Chapter4- Network Layer

forwarding: from one input link to one output link in a router

routing: the path organization from source to destination

Topics:

- Introduction
- Virtual circuit and datagram networks
- Inside a router
- IP: Internet Protocol
- Routing algorithms
- Routing in the internet
- Broadcast and multicast routing

Introduction

Network Layer: interconnect lower-level networks together, allow packets to be sent between any pairs or hosts. Transport segment from sending to receiving via multiple hops of routers.

A router could:

- forwarding
- routing
- congestion control: drop packets & update routing table

IP is **unreliable, best-effort and connectionless**.

The reasons that IP is simple:

- faster, more streamlined and lower cost to build and maintain.
- End-to-end principle
- up service more control
- little requirements of link layer

Virtual circuit and datagram networks

- datagram networks
    - no call setup at network layer, routers have no state about end-to-end connections, **destination address** is the index of forwarding.

    Longest Prefix Matching

    The forwarding table:

Prefix Match	Link Interface
……	0
……	1
otherwise	2

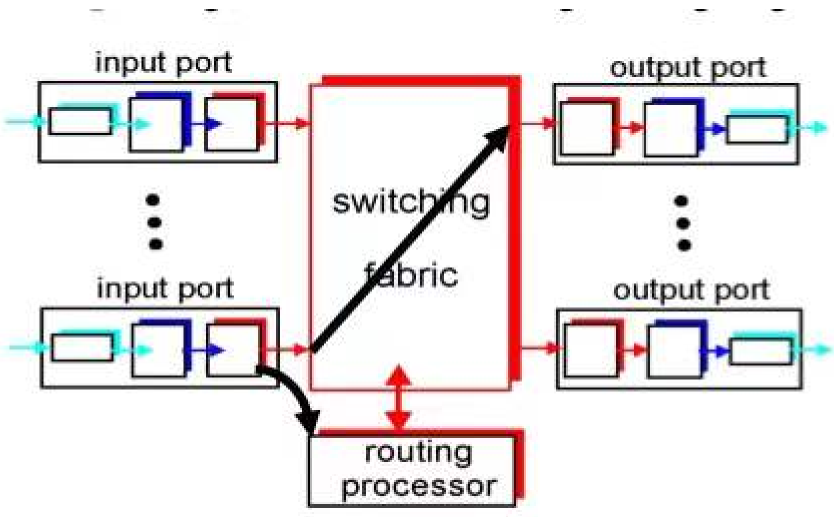
- virtual circuit
    - path from source to destination, VC numbers, entries in routers along path.
    - a packet carries VC number as the index of forwarding, which could be changed on each link.

    The forwarding table:

Incoming Interface	Incoming VC#	Outgoing Interface	Outgoing VC#
1	12	3	22
2	63	1	18
3	7	2	17
1	97	3	87
….	…	…	…

Inside a router

Input port, output port, routing processor and switching fabric

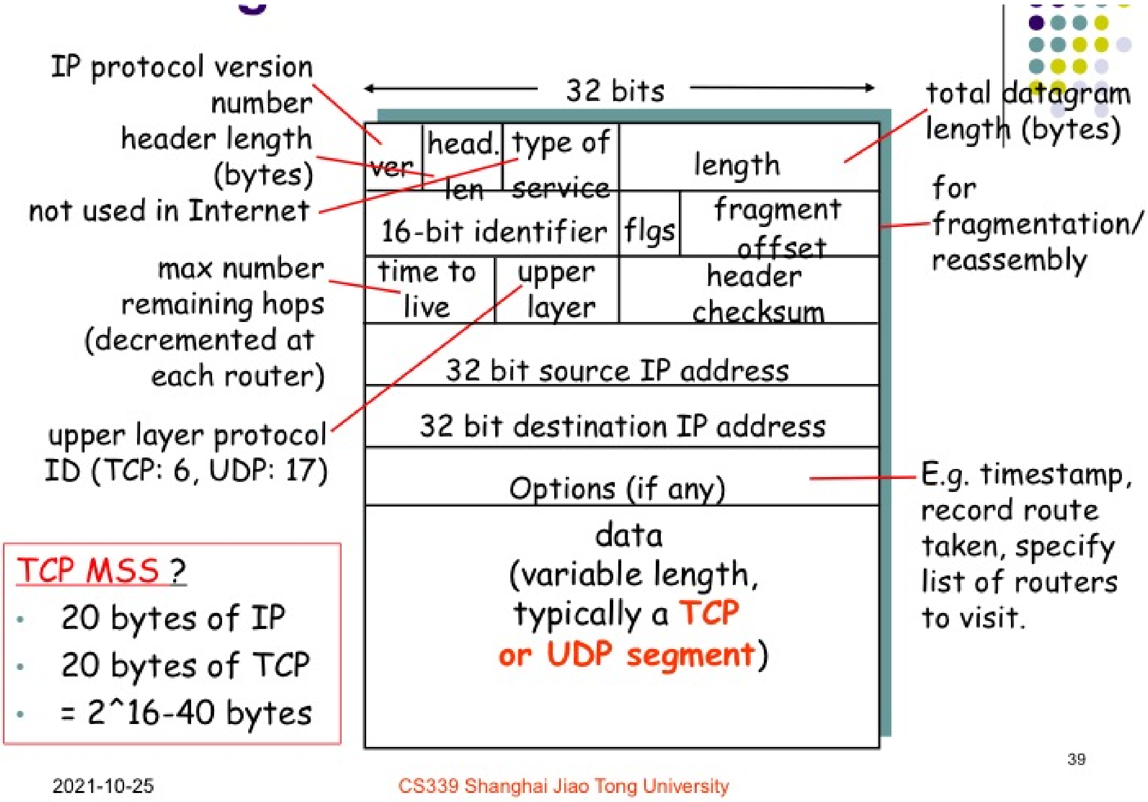


- Input port: lookup output port using forwarding table in memory, queue for forwarding if datagrams come faster than the forwarding rate.
  - queue: Head-of-the-Line blocking: queued datagram at the front block others
  - buffer
- switching fabric: memory / bus / crossbar
- output port: queue when datagrams arrive from fabric is faster than the transmission rate.
  - packet switching: choose a packet to transmit
  - buffer: the design of the buffer

$$average\ buffer = RTT * C$$
$$recent:$$
$$average\ buffer = \frac{RTT * C}{\sqrt{N}}$$

IP: Internet Protocol

1- IP datagram



Some IP options:

Security, strict source routing, loose source routing, record route, timestamp

2- IP fragmentation

MTU(Maximum Transmission Unit) for network links.

Those datagrams fragmented will be reassembled at final destination.

ID	flags	offset
The ID for the original datagram	0 for the last datagram, 1 for others	the bytes of data

3- IP addressing

IP address: 32-bit identifier for interface of hosts and routers.

IP network: all computers addressed with a common, identical network id. ----> divided into different networks: subnetting

VLSM: Variable Length Subnet Mask

CIDR(Classless InterDomain Routing): Assign class C addresses in contiguous blocks of 256 addresses so that multiple entries in routing table can be aggregated into one.

4- the get-process of an IP address

ISP: from ICANN

smaller ISPs: from ISP's subnetting

a host: 1) hard-coded by system admin in a file 2) DHCP(dynamic host configuration protocol)

DHCP

- DHCP discover
- DHCP offer
- DHCP request
- DHCP ACK

5- NAT(Network Address Translation)

WAN side addr	LAN side addr
138.76.29.7, 5001	10.0.0.1, 3345

controversial for: violation of the independence layering principle, violation end-to-end argument, some think address shortage should instead be solved by IPv6.

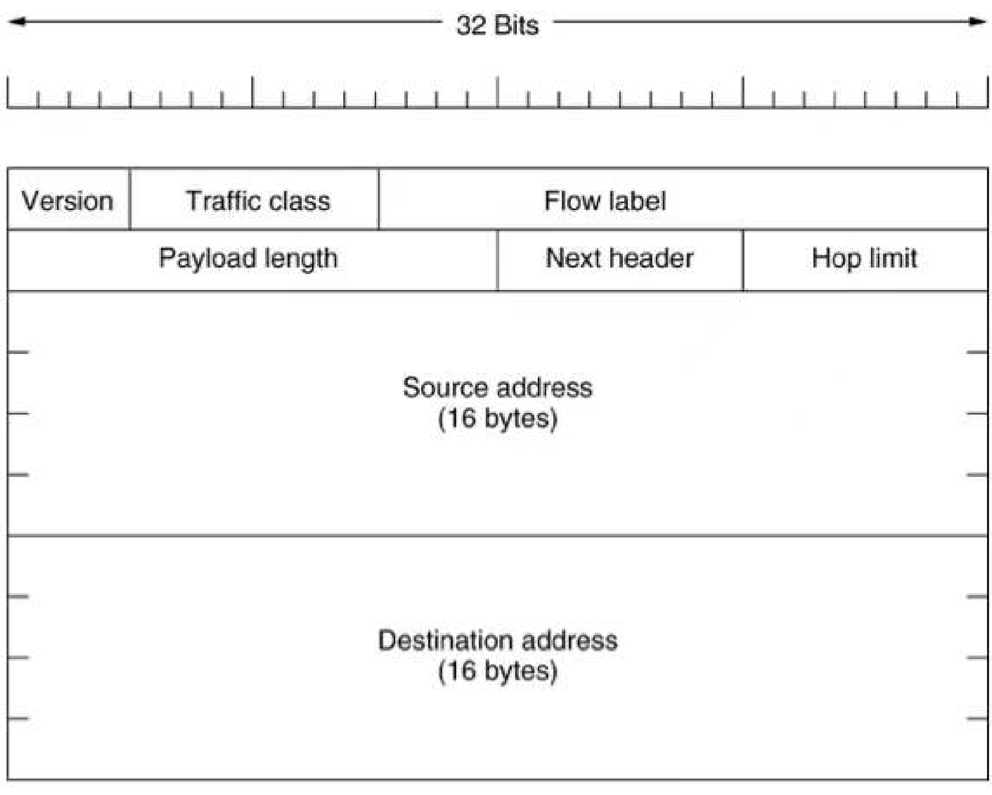
NAT traversal problem:(?)

- statically configure NAT to forward incoming connection requests at given port to server.
- universal plug and play internet gateway device protocol
- relaying

6- ICMP(Internet Control Message Protocol)

7- IPv6

- motivations:
  - address space to be completely allocated
  - header format helps speed processing/forwarding
  - header changes to facilitate QoS



classification of ipv6:

- Unicast
- multicast

- anycast

Routing Algorithms

routing algorithms classification:

- global / local: whether a node know the complete topology information
- static / dynamic: the routes change slowly or quickly over time
- load-sensitive / load-insensitive

1- link state routing(LSR) - Dijkstra

Each router learns the entire network topology through exchanging information with all other routers.

each router:

- discover neighbors, measure delay and cost
- construct a packet and flood it
- calculate the least path to every other routers with all the information: maintain a set of dots

Time Complexity: O(n^2)/O(nlogn)for heap

One problem: oscillations possible

2- distance vector

Each router contains a table with least cost to every other router.

each router:

- discover neighbors, measure delay
- exchange distance vector with neighbors
- recalculate distance vector

$$d_x(y) = min_v c(x,y) + d_v(y)$$

Once the vector has changed, there is need to send information to its neighbors.

One problem: count-to-infinity problem.

Solution: poisoned reverse could solve two-node situation.

	LSR	DVR
message complexity	O(nE)	O(n)
computation complexity	O(n^2)	O(n)
speed of convergence	1 iteration	n iterations
robustness	robust	an incorrect node calculation diffused entire network

5- hierarchical routing

reasons:

- The network scale is relatively large
- The internet is hierachical

inter-AS	intra-AS
single domain, no policy decisions needed	admin needs to control
save the size	save the size
sometimes policy over performance	focus on performance

Most common intra-AS: RIP, OSPF, IGRP

Most common inter-AS: BGP

Routing in the Internet

1- RIP

A kind of DV algorithm.

DV advertisement exchanged among neighbors every 30 sec in UDP packets.

distance limited to 15 hops, take 16 as infinite to avoid count-to-infinity.

2- OSPF

A kind of LS algorithm.

Advertisement at least once every 30 min.

3- BGP(Border Gateway Protocol)

iBGP connection : the BGP connection between internal routers

eBGP connection: the BGP connection between gateway routers

BGP attribute: 1)AS-PATH; 2)NEXT-HOP contains the path, and cancel the ring of routing.

hot potato routing algorithm : find the interface of the minimum cost, without considering what's out the AS.

router choice algorithm : choose path in the order of: 1) router local preference; 2) the shortest AS-PATH; 3) hot-potato 4) router identifier

broadcast and multicast routing

1- broadcast routing

deliver packets to all other nodes

- flooding: when a node receives broadcast packet, it will send copies to all other neighbors.
- controlled flooding: 1) use TTL/age; 2)node keeps track of packet ID already broadcasted 3)only forward packet

- spanning tree