttl=64 time=0.060 ms
64 bytes from 10.0.0.2: icmp_seq=4 ttl=64 time=0.071 ms

--- 10.0.0.2 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 3068ms
rtt min/avg/max/mdev = 0.060/0.099/0.200/0.058 ms
```

图 4.4. h3 ping h1, h2

可以看出, h1, h2, h3 三个节点确实能够相互 ping 通, 这表明广播网络能够正常运行。

### 4.2.3 验证广播网络的效率

```
root@zhangjiawei-VirtualBox: /home/zhangjiawei/EE3/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# iperf client
iperf: ignoring extra argument -- client
Usage: iperf [-s|-c host] [options]
Try 'iperf --help' for more information.
root@zhangjiawei-VirtualBox: /home/zhangjiawei/EE3/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# iperf -c 10.0.0.2 -t 30

-----
Client connecting to 10.0.0.2, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 52960 connected with 10.0.0.2 port 5001 (icwnd/mss/irt
t=14/1448/114)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.2543 sec 7.38 MBytes 1.98 Mbits/sec
root@zhangjiawei-VirtualBox: /home/zhangjiawei/EE3/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# iperf -c 10.0.0.2 -t 30

-----
Client connecting to 10.0.0.2, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 41452 connected with 10.0.0.2 port 5001 (icwnd/mss/irt
t=14/1448/76)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.2563 sec 15.5 MBytes 4.16 Mbits/sec
root@zhangjiawei-VirtualBox: /home/zhangjiawei/EE3/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# iperf -c 10.0.0.2 -t 30

-----
Client connecting to 10.0.0.2, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 45332 connected with 10.0.0.2 port 5001 (icwnd/mss/irt
t=14/1448/163)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.3972 sec 10.5 MBytes 2.81 Mbits/sec
```

图 4.5. h1 向 h2 测量

```
root@zhangjiawei-VirtualBox:/home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# iperf -c 10.0.0.3 -t 30
-----
Client connecting to 10.0.0.3, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 35204 connected with 10.0.0.3 port 5001 (icwnd/mss/irt
t=14/1448/48611)
[ ID] Interval      Transfer    Bandwidth
[ 1] 0.0000-30.6967 sec 27.3 MBytes 7.45 Mbits/sec
root@zhangjiawei-VirtualBox:/home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# iperf -c 10.0.0.3 -t 30
-----
Client connecting to 10.0.0.3, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 46096 connected with 10.0.0.3 port 5001 (icwnd/mss/irt
t=14/1448/79442)
[ ID] Interval      Transfer    Bandwidth
[ 1] 0.0000-30.7181 sec 19.5 MBytes 5.33 Mbits/sec
root@zhangjiawei-VirtualBox:/home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# iperf -c 10.0.0.3 -t 30
-----
Client connecting to 10.0.0.3, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 43652 connected with 10.0.0.3 port 5001 (icwnd/mss/irt
t=14/1448/85787)
[ ID] Interval      Transfer    Bandwidth
[ 1] 0.0000-30.6256 sec 24.6 MBytes 6.75 Mbits/sec
```

图 4.6. h1 向 h3 测量

可以看出, h1 向 h2 测量和 h1 向 h3 测量的实际速率差异较大, 而且都远未达到理论带宽值。这是因为 h1 发出的数据都会广播至 h2 和 h3, 实际来看, h1 发送给 h2 的数据会占据 b1 到 h3 的带宽, 而 h1 发送给 h3 的数据也会占据 b1 到 h2 的带宽, 所以实际速率必定达不到理论带宽值。而对于实际速率的差异, 我的解释是, 因为我们在 xterm 终端中并不能保证两个 iperf 进程同时启动, 所以会造成 TCP 窗口大小的差异, 从而导致实际速率的差异。可以预测出的是, 在接下来的 h2 向 h1 测量和 h3 向 h1 测量中, 因为路径不是竞争关系, 所以速率应该会更接近理论带宽值。事实果然如此:

```
"Node: h2"
root@zhangjiawei-VirtualBox:/home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# iperf -c 10.0.0.1 -t 30
-----
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.2 port 39354 connected with 10.0.0.1 port 5001 (icwnd/mss/irt
t=14/1448/246)
[ ID] Interval      Transfer    Bandwidth
[ 1] 0.0000-31.0295 sec 33.5 MBytes 9.06 Mbits/sec
```

图 4.7. h2 向 h1 测量

```

"Node: h3"
root@zhangjiawei-VirtualBox: /home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/hub# iperf -c 10.0.0.1 -t 30
-----
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.3 port 59558 connected with 10.0.0.1 port 5001 (icwnd/mss/irt
t=14/1448/31931)
[ ID] Interval      Transfer    Bandwidth
[ 1] 0.0000-30.7951 sec 33.1 MBytes 9.02 Mbits/sec

```

图 4.8. h3 向 h1 测量

#### 4.2.4 构建环形拓扑, 验证数据包环路

拓扑图如下:

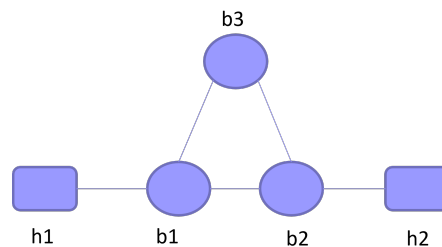


图 4.9. 环形拓扑图

此时需要更改 three\_nodes\_bw.py 文件, 重新配置拓扑:

```

class BroadcastTopo(Topo):
    def build(self):
        h1 = self.addHost('h1')
        h2 = self.addHost('h2')
        b1 = self.addHost('b1')
        b2 = self.addHost('b2')
        b3 = self.addHost('b3')

        self.addLink(h1, b1, bw=10)
        self.addLink(h2, b2, bw=10)
        self.addLink(b1, b2, bw=10)
        self.addLink(b2, b3, bw=10)
        self.addLink(b3, b1, bw=10)

```

使用 h1 向 h2 广播 ping 消息, 经 wireshark 抓包, 可以看到数据包在环路中不断传递:

No.	Time	Source	Destination	Protocol	Length	Info
4070...	26.599318531	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.599396930	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.599475200	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.599553726	2a:d2:14:e9:44:7d	72:75:7e:fe:90:74	ARP	42	10.0.0.1 is at 2a:d2:14:e9:44:7d
4070...	26.599587619	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.599665702	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.599744241	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.599822622	2a:d2:14:e9:44:7d	72:75:7e:fe:90:74	ARP	42	10.0.0.1 is at 2a:d2:14:e9:44:7d
4070...	26.599856163	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.599934259	2a:d2:14:e9:44:7d	72:75:7e:fe:90:74	ARP	42	10.0.0.1 is at 2a:d2:14:e9:44:7d
4070...	26.599968347	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600046493	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600124563	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600203348	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600277938	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600356105	2a:d2:14:e9:44:7d	72:75:7e:fe:90:74	ARP	42	10.0.0.1 is at 2a:d2:14:e9:44:7d
4070...	26.600388530	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600478161	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600553090	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600627009	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600708083	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600785838	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600862155	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.600939297	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.601018864	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.601096825	2a:d2:14:e9:44:7d	72:75:7e:fe:90:74	ARP	42	10.0.0.1 is at 2a:d2:14:e9:44:7d
4070...	26.601132956	10.0.0.2	10.0.0.1	ICMP	98	Echo (ping) reply id=0x3cf8, seq=1/256, ttl=64
4070...	26.601431655	2a:d2:14:e9:44:7d	72:75:7e:fe:90:74	ARP	42	10.0.0.1 is at 2a:d2:14:e9:44:7d

图 4.10. 数据包环路

可以看到, h1 一直收到来自 h2 的相同消息, 这说明数据包在环路中不断被广播, 根本在于拓扑网络出现了环路, 使得数据包不断被循环转发。

### 4.3 实验总结

本次实验主要是关于广播网络的实验, 我实现了节点广播的函数, 验证了广播网络的正常运行和效率, 以及验证了环形拓扑下数据包环路的现象。实验过程中, 我对广播网络的工作原理有了更深入的了解, 广播网络会占据更多的网络资源, 效率低下。我也对环形拓扑下数据包环路的现象有了直观的认识, 这是广播网络的一个关键弱点, 一旦出现环路, 数据包会不断被循环转发, 直到网络崩溃。于是, 为了避免这种情况以及提高效率, 新的转发机制亟待设计, 这就是马上就要进行实验的交换机网络。

## 第二部分 Switch

### 4.1 实验内容

1. 实现对数据结构 `mac_port_map` 的所有操作, 以及数据包的转发和广播操作

```
iface_info_t *lookup_port(u8 mac[ETH_ALEN]);  
void insert_mac_port(u8 mac[ETH_ALEN], iface_info_t *iface);  
int sweep_aged_mac_port_entry();  
void broadcast_packet(iface_info_t *iface, const char *packet, int len);  
void handle_packet(iface_info_t *iface, char *packet, int len);
```

2. 使用 `iperf` 和给定的拓扑进行实验, 对比交换机转发与集线器广播的性能

### 4.2 实验过程

#### 4.2.1 实现转发表的查询操作

```
// lookup the mac address in mac_port table  
iface_info_t *lookup_port(u8 mac[ETH_ALEN])  
{  
    // TODO: implement the lookup process here  
    // fprintf(stdout, "TODO: implement the lookup process here.\n");  
    int hash = (int)hash8((char *)mac, ETH_ALEN);  
    mac_port_entry_t *entry;  
    pthread_mutex_lock(&mac_port_map.lock);  
  
    list_for_each_entry(entry, &mac_port_map.hash_table[hash], list) {  
        if (memcmp(entry->mac, mac, ETH_ALEN) == 0) {  
            pthread_mutex_unlock(&mac_port_map.lock);  
            return entry->iface;  
        }  
    }  
  
    pthread_mutex_unlock(&mac_port_map.lock);  
    return NULL;  
}
```

在这个函数里, 我们首先计算出 `mac` 地址的哈希值, 然后遍历哈希表, 如果找到了对应的 `mac` 地址, 就返回对应的接口信息, 否则返回 `NULL`。函数中需要线程互斥锁是因为多个线程可能同时访问转发表(比如之后的老化操作)。

### 4.2.2 实现转发表的插入操作

---

```
// insert the mac -> iface mapping into mac_port table
void insert_mac_port(u8 mac[ETH_ALEN], iface_info_t *iface)
{
    // TODO: implement the insertion process here
    // fprintf(stdout, "TODO: implement the insertion process here.\n");
    int hash = (int)hash8((char *)mac, ETH_ALEN);
    mac_port_entry_t *entry;
    pthread_mutex_lock(&mac_port_map.lock);

    list_for_each_entry(entry, &mac_port_map.hash_table[hash], list) {
        if (memcmp(entry->mac, mac, ETH_ALEN) == 0) {
            entry->iface = iface;
            entry->visited = time(NULL);
            pthread_mutex_unlock(&mac_port_map.lock);
            return;
        }
    }

    mac_port_entry_t *nentry = (mac_port_entry_t *)malloc(sizeof(mac_port_entry_t));
    nentry->iface = iface;
    nentry->visited = time(NULL);
    for (int i = 0; i < ETH_ALEN; i++)
        nentry->mac[i] = mac[i];
    list_add_head(&nentry->list, &mac_port_map.hash_table[hash]);

    pthread_mutex_unlock(&mac_port_map.lock);
    return;
}
```

---

仍然计算出 mac 地址的哈希值, 然后遍历哈希表, 如果找到了对应的 mac 地址, 就更新对应的接口信息, 否则新建一个新的表项插入到哈希表中。这里需要注意的是, 每次插入新的表项时, 需要更新访问时间。同理, 函数中需要线程互斥锁, 因为多个线程可能同时访问转发表(比如之后的老化操作)。

### 4.2.3 实现转发表的老化操作

---

```
// sweeping mac_port table, remove the entry which has not been visited in the
// last 30 seconds.
int sweep_aged_mac_port_entry()
{
    // TODO: implement the sweeping process here
    // fprintf(stdout, "TODO: implement the sweeping process here.\n");
}
```

---



```
mac_port_entry_t *entry, *q;
int n = 0;
time_t now = time(NULL);
pthread_mutex_lock(&mac_port_map.lock);

for (int i = 0; i < HASH_8BITS; i++) {
    list_for_each_entry_safe(entry, q, &mac_port_map.hash_table[i], list) {
        if ((int)(now - entry->visited) > MAC_PORT_TIMEOUT) {
            list_delete_entry(&entry->list);
            free(entry);
            n++;
        }
    }
}

pthread_mutex_unlock(&mac_port_map.lock);
return n;
}
```

老化操作是删除那些访问时间超过 30 秒的表项,即扫描转发表,清理那些当前时间与上次访问时间之差大于 30 秒的表项。这里需要注意的是,老化操作是线程安全的,因为在老化操作时,可能有其他线程在访问转发表(比如插入操作)。

#### 4.2.4 实现数据包的广播操作

代码与实验一中的相同,这里不再赘述。

#### 4.2.5 实现数据包的处理

```
// handle packet
// 1. if the dest mac address is found in mac_port table, forward it; otherwise,
// broadcast it.
// 2. put the src mac -> iface mapping into mac hash table.
// 3. release the memory of ``packet''

// Note: the log & fprintf here are only used for debug, which should be commented
// out for better performance.
void handle_packet(iface_info_t *iface, char *packet, int len)
{
    // TODO: implement the packet forwarding process here
    // fprintf(stdout, "TODO: implement the packet forwarding process here.\n");

    struct ether_header *eh = (struct ether_header *)packet;
```

```
// log(DEBUG, "the dst mac address is " ETHER_STRING ".\n",  
    ETHER_FMT(eh->ether_dhost));  
  
iface_info_t *dst_iface = lookup_port(eh->ether_dhost);  
if (dst_iface)  
    iface_send_packet(dst_iface, packet, len);  
else  
    broadcast_packet(iface, packet, len);  
  
insert_mac_port(eh->ether_shost, iface);  
  
free(packet);  
}
```

在这个函数里, 我们首先解析数据包, 然后查找目的 mac 地址对应的接口信息, 如果找到了, 就转发数据包, 否则广播发送数据包。接着将源 mac 地址和接口信息插入到转发表中, 最后释放数据包的内存。

#### 4.2.6 测量交换机转发的性能与集线器广播的性能对比

拓扑图如下:

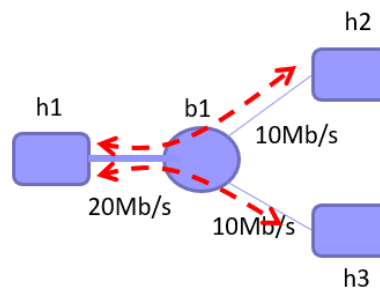


图 4.11. 交换机网络拓扑图

与实验一中的拓扑相同, 这里直接开始测量交换机转发的性能。

```

root@zhangjiawei-VirtualBox:/home/zhangjiawei/ㄟㄟㄟ/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.2 -t 30
-----
Client connecting to 10.0.0.2, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 45362 connected with 10.0.0.2 port 5001 (icwnd/mss/irt
t=14/1448/3677)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-30.6698 sec 34.4 MBytes  9.40 Mbits/sec
root@zhangjiawei-VirtualBox:/home/zhangjiawei/ㄟㄟㄟ/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.2 -t 30
-----
Client connecting to 10.0.0.2, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 33130 connected with 10.0.0.2 port 5001 (icwnd/mss/irt
t=14/1448/1777)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.4188 sec 35.0 MBytes  9.34 Mbits/sec
root@zhangjiawei-VirtualBox:/home/zhangjiawei/ㄟㄟㄟ/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.2 -t 30
-----
Client connecting to 10.0.0.2, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 58810 connected with 10.0.0.2 port 5001 (icwnd/mss/irt
t=14/1448/112)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-32.0691 sec 36.0 MBytes  9.42 Mbits/sec

```

图 4.12. h1 向 h2 测量

```

root@zhangjiawei-VirtualBox:/home/zhangjiawei/ㄟㄟㄟ/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.3 -t 30
-----
Client connecting to 10.0.0.3, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 59052 connected with 10.0.0.3 port 5001 (icwnd/mss/irt
t=14/1448/119)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-30.8253 sec 35.0 MBytes  9.52 Mbits/sec
root@zhangjiawei-VirtualBox:/home/zhangjiawei/ㄟㄟㄟ/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.3 -t 30
-----
Client connecting to 10.0.0.3, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 40816 connected with 1
t=14/1448/194)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.3387 sec 35.6 MBytes  9.54 Mbit
root@zhangjiawei-VirtualBox:/home/zhangjiawei/ㄟㄟㄟ/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.3 -t 30
-----
Client connecting to 10.0.0.3, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.1 port 41236 connected with 1
t=14/1448/95)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.4644 sec 35.3 MBytes  9.40 Mbit

```

图 4.13. h1 向 h3 测量

```

root@zhangjiawei-VirtualBox:/home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.1 -t 30
-----
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.2 port 44908 connected with 10.0.0.1 port 5001 (icwnd/mss/irt
t=14/1448/13436)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.4415 sec 35.8 MBytes  9.54 Mbits/sec
root@zhangjiawei-VirtualBox:/home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.1 -t 30
-----
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.2 port 35356 connected with 10.0.0.1 port 5001 (icwnd/mss/irt
t=14/1448/4115)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.8408 sec 36.3 MBytes  9.55 Mbits/sec
root@zhangjiawei-VirtualBox:/home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.1 -t 30
-----
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 93.5 KByte (default)
-----
[ 1] local 10.0.0.2 port 42720 connected with 10.0.0.1 port 5001 (icwnd/mss/irt
t=14/1448/58)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.5668 sec 35.9 MBytes  9.53 Mbits/sec

```

图 4.14. h2 向 h1 测量

```

root@zhangjiawei-VirtualBox:/home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.1 -t 30
-----
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.3 port 37522 connected with 10.0.0.1 port 5001 (icwnd/mss/irt
t=14/1448/152)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.2045 sec 35.4 MBytes  9.51 Mbits/sec
root@zhangjiawei-VirtualBox:/home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.1 -t 30
-----
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.3 port 43848 connected with 10.0.0.1 port 5001 (icwnd/mss/irt
t=14/1448/95)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.9559 sec 36.3 MBytes  9.52 Mbits/sec
root@zhangjiawei-VirtualBox:/home/zhangjiawei/2024_zjw_ComputerNetwork/Lab
04/04-hub+switch/switch# iperf -c 10.0.0.1 -t 30
-----
Client connecting to 10.0.0.1, TCP port 5001
TCP window size: 85.3 KByte (default)
-----
[ 1] local 10.0.0.3 port 55024 connected with 10.0.0.1 port 5001 (icwnd/mss/irt
t=14/1448/131)
[ ID] Interval      Transfer      Bandwidth
[ 1] 0.0000-31.8827 sec 36.3 MBytes  9.54 Mbits/sec

```

图 4.15. h3 向 h1 测量

在 h1 向 h2 测量和 h1 向 h3 测量中, 实验结果与实验一差距较大, 速率已经接近理论带宽值。这是因为交换机网络中, 数据包除了第一次转发表为空之外不会被广播, 而是根据目的 mac 地址直接转发, 所以不会出现

竞争关系,速率更接近理论带宽值,带宽得到了充分利用。

h2 向 h1 测量和 h3 向 h1 测量的结果也与预期一致,速率接近理论带宽值,这是因为路径不是竞争关系,所以速率应该会更接近理论带宽值。这个原因与实验一中的解释相同。

总体而言,交换机网络的性能要好于集线器广播网络,尤其是当广播网络因各种各样原因导致数据包竞争时,交换机网络的性能优势更加明显。即便首次传播时需要进行广播,但是交换机网络会学习到目的 mac 地址,之后的数据包都会直接转发,不会再广播,这样就避免了数据包竞争,提高了网络性能。

### 4.3 实验总结

本次实验主要是关于交换机网络的实验,我实现了转发表的查询、插入和老化操作,以及数据包的转发和广播操作,验证了交换机网络的性能优势。实验过程中,我对交换机网络的工作原理有了更深入的了解,交换机网络会学习到目的 mac 地址,之后的数据包都会直接转发,不会再广播,这样就避免了数据包竞争,提高了网络性能。而集线器广播网络则会占据更多的网络资源,效率低下。这也是交换机网络取代集线器网络的原因之一。