The Internet Protocol

Hui Chen [a]

[a] CUNY Brooklyn College

September 21, 2023

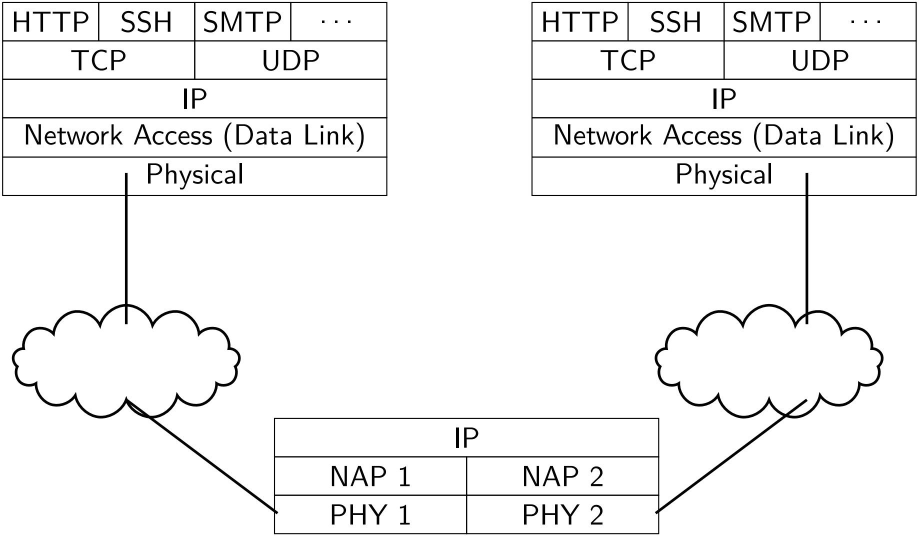
Outline

The Internet and Internetworking

The Internet is a network of networks, i.e., an internetwork.

- What are the motivation to build such a network?
- What are the requirements?
- What are the problems?

TCP/IP Internetworks



Challenges

- (Heterogeneity) The networks in an internwork are heterogenous.
- (Scability) There are a lot of hosts and networks on an internetwork.
- (Surviablity) Hosts on part of networks should still be able to communicate when others fail.
- ...

Outline

Internet Protocol Operation

The Internet Protocol (IP) provides a connectionless service (or datagram service) between two end systems (e.g., two hosts, or two routers, or a router and a host)

- It is easy to deal with variety of networks as it does not require much for these networks, and it is simple by itself.
- The connectionless service delivers packets with the best effort approach and there is no centralized control, which makes IP service is highly robust.
- It is best for connectionless transport protocols, as it does not impose unnecessary overhead.
- IP realizes a network of networks, which allows a network (i.e., an internetwork) to scale.

Design Issues

- Routing
- Datagram lifetime
- Fragmentation and assembly
- Error control
- Flow control
- Congestion control

Outline

IPv4 Address

An IPv4 address is 4 bytes (or 32 bits).

- Unicast address ($00000000_h/1$, $80000000_h/2$, and $C0000000/3$)
- Multicast address ($E0000000_h/4$)
- Reserved address ($F0000000_h/5$)
- Broadcast address

IPv4 Unicast Address

- Private network
  - 192.168.0.0/16
  - 172.16.0.0/12
  - 10.0.0.0/8
- Loopback. 127.0.0.0/8
- Link-local unicast. 169.254.0.0/16
- Documentation (TEST-NET-1). 192.0.2.0/24
- Documentation (TEST-NET-2). 198.51.100.0/24
- Documentation (TEST-NET-3). 203.0.113.0/24
- Global unicast. Everything else with exceptions.

IPv4 Unicast Address: Network and Host Parts

An IPv4 address consists of two parts:

- Network part
- Host part

To understand this, let's look at the IP forwarding algorithm

IPv4 Packet Forwarding

Conceptually, we can describe the IPv4 packet forwarding (unicast packet forwarding) algorithm as follows,

```
D = destination IP address // D = <NetworkNumber, HostNumber>
Selected = {}
for each entry of <NetworkNumber, NextHop> in forwarding table
  // Get_Network_Number returns the entry
  // if D.NetworkNumber = NetworkNumber
  Ds = Get_Network_Number(D) // {Ds} can be ∅ if not a match
  Selected = Selected ∪ {Ds}
endfor
Ds = Longest_Match(Selected)
if {Ds} != ∅
  if Ds.NextHop is an interface
    deliver datagram directly to destination
  else
    deliver datagram to Ds.NextHop (a router)
else
  drop the packet
```

Forwarding Table

- A forwarding table consists of entries of network and next hop entity where a next hop entity is either a network interface or a next hop router.
- Run these to observe examples.

```
ip route show
```

Listing: Linux

```
netstat -n -r
```

Listing: Unix and Windows

Fragmentation and Reassembly

- Different network can have different MTU
- MTU. Maximum transmission unit is the maximum sized datagram that can be transmitted through the next network is called the maximum transmission unit.
  - IPv4 over Ethernet V2. MTU = 1500 bytes.
  - IPv4 over IEEE 802.11 Wi-Fi (WLAN). MTU = 2304 bytes before encryption.
  - IPv4 over FDDI. MTU = 4352 bytes.
- But how big an IPv4 packet can be?
- Fragmentention (https://tools.ietf.org/html/rfc791#page-26)
- Reassembly (https://tools.ietf.org/html/rfc791#page-28)

IPv4 Packet Header

<table>
<tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td><td>17</td><td>18</td><td>19</td><td>20</td><td>21</td><td>22</td><td>23</td><td>24</td><td>25</td><td>26</td><td>27</td><td>28</td><td>29</td><td>30</td><td>31</td></tr>
<tr><td colspan="4">V=4</td><td colspan="4">IHL</td><td colspan="6">DS</td><td colspan="2">ECN[1]</td><td colspan="16">Total Length</td></tr>
<tr><td colspan="16">Identification</td><td colspan="3">Flags</td><td colspan="13">Fragment Offset</td></tr>
<tr><td colspan="8">Time To Live</td><td colspan="8">Protocol[2]</td><td colspan="16">Header Checksum</td></tr>
<tr><td colspan="32">Source Address</td></tr>
<tr><td colspan="32">Destination Address</td></tr>
<tr><td colspan="32">Options + Paddings
(32 bits × n, n = 0, 1, 2, . . .)
. . .</td></tr>
</table>

[1] See RFC 3168

[2] https://www.iana.org/assignments/protocol-numbers

Internet Control and Message Protocol (ICMP)

- ICMP is a network layer protocol, is also a user of IP, i.e., an ICMP packet is the pay load of an IP packet. (RFCs 792, 950, 1250, 1393, 1475, 1788)

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

Type (bits 0–7)	Code (bits 8–15)	Checksum (bits 16–31)
Varying based on Type		
...		

Example ICMP Message Types

- Type 0. Echo Reply Message
- Type 8. Echo (Request) Message
- Type 3. Destination Unreachable Message
- Type 5. Redirect Message
- Type 30. Traceeroute Message (RFC 1393)
- Type 11. Time Exceeded

Address Resolution

- Needs to establish the mapping between IP address of the next-hop node and the hardware (or MAC) address
- Address Resolution Protocol (ARP).
- Let's try,

```
sudo arp
```

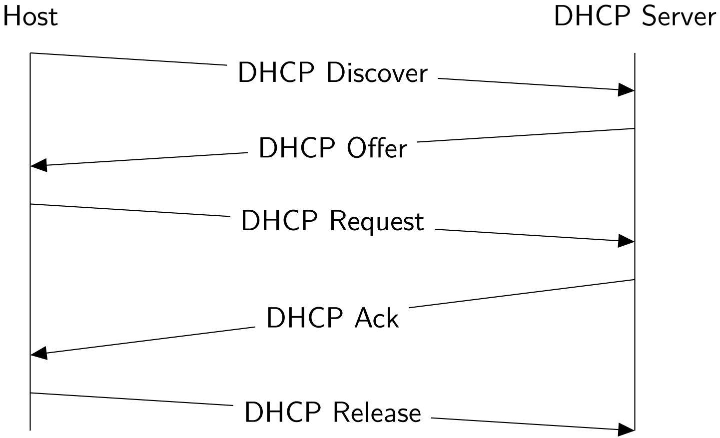
Listing: Linux

- Where do these come from?

Dynamic Host Configuration Protocol (DHCP)

- How do we assign IPv4 addresses?
- We can enable dynamic allocation of IPv4 addresses and supply other configuration parameters to hosts (automatically) via DHCP (RFC 2131).
- DHCP is a user of UDP, i.e., DHCP uses UDP as its transport protocol.

Example of DHCP Message Exchange



Outline

Comparing with IPv4

- IPv6 address
- Packet format
- Address translation and host configuration?

IP Next Generation to IPv6

To apply a few important findings from IPv4 experience and research,

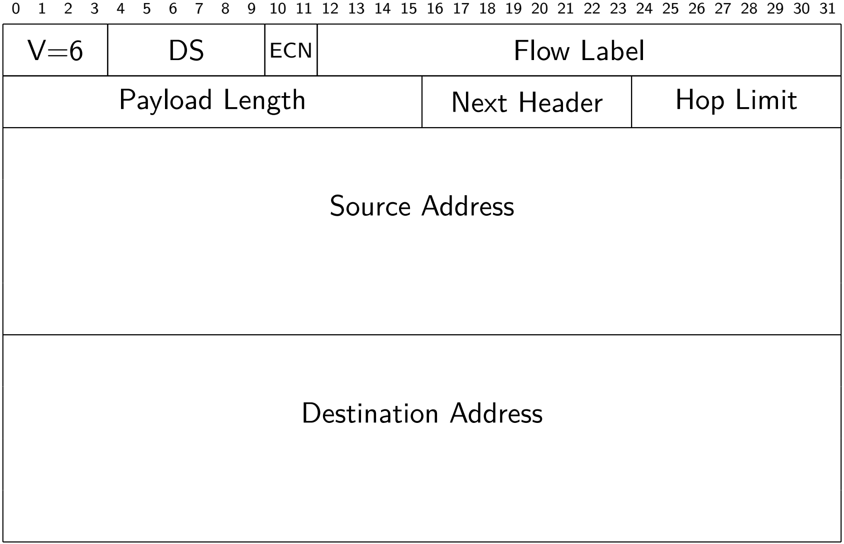
- IPv4 Address space (32 bits) is too mall. IPv6 address space is 128 bits.
- Routers often do not handle optional fields in IPv4 headers. IPv6 options (extension headers) are placed in separated optional headers, which simplifies processing delay at routers
- Do away with DHCP? IPv6 has address autoconfiguration capability and can assign addresses without an application layer server like DHCP.
- Support a few innovations? IPv6 introduces anycast address to support anycase, and addes a scope field to multicast address to improve scalability of multicast routing.
- Resource allocation is difficult in IPv4. IPv6 can label packets for different traffic flow, which aids resource allocation for specialized traffic (e.g., real-time video)

IPv6 Address

Divided into a few categories, e.g.,

- Embedded IPv4 Address ($:: FFFF/96$)
- Loopback ($:: 1/128$)
- Link-local unicast ($FE80 :: /10$)
- Private network. ($FC00 :: /7$)
- Documentation ($2001 : 0DB8 :: /32$)
- Multicast ($FF00 :: /8$)
- Global unicast (Everything else with exceptions)

IPv6 Packet Header



IPv6 Packet Structure

IPv6 header	Extension header	. . .	Extension header	Transport Layer PDU

IPv6 Stateless Address Autoconfiguration

- Assign IPv6 addresses to hosts without a server? (RFC 4862)
  1. Generate a link-local address.
  2. Test the uniqueness of a link-local address.
  3. Assign a link-local address.
  4. Contact the router.
  5. Provide direction to the node.
  6. Configure the global address.