CS 425: Computer Networks **Jan-Apr 2020**

Lecture 15: Computer Networks – February 28, 2020

Lecturer: Swaprava Nath *Scribe(s): Aditya Mishra, Anany Sharma, Ram Goyal, Ritesh Kumar*

Disclaimer: *These notes aggregate content from several texts and have not been subjected to the usual scrutiny deserved by formal publications. If you find errors, please bring to the notice of the Instructor.*

In the last lecture, we discussed

1. Network/IP Layer
2. Routing and Forwarding

In this lecture, we will discuss

1. Differences between Networks
2. IPv4
3. IP Forwarding

15.1 Differences between Networks

We have shown the parameters on which networks differ in Table 15.1.

- Networks differ on their service model. They can be connection-less or connection oriented.
- Addressing schemes can be different for different networks. For internetworking, address scheme has to be uniformised over all networks.
- Quality of Service at network layer differs across networks. To quantitatively measure quality of service, several related aspects of the network service are often considered, such as packet loss, bit rate, throughput, transmission delay, availability, jitter, etc.
- Packets size is also dependent on network. We have to keep smaller packets sizes for WiFi transmission, but we can keep large packet sizes for LAN transmission.
- Networks also differ on the type of security they carry.
- Congestion control techniques, flow control techniques and error handling techniques can also be different for different networks.

Item	Some possibilities
Service offered	Connection oriented versus connection-less
Protocols	IP, IPx, SNA, ATM, MPLS, AppleTalk, etc.
Addressing	Flat (802) versus hierarchical (IP)
Multicasting	Present or absent (also broadcasting)
Packet size	Every network has its own maximum
Quality of service	Present or absent; many different kinds
Error handling	Reliable, ordered, and unordered delivery
Flow control	Sliding window, rate control, other, or none
Congestion control	Leaky bucket, token bucket, RED, choke packets, etc.
Security	Privacy rules, encryption, etc.
Parameters	Different timeouts, flow specifications, etc.
Accounting	By connect time, by packet, by byte, or not at all

Table 15.1: Differences across networks [UOS]

15.2 An Example of Internetworking

Internetwoking was introduced by Cerf and Kahn in 1974. They proposed the solution that can solve the problem of communicating without mandating a single network technology. This was the origin of TCP/IP. Internetworking is useful when different kinds of networks are connected together. The goal of internetworking is to ensure smooth transmission of information. The protocol used worldwide at present in the network layer is the Internet Protocol (IPv4). We have many protocols for layers above network layer and many protocols for layers below network layer in our reference model, the TCP/IP model, but for the network layer only IP is used. Now we look at an example of how internetworking works.
The network we consider in this example is shown in Figure 15.1. The first host, shown by H1 is connected to router R1 by a wifi link using 802.11 protocol. The router is connected to another router depicted by R2 by an MPLS protocol, then R2 is connected to receiving host H2 by an ethernet protocol. The routers at ends of two protocols are called edge routers. Further, service model used in the first and last link is Datagram and middle link is Virtual Circuit based.

We can see the flow of data in figure 15.2. We can see that the routers strip the headers of the past protocol to reach the IP and the payload, which is shown by a blank entry in the diagram. R1 removes the headers of 802.11 protocol and add the headers of MPLS protocol to transmit it and then R2 removes the MPLS

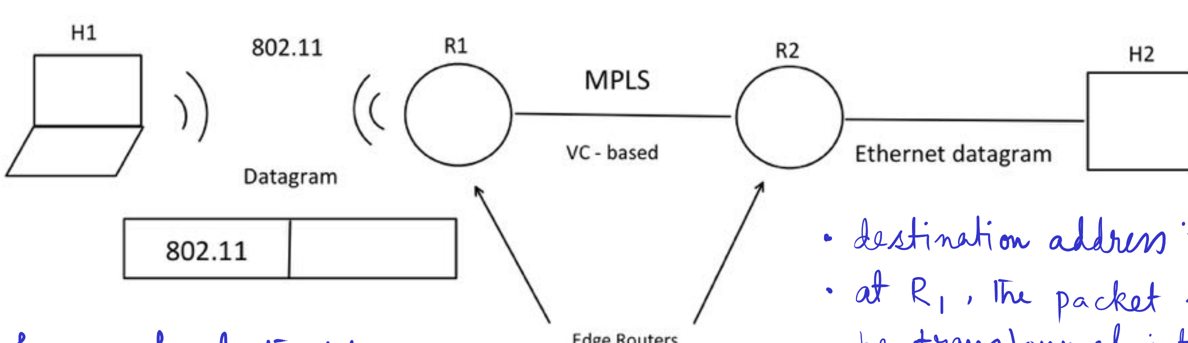


Figure 15.1: Example Network

example where not only the LL network type is changing but the service model is also changing

- destination address is needed
- at R_1, the packet needs to be transformed into a VC packet
(needs a mapping table of destination to VC label)
- The same transformation at R_2

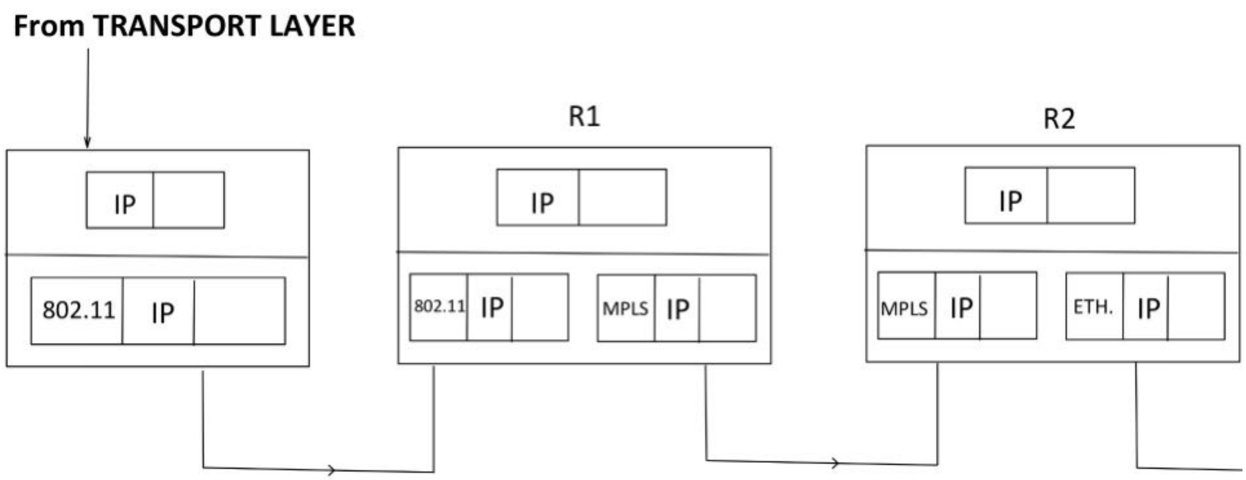


Figure 15.2: Flow of data across different types of networks

header and then adds ethernet header, shown by ETH. in the diagram. This is how internetworking works at the router level to transmit messages across networks.

different networks with protocols to adapt to one another

15.3 IPv4

— internetworking : key ingredient of TCP/IP

We would now look at the version of IP currently in use, version 4 (IPv4), in detail.

15.3.1 Packet Structure

The packet structure is shown in Figure 15.3. A few of the important members of the packet structure are:

- The version field keeps track of the version this packet belongs to. For IPv4, it is always four.
- The IHL stands for Internet Header Length. It is a 4-bit field and contains the length of the header in 32-bit words. The minimum value being 5.
- The type of services field also known as differentiated services field is intended to distinguish between different classes of service, and thus helps us maintain the quality of service using relative priorities.
- The Identification field is needed to allow the destination host to determine which datagram a newly arrived fragment belongs to.
- The time to live field, also known as TTL field, is used to prevent infinite transmission of a packet in case of errors. It is initialized with a large number which decrements on each hop. The packet is discarded when it becomes zero.
- The Fragment offset tells where in the current datagram this fragment belongs.
- The header checksum verifies the header.
- Protocol field carries information about the higher layer. It acts as the DeMUX key for IP layer.

Packet structure
writing convention
– bits folded into 32 bits

internet header length

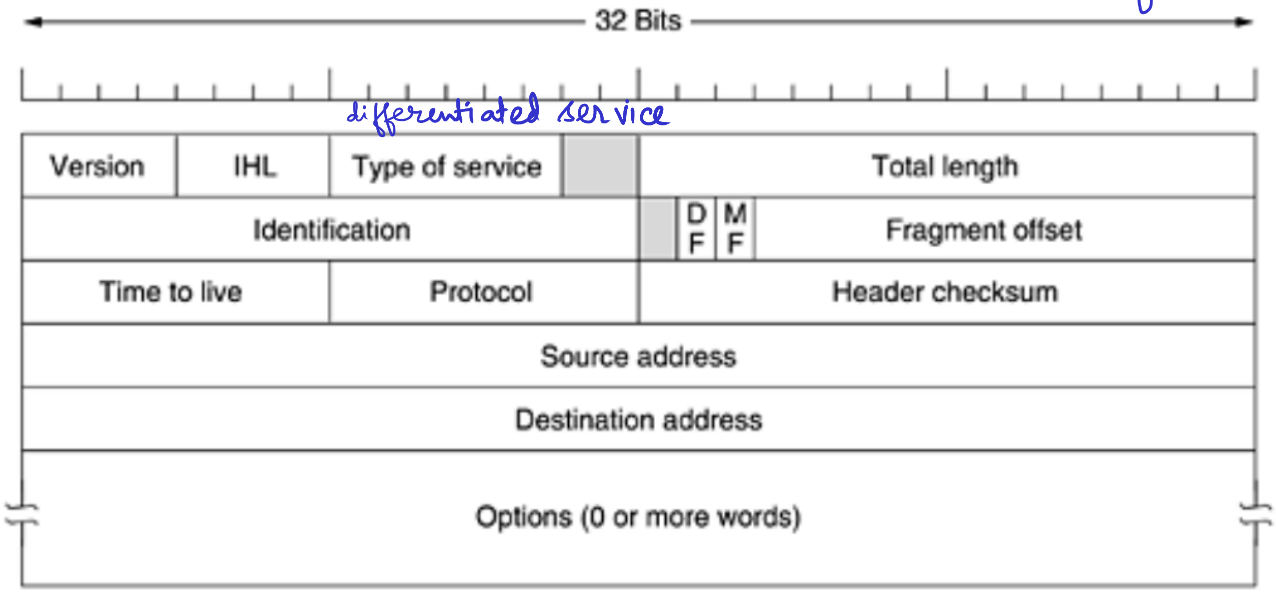


Figure 15.3: IPv4 Packet Structure [TW10]

8 bits 8 bits 8 bits 8 bits

aa ...a b - - - b

decimal A B C D

IP address (v4)
A . B . C . D

15.3.2 Addressing

Every host and router on the Internet has an IP address, which encodes its network number and host number. The combination is unique: in principle, no two machines on the Internet have the same IP address. IP addresses are used in the Source address and Destination address fields of IP packets. We will now look at how IP addresses are represented. They are 32 bit long and are written in the "dotted quad" notation. In this, four 8-bit numbers are converted to decimal numbers and these numbers are written with dots in between.

Example: 11000000101010000000000000001011 is written as 192.168.0.11

IP addresses are prefixed to cluster addresses together. Addresses in L bit prefix have the same most significant L bits. Thus the first L bits remain same and the last 32-L bits can vary from 0 to $2^{32-L} - 1$. Thus larger L means a more specific cluster which is less flexible as it supports less number of addresses.

Representation of IP address prefixes is done by "IP address/length" notation. In this notation, IP address is the lowest IP address in that prefix group and length is the length of the prefix.

Example: 192.168.0.0/16 means all addresses from 192.168.0.0 to 192.168.255.255

Exercise: Calculate maximum IP address for 192.168.0.0/13

Ans: 192.168.0.0 can be written as 11000000101010000000000000000000.
Thus, we can see that first thirteen bits are fixed and the maximum address is the address with the values from the fourteenth bit to the last bit being 1.
Thus the address is 192.175.255.255.

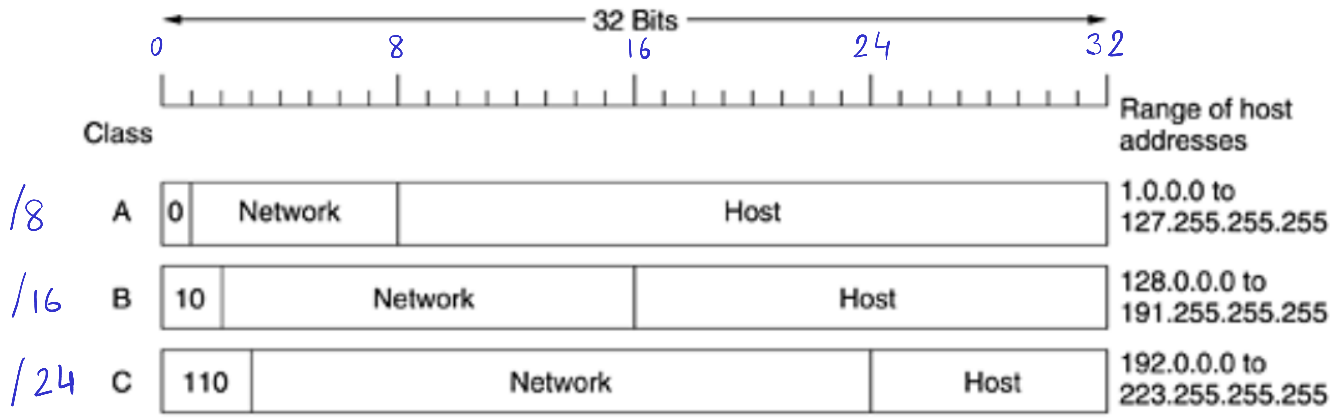


Figure 15.4: Classes of IP Addresses [TW10]

Q: Which class is 176.13.15.11 ?

15.3.2.1 Classes of IP Addresses

Public IPs

All the public IP addresses used in the internet belong to one of the three classes specified in the diagram ~~below.~~ above

Here, we can see that class A always starts from a zero, has a prefix of length 8 and supports 2^{24} different addresses. Similarly class B starts from 1 followed by a zero, has a prefix of length 16 and supports 2^{16} different addresses. Class C starts from 1 followed by a one which is followed by a zero, has a prefix of length 24 and supports 2^8 different addresses.

We can thus see that for large networks we should use class A as we want many hosts on the network. But for small networks C would suffice, as it supports lower number of hosts.

There is a unique destination on internet corresponding to a particular IP address. The IP address is assigned before use.

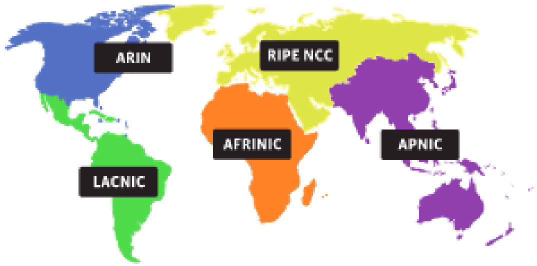
15.3.2.2 Private IP Addresses

Private IP addresses are not routed on the Internet and no traffic cannot be sent to them from the Internet, they only supposed to work within the local network. Private IP addresses can be used freely within an organization. These addresses are intended for use in closed local area networks and the allocation of such addresses is not globally controlled by anyone. Anyone may use private IP addresses without approval from Regional or Local Internet registries. Direct access to the Internet using a private IP address is not possible. In this case, the connection to the Internet is via NAT. Private IP addresses within the same local network must be unique and cannot be repeated. [KNTC]

examples: 10.0.0.0/8 , 172.16.0.0/12 , 192.168.0.0/16

15.3.2.3 Authorities for allocation of IP addresses

- IANA (Internet Assigned Numbers Authority) has control over all the IP address across the world.
- Below in the hierarchy, after IANA, are various Local Internet Registries (LIRs), National Internet Registries (NIRs) and Regional Internet Registries (RIRs).
- IANA delegates allocations of IP address blocks to Regional Internet registries (RIRs). Each RIR allocates addresses for a different area of the world. [WIKI]



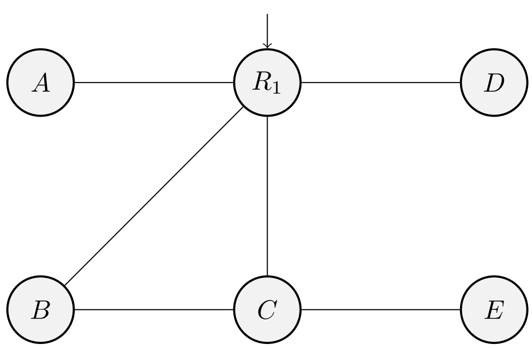
REGISTRY	AREA COVERED
AFRINIC	Africa Region
APNIC	Asia/Pacific Region
ARIN	Canada, USA, and some Caribbean Islands
LACNIC	Latin America and some Caribbean Islands
RIPE NCC	Europe, the Middle East, and Central Asia

Figure 15.5: IP address allocation authorities (below IANA in hierarchy) across the world [INUM]

- The RIRs divide their allocated address pools into smaller blocks and delegate them to Internet service providers and other organizations in their operating regions

15.3.3 IP Forwarding

IP forwarding also known as Internet routing is a process used to determine which path a packet can be sent. The process uses routing information to make decisions and is designed to send a packet over multiple networks. Generally, networks are separated from each other by routers.[SER]
IP forwarding in a network belong to the same prefix Forwarding table lists the next hop routers/node for a specific prefix.



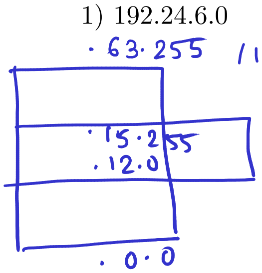
Prefix	Next Hop
192.24.0.0/18	D
192.24.12.0/22	B

Table 15.2: Forwarding Table

Concise representation of a lot of addresses.

Entries in the forwarding table may be overlapping. This is mainly because of reliability ~~redundancy~~ in networks and for maintaining the quality of service. To resolve the conflict Longest prefix matching is used. For each packet, the longest prefix in the table that matches the destination address is used and the packet is forwarded accordingly.

Question : Assume the IP forwarding table as Table 15.2. Which router should the following three addresses be forwarded through?
1) 192.24.6.0 2) 192.24.14.32 3) 192.24.54.1



/22
192.24.12.0 → 192.24.15.255

/18
192.24. 0000 0000 . 00000000
0011 1111 . 11111111
192.24.0.0 → 192.24.63.255

011
192.24. 000 ~~110~~00 . 00000000
00001011 . 11111111
error in the lecture

Answer : Following the longest prefix matching:
192.24.6.0 is written as 11000000.00011000.00000110.00000000
192.24.14.32 is written as 11000000.00011000.00001110.00100000
192.24.54.1 is written as 11000000.00011000.00110110.00000001

The prefix in 192.24.0.0/18 is 11000000.00011000.00
The prefix in 192.24.12.0/22 is 11000000.00011000.000011

Stripping the first 22 characters from the given addresses we get:
11000000.00011000.000001
11000000.00011000.000011
11000000.00011000.001101
respectively.
For the first address, we know that it cannot correspond to 192.24.12.0/22, so it cannot be forwarded to B, so it is forwarded to D. For the second address, it can match the prefix for 192.24.12.0/22, so it would be forwarded to B as it is the longer prefix. By the same logic as the first address, the third address is forwarded to D.

Thus the solution is D, B, D.

References

[WIKI] `https://en.wikipedia.org/wiki/Internet_Assigned_Numbers_Authority`

[UOS] `https://www.southampton.ac.uk/~sqc/EL336/CNL-12.pdf`

[INUM] `https://www.iana.org/numbers`

[KNTC] `https://help.keenetic.com/hc/en-us/articles/213965789-What-is-the-difference-between-a-public-and-private-IP-address-`

[TW10] Andrew S. Tanenbaum and S. Winograd, "Computer Networks" *5th Edition*, 2010

[SER] `https://serverfault.com/questions/248841/ip-forwarding-when-and-why-is-this-required`