Writing Task 2

1.

The source MAC address.

2.

1674 .

3.

IPv4: 20 bytes. IPv6: 40 bytes.

Run program and tests

First change the destination IP address in `src/tests/ns1.c` . In every test, `ns1` regularly sends packets to a fixed IP address.

Run `sudo make` .

`cd vnetUtils/examples`, `sudo bash ./makeVNet < test1.txt` or `test2.txt, test3.txt`.

The three test networks are:

```
// test1
1 - 2 - 3 - 4

// test2
1 - 2 - 3 - 4
    |   |
    5 - 6

// test3
1 - 2 - 3
|   |   |
4 - 5 - 6
```

Then open a terminal with every ns hosts.

```
cd vnetUtils/helper;
sudo ./execNS ns* bash
cd ../../build
```

Then `sudo ./ns1` or `sudo ./router` . We can also `sudo ./ns1` in another `ns` to make it the packet sender.

Programming Task 3

I implemented these functions in `arp.h/c`:

```
int getMACaddress(struct in_addr *target_ip, uint8_t *mac_address, int last_id);

void sendARPrequest(struct in_addr *target_ip, int last_id);
void sendARPreply(struct in_addr *dest_ip, uint8_t *dest_mac_address, uint8_t
*source_mac_address, int last_id);

void processARPrequest(const uint8_t *packet, int last_id);
void processARPreply(const uint8_t *packet);
```

I implemented these functions in `ip.h/c`:

```
int sendIPPacket(const struct in_addr src , const struct in_addr dest ,
int proto , const void *buf , int len, int TTL);

void processARPpacket(const uint8_t *packet, int last_id);
void processIPpacket(const uint8_t *packet, int deviceID);
```

I implemented these functions in `rip.h/c`:

```
void initDVTrie(void);
void insertDVTrie(struct in_addr ip, struct in_addr mask, int hops, int deviceID);
void sendRIPpacket(void);
int setRoutingTable(struct in_addr dest, struct in_addr mask, const char *device);
void processRIPpacket(const uint8_t *packet, int payloadLength, int deviceID);
int route(const struct in_addr ip);
TrieNode *getDVTrieRoot(void);
```

Writing Task 3

I implemented the ARP. If the caller of `sendFrame()` doesn't know the MAC address corresponded to the IP address, it broadcasts ARP packets to adjacent hosts.

Here's an example with kernel protocol on: (the wireshark monitors vnet2-1 on ns2)

```
ns1 - ns2 (10.100.1.0/24)

(the whole network is below, but only ns1 and ns2 are activated)
1 - 2 - 3 - 4
    |   |
    5 - 6
```

arp

No.	Time	Source	Destination	Protocol	Length	Info
1	0.000000000	0a:6c:f1:1a:e…	Broadcast	ARP	…	Who has 10.100.1.2? Tell 10.100.1.1
2	0.000062172	8e:04:74:a4:c…	0a:6c:f1:1a:e7…	ARP	…	10.100.1.2 is at 8e:04:74:a4:c5:31
3	2.389697424	8e:04:74:a4:c…	Broadcast	ARP	…	Who has 10.100.1.1? Tell 10.100.1.2
4	2.389719415	0a:6c:f1:1a:e…	8e:04:74:a4:c5…	ARP	…	10.100.1.1 is at 0a:6c:f1:1a:e7:90
5	2.389773878	8e:04:74:a4:c…	Broadcast	ARP	…	Who has 10.100.2.2? Tell 10.100.1.2
6	2.389814937	8e:04:74:a4:c…	Broadcast	ARP	…	Who has 10.100.4.2? Tell 10.100.1.2
7	3.029161012	0a:6c:f1:1a:e…	8e:04:74:a4:c5…	ARP	…	10.100.1.1 is at 0a:6c:f1:1a:e7:90

With kernel protocol on, the ARP request receives 2 ARP replies.

After receiving an ARP reply, the host adds the info to its ARP cache.

Writing Task 4

I implemented an simplified version of RIP. I maintained a routing table on every host. I chose Trie to easily handle IPmasks and longest prefix match. Every host in network regularly (every 5 seconds) sends its info to adjacent hosts.

```
typedef struct TrieNode {

  struct in_addr ip;
  struct in_addr mask;

  int hops;
  int attenuate_timer;

  int deviceID;

  struct TrieNode *ch[2];

} TrieNode;
```

`hops` marks the distance between this host and the target subnet. The info with minimum `hops` takes precedence.

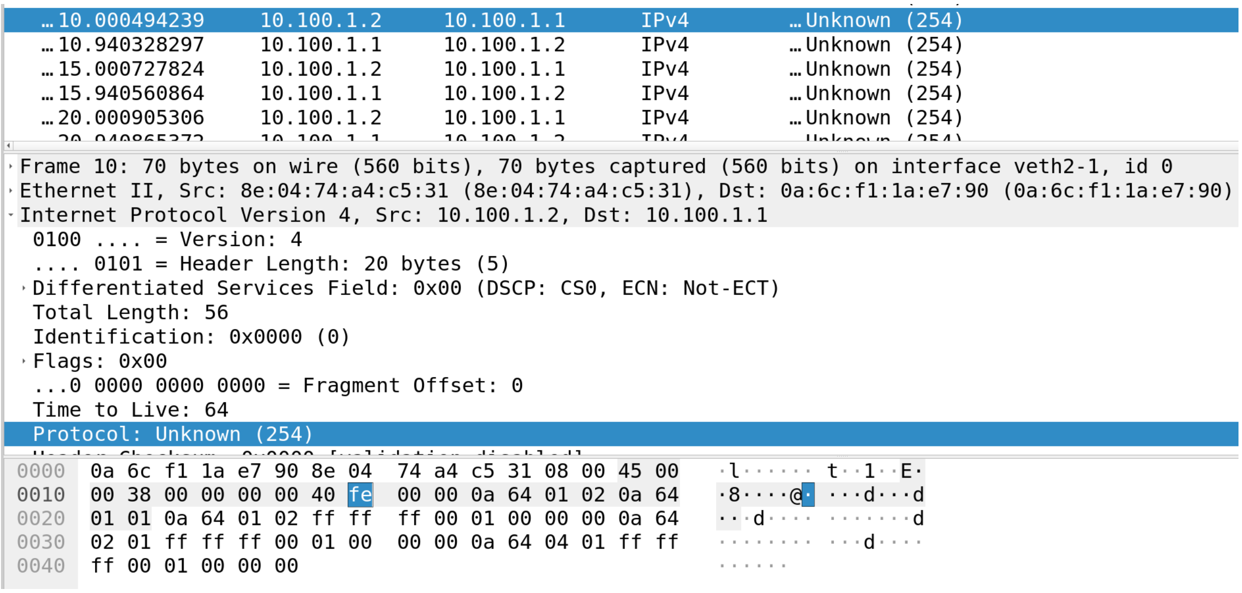
To deal with broken hosts, I used the `attenuate_timer` . If the current info is out-dated, it will be replaced by another info (likely with a larger `hops`) . Each time a worse info arrives, `attenuate_timer++` .

Here's the whole replacing policy: (`tmp` is the old info)

```
if (hops + 1 < tmp->hops || tmp->attenuate_timer >= 5) {
    tmp->ip = ip;
    tmp->mask = mask;
    tmp->hops = hops + 1;
    tmp->attenuate_timer = 0;
    tmp->deviceID = deviceID;
} else if (hops + 1 == tmp->hops) {
    tmp->deviceID = deviceID;
    tmp->attenuate_timer = 0;
} else if (hops + 1 > tmp->hops && tmp->hops > 1) {
    // tmp->hops = 0 means this is local IP, or this is manually added(with highest
priority)
```

```
        // tmp->hops = 1 means this is direct link, don't change
        tmp->attenuate_timer++;
    }
```

I used protocol ID `0XFE` to mark these RIP packets. And for simplicity, I compressed each info to 12 bytes.



Checkpoint 3

In this network, `ns1` regularly sends IPv4 packets to `ns6`, with protocol ID `0XFD`: (the wireshark monitors vnet6-5 on ns6)

```
1 - 2 - 3 - 4
    |   |
    5 - 6

(below is fed to makeVNet)
6
1 2 10.100.1
2 3 10.100.2
3 4 10.100.3
2 5 10.100.4
3 6 10.100.5
5 6 10.100.6
```

ip.version==4 && ip.proto==0xfd

No.	Time	Source	Destination	Protocol	Length	Info
…	13.859065039	10.100.1.1	10.100.6.2	IPv4	…	Unknown (253)
…	14.899008247	10.100.1.1	10.100.6.2	IPv4	…	Unknown (253)
…	15.939053339	10.100.1.1	10.100.6.2	IPv4	…	Unknown (253)
…	16.979147172	10.100.1.1	10.100.6.2	IPv4	…	Unknown (253)
…	16.979165247	10.100.1.1	10.100.6.2	IPv4	…	Unknown (253)
…	18.019343881	10.100.1.1	10.100.6.2	IPv4	…	Unknown (253)
…	19.059126840	10.100.1.1	10.100.6.2	IPv4	…	Unknown (253)
…	20.099162477	10.100.1.1	10.100.6.2	IPv4	…	Unknown (253)
…	21.138995144	10.100.1.1	10.100.6.2	IPv4	…	Unknown (253)

```
Frame 12: 60 bytes on wire (480 bits), 60 bytes captured (480 bits) on interface veth6-5, id 0
Ethernet II, Src: ba:8a:31:09:c5:6b (ba:8a:31:09:c5:6b), Dst: 2e:2a:7f:59:cb:ef (2e:2a:7f:59:cb:ef)
Internet Protocol Version 4, Src: 10.100.1.1, Dst: 10.100.6.2
Data (12 bytes)
  Data: 48656c6c6f20576f726c6421
  [Length: 12]
```

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00   .*·Y····  1··k··E·
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64   · ····>·  ···d···d
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00   ··Hello  World!··
0030  00 00 00 00 00 00 00 00  00 00 00 00               ········  ····
```

The first 12 bytes mark the source MAC address and the dest MAC address:

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

The 13th and 14th bytes are `0x0800`, which shows this is an IPv4 packet.

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

The 15th byte is `0x45`, `0100 0101` under binary. `0100` shows the IP version is 4, `0101` shows the header length is $5 \times 4 = 20$ bytes.

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

The 16th byte is `0x00`. It's the TOS byte.

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

The 17th and 18th bytes are `0x0020` , showing the total packet length is 32 bytes.

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

The 19th, 20th, 21st, 22nd bytes are all `0x00`, they are identification code and flags, manually set to 0 without fragmentation.

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

The 23rd byte is `0x3e`, showing this packet's TTL is 62.

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

The 24th byte is `0xfd`, the protocol ID.

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

The 25th and 26th bytes are `0x0000`, disabling the header checksum.

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

The following 8 bytes mark the source IP address `10.100.1.1` and the dest IP address `10.100.6.2`.

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

The following 12 bytes are the payload `Hello world!`

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00   .*·Y····1··k··E·
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64   ·····>·  ···d···d
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00   ··Hello World!··
0030  00 00 00 00 00 00 00 00  00 00 00 00               ········ ····
```

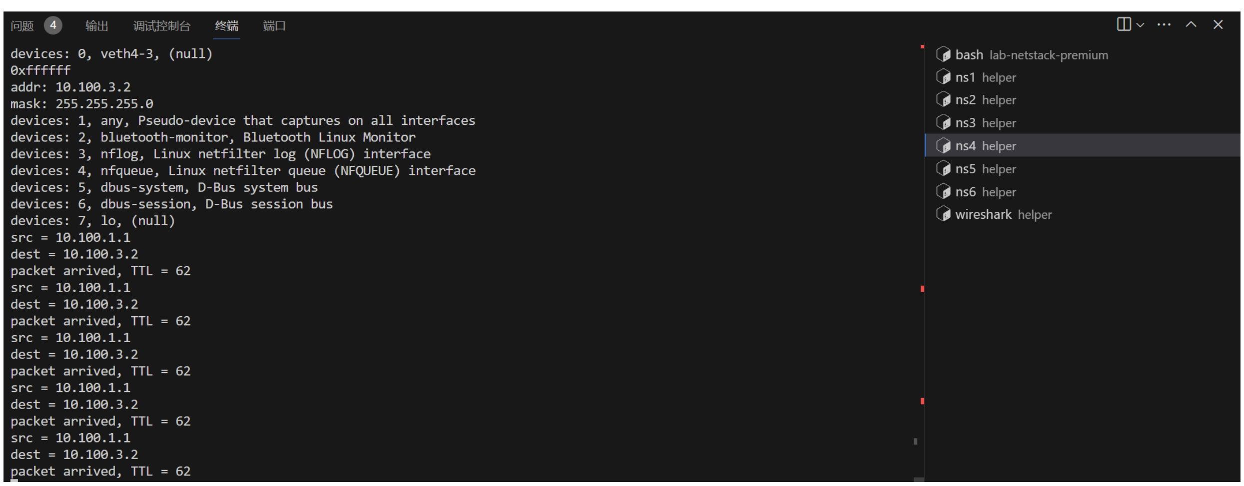
The rest bytes are ethernet padding.

```
0000  2e 2a 7f 59 cb ef ba 8a  31 09 c5 6b 08 00 45 00
0010  00 20 00 00 00 00 3e fd  00 00 0a 64 01 01 0a 64
0020  06 02 48 65 6c 6c 6f 20  57 6f 72 6c 64 21 00 00
0030  00 00 00 00 00 00 00 00  00 00 00 00
```

Checkpoint 4

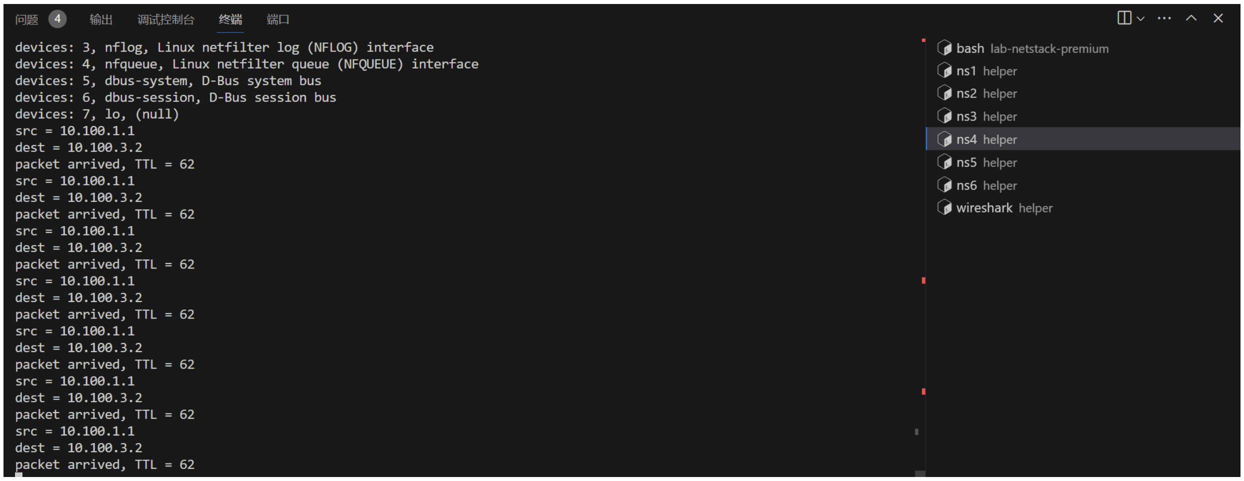
`ns1` regularly sends packets to `ns4` .

In the beginning, `ns4` can receive the packets.



After disconnecting `ns2`, `ns4` stops receiving packets.

After reconnecting `ns2`, `ns4` can receive the packets.



Checkpoint 5

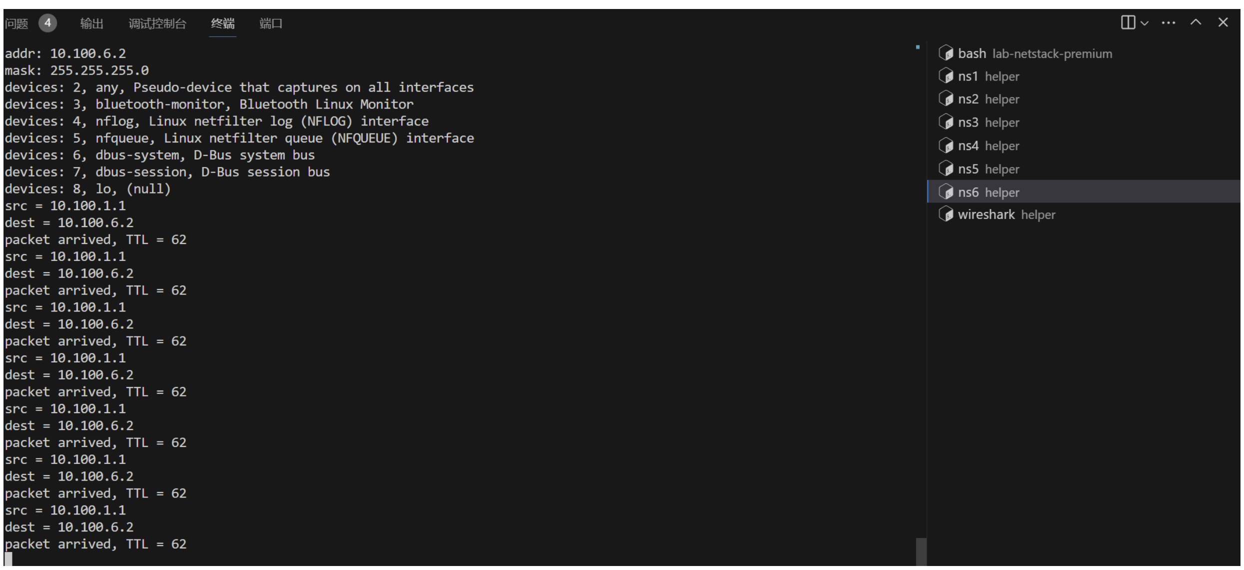
The distances are:

$$1 - 2 : 1,\ 2 - 3 : 1, \ldots$$

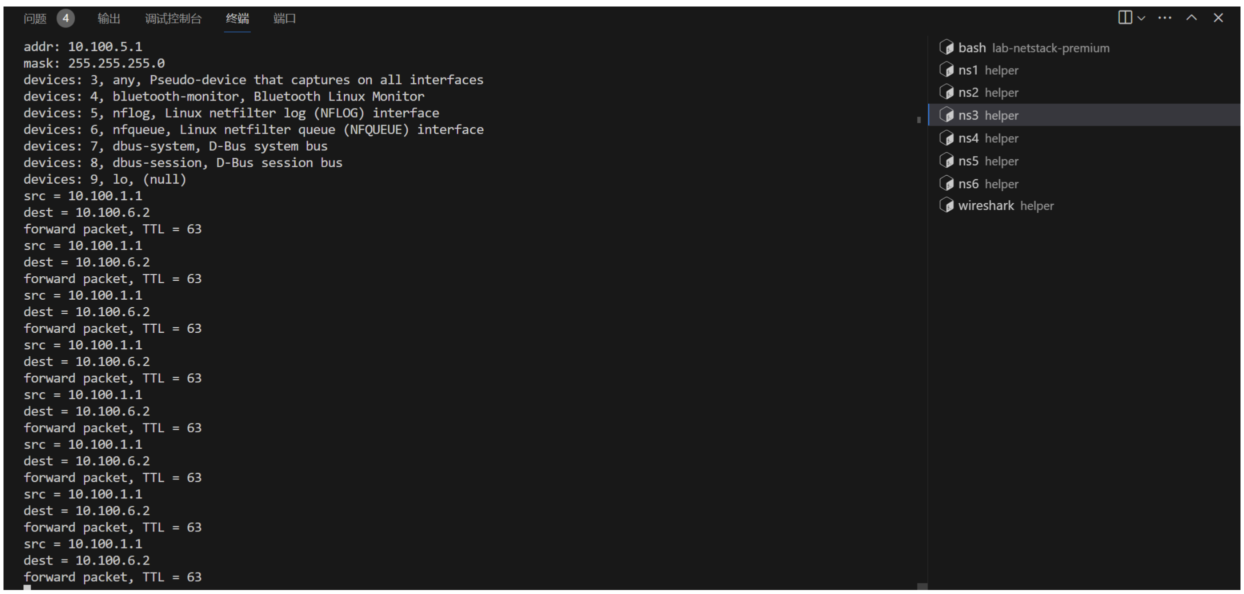
Disconnecting `ns5` doesn't change distance between any pair of hosts.

For example, to measure the distance between `ns1` and `ns6` , `ns1` regularly sends packets to `ns6`.

In the beginning, the packets travel `ns1 -> ns2 -> ns5 -> ns6`.



After disconnecting `ns5` , the packets travel `ns1 -> ns2 -> ns3 -> ns6`



Thus the distance between `ns1` and `ns6` is constantly $64 + 1 - \mathrm{TTL} = 3$.

I ran another test which involves change of distance:

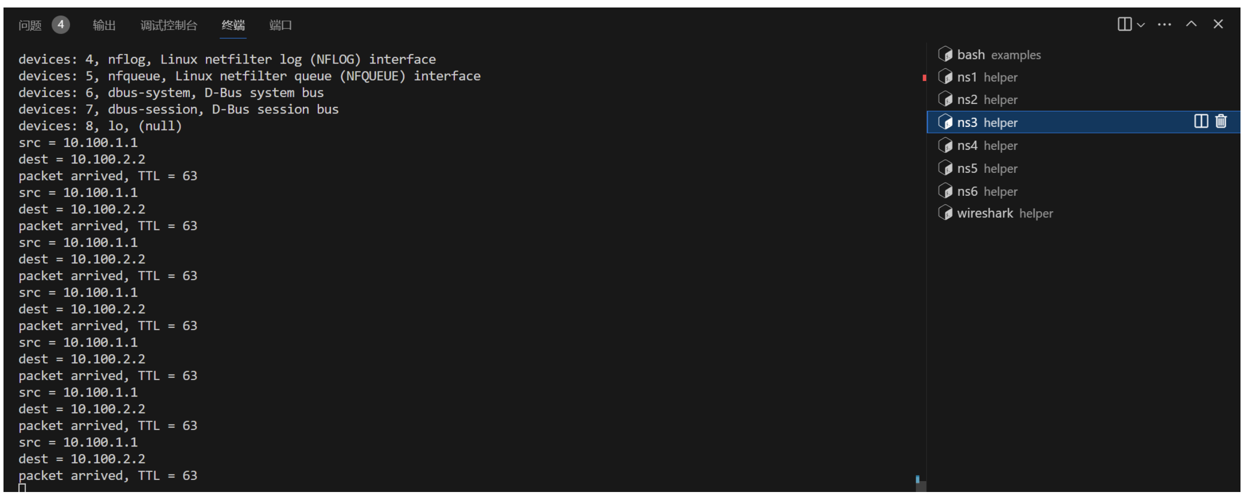
```
1 - 2 - 3
|   |   |
4 - 5 - 6

(the following is fed to makeVNet)

6
1 2 10.100.1
2 3 10.100.2
1 4 10.100.3
2 5 10.100.4
3 6 10.100.5
4 5 10.100.6
5 6 10.100.7
```

To measure $dis(1, 3)$, `ns1` regularly sends packets to `ns3`.

In the beginning, the packets travel `ns1 -> ns2 -> ns3`, so the distance is 2.



After disconnecting `ns2`, the packets travel `ns1 -> ns4 -> ns5 -> ns6 -> ns3`, so the distance is 4.

(In my implementation, the recovery needs some iterations, so there will be wrongly forwarded packets for a short period of time after disconnection)

Checkpoint 6

```c
int route(const struct in_addr ip) {
  uint32_t rev_ip = ((ip.s_addr & 255) << 24) +
                    (((ip.s_addr >> 8) & 255) << 16) +
                    (((ip.s_addr >> 16) & 255) << 8) +
                    ((ip.s_addr >> 24) & 255);
  TrieNode *tmp = DVTrieRoot;
  for (int i = 31; i >= 0; i--) {
    if (tmp->ch[rev_ip >> i & 1] == NULL)
      break;
    tmp = tmp->ch[rev_ip >> i & 1];
  }
  return tmp->deviceID;
}
```

During a routing procedure, only the IP mask with the longest prefix will match the current IP. While traversing on the Trie, whenever a node has a child, there's a longer prefix match.