Computer Networks (UE18CS301)

Unit 4

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1 Network Layer

- The network layer has two main functions: **forwarding** and **routing**.
- **Forwarding**: The task of taking packets from the input link of a router and moving them to the appropriate output link of the router. This is done entirely within the router (layer 3 device).
- **Routing**: Determining the path to be taken by a packet from one device on the network to the next.
- Routers contain **forwarding tables** that take the header value of the incoming packet, use it as an index into the forwarding table and determine the appropriate output link

1.1 Services offered by Network Layer

- *Guaranteed Delivery*: A guarantee that the packet will reach its intended destination. This guarantee can include an upper bound on the transmission delay or not.
- *In-order packet delivery*: Packets reach the destination in the same order that they were sent.
- **Guaranteed Min. Bandwidth**: The network layer emulates a link of fixed transmission bit rate. As long as sender sends bits at a rate less than or equal to this fixed rate, no packets will be lost.
- *Guaranteed Maximum Jitter*: The interval between transmission of 2 packets at the sender should be the same as the interval between their receipt at the receiver, or this spacing should change only within some constant value.
- *Security Services*: Using a secret key that only the source and destination hosts know, the network layer provides confidentiality of the transport layer to the network layer. Also the network layer offers data integrity verification and source authentication.

2 Router Architecture

Router is a layer-3 device that implements network layer functionality at hardware level. The components of a router are:

2.1 Router Components

- *Input Ports*:
  - Link termination at the physical layer, as well as link-layer functionalities are performed here.
  - The input port also maintains a queue of incoming packets. These packets are then sent to the appropriate output links as described below.
  - Most importantly, the lookup function is performed at the input port. The forwarding table is consulted and the appropriate output port is decided for the packet.
- *Switching Fabric*
  - A network of connections that connects the input and output ports of the router.

- *Output Ports*:
  - Stores packets received from the switching fabric, and performs the link layer and physical layer functions for the outbound links of the router.
  - For bidirectional links, an output port and an input port on the same line card are paired together. (Line card is a PCB containing multiple input ports).
- *Routing Processor*:
  - It executes routing protocols, maintains routing tables and link state information, and computes the forwarding table.

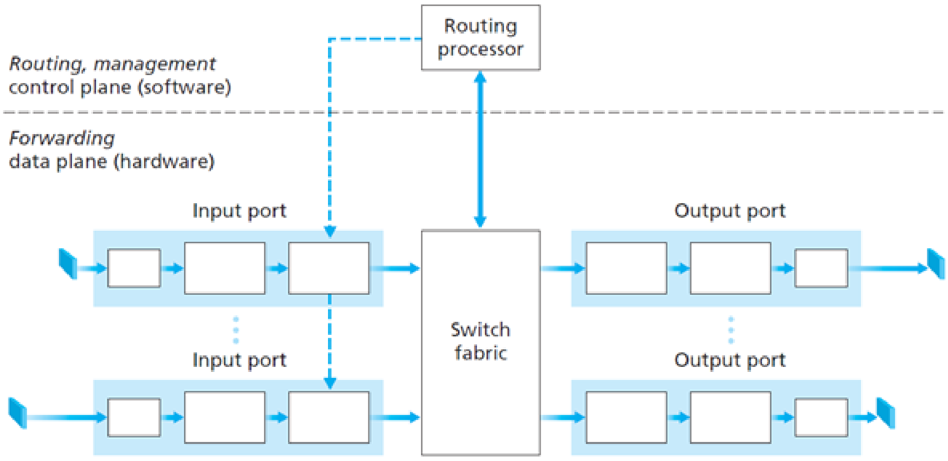


Figure 1: Router Architecture

- The forwarding plane is implemented entirely in hardware as software implementations will not keep up with high rates of incoming data from the input ports. (eg: with 10 Gbps link and 64 byte datagram size, each datagram has to be processed in 51.2ns. If there are N ports on a single line card, then the processing time becomes $51.2/N$ ns.
- The forwarding table lookup at the input port is sped up by more efficient searching algorithms, as well as faster memory like DRAM and SRAM (used as secondary DRAM) on the chip itself.
- Technologies like **TCAM** (Ternary Content Access Memory) deliver $O(1)$ lookup time for a given key (in this case a 32-bit IP Address).
- There are three main types of switching techniques:
  1. *Switching via Memory*:
     - The packets arrive at the input port, and an interrupt is sent to the routing processor.
     - The packet is copied into the processor memory. Lookup is performed by extracting the header from the packet.
     - Then the packet is copied again to the buffer of the appropriate output port.
     - As only one read/write can take place at a time over the shared bus, only one packet can be switched at a time. Also if the memory bandwidth is B packets per sec, then the overall switching bandwidth is less than $B/2$ packets/s.
     - In modern routers that use memory switching the forwarding computation is done in the input port itself, and the processor only handles the movement of packets to the correct output.
  2. *Switching via bus*:

- The input port prepends a switch label (header) to each packet and sends it along the shared bus to all the output ports.
- The packet will be discarded by all the output ports that don't match the switch label.
- Here too, only one packet can use the bus at a time. The switching speed is bottlenecked by the bus speed.
- This is commonly used for small area or enterprise networks.

3. *Switching via interconnection network*:
    - Crossbar switches are switches that use $2N$ connections to connect N output and N input ports to each other.
    - **Crossbar switches** allow multiple packets to be switched in parallel, unless they are destined for the same output port, in which case they have to queue at the input.
    - **Multistage switches** are built from layers of smaller switches for further parallelism in the switching process.
    - Cisco CRS routers use **multiple switching planes** in parallel. (8 planes, each with 3 stage switching logic, totally upto 100s of Tbps switching speeds).

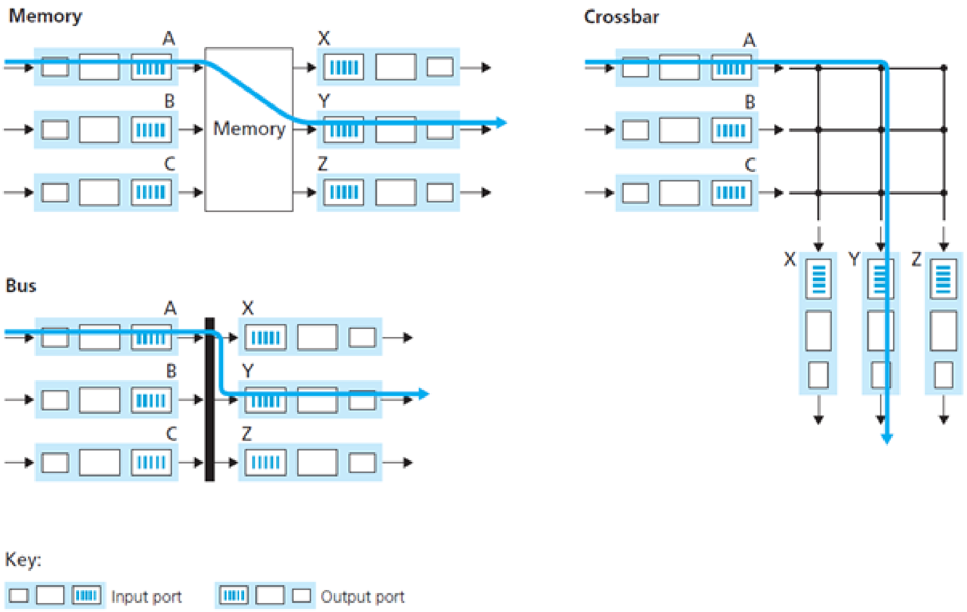


Figure 2: Switching Technologies

2.2 Queuing in Routers

- Let the input and output ports have a speed of R_{link} and the switching rate be R_{switch} which is N times as fast as R_{link}. (N being number of input and output ports).
- It is assumed here that all the incoming packets are destined for one output port.
- This setup leads to negligible queuing at the input buffer as N packets can be switched through the fabric in the same time that it takes N packets to arrive at all the input ports.
- At the output ports however, only one packet can be transmitted at a time. In the time that a single packet is transmitted out on the output port, there are N packets arriving at that output port.
- The packets that are not being sent out immediately must queue at the output port.

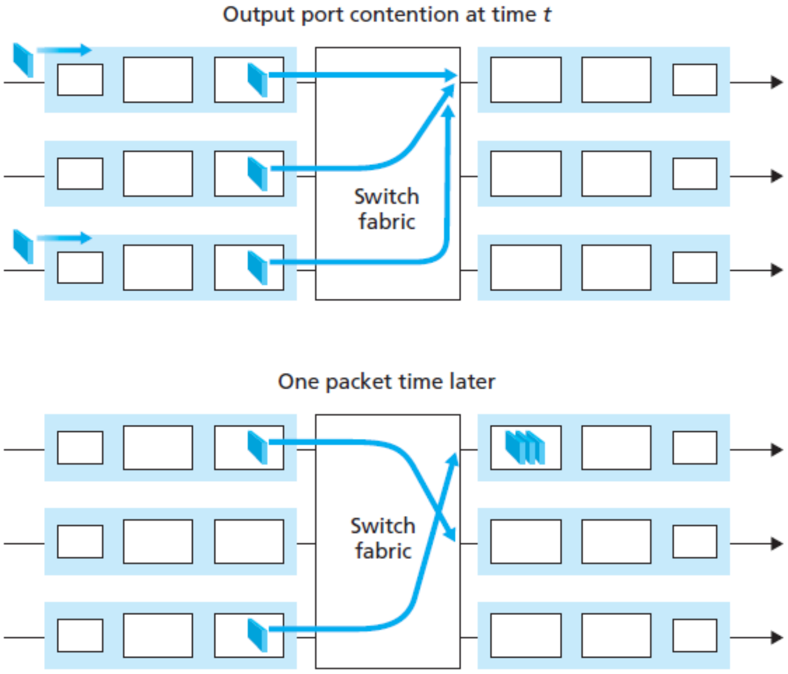


Figure 3: Output Port Queuing

- The ideal buffer size B was for many years calculated as

$$B = RTT \times C \tag{1}$$

  where RTT is the average round trip time for a packet and C is the link capacity. This was calculated based on analysis of a relatively smaller number of TCP flows.

- With large scale networks, this is modified to

$$B = \frac{RTT \times C}{\sqrt{N}} \tag{2}$$

  where N is the number of TCP flows.

- Too much buffer size however leads to delays, caused by longer RTTs.

2.2.1 Output Queue Scheduling

- The objective of this scheduling algorithm is to select one packet from the output queue for transmission.

- Basic algorithm for this is **FCFS**, also referred to as FIFO.

- **Priority scheduling** of packets is implemented as 2 o more queues (sorted by priority). The packets are sent out from the output queue that has buffered packets and has the highest priority.

- In **Round Robin Scheduling**, the arriving packets are sent into queues that are based on the class of the packet. Each queue is served an equal amount of time.

- In **Weighted Fair Queuing** (WFQ), each queue has a weight attached to it. The queue is served for a slice of time that is proportional to its weight. This policy guarantees minimum bandwidth per class of packet.

2.2.2 Output Queue Packet Management

- If a packet arrives at the output port and the buffer is full, then packets have to be dropped.
- If the currently arriving packet is dropped, the policy is called **tail-drop**.
- Packets that are currently in the queue can also be dropped on a priority basis to make room for the incoming packet.
- Algorithms such as RED (*Random Early Detection*) are used to mark packets that signify that congestion is occurring in the network.

2.2.3 HOL Blocking

- Suppose packets at the input port are scheduled in an FCFS manner. Let there be 2 packets destined for the same output port at the head of the input queues.
- The queued packet in an input queue must wait for transfer through the fabric (even though its output port is free) because it is blocked by another packet at the head of the line. This phenomenon is called **Head Of Line Blocking** or HOL Blocking.
- It can be shown that HOL Blocking can cause the input queue to grow without bound, under certain assumptions, as soon as the packet arrival rate on the input links reaches only 58 percent of their capacity.

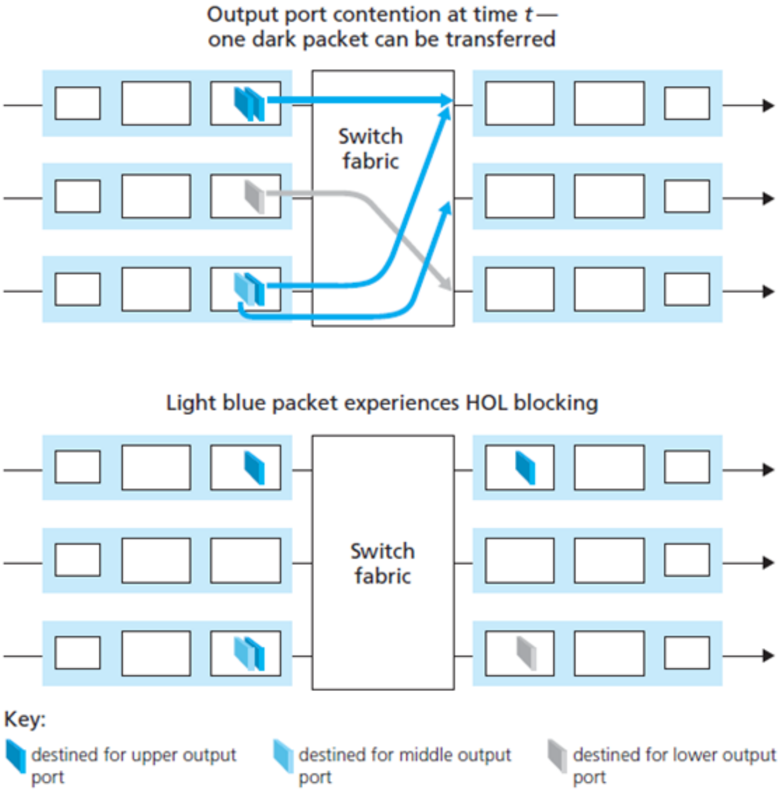

Output port contention at time *t*—
one dark packet can be transferred
Switch fabric
Light blue packet experiences HOL blocking
Switch fabric
Key:
destined for upper output port
destined for middle output port
destined for lower output port

Figure 4: Example for HOL Blocking

3 Internet Protocol v4 (IPv4)

- IP is the most common network layer protocol. Its two most common functionalities are *addressing* and *forwarding*.

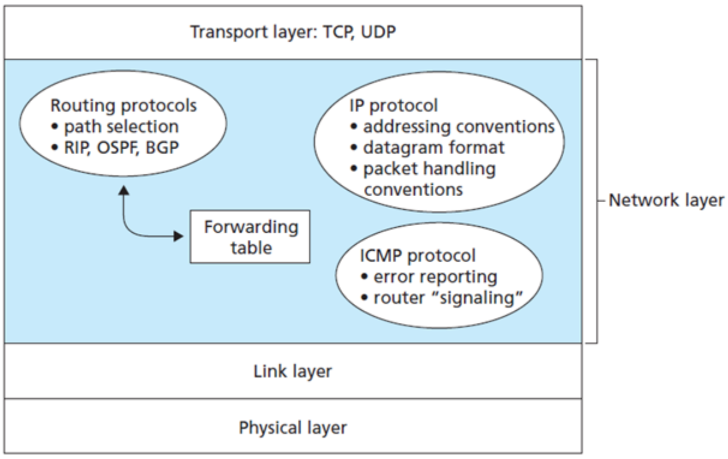


Figure 5: Network Layer Protocols

- The network layer of TCP/IP stack has three main components:
  1. Routing protocols to fill forwarding table entries in the routers
  2. IP protocol for forwarding/addressing
  3. Error reporting and network layer info delivery service which is called ICMP (Internet Control Message Protocol)

3.1 IPv4 Datagram Format

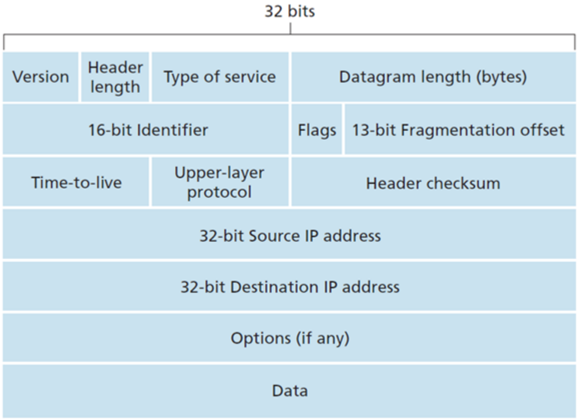


Figure 6: IPv4 Datagram Format

- *Version Number*: 4 byte number indicating IP version (4 or 6). This indicates the rest of the datagram format.
- *Header Length*: Including the options field. Without the variable-length options the IP header is 20 bytes long.
- *Type of Service* (ToS): Special requirements like low delay or high throughput for certain datagrams are indicated in this field. This distinguishes packets from services like real-time telephony from non real-time applications like FTP. The policies set by router admin indicate the implementation of these services.

- *Identifier, Flags, Frag offset*: 3 bit flags, 13 bit offset is used during IP Fragmentation used to split large IP datagrams.
- *Time To Live* (TTL): To ensure that datagrams do not stay forever in the network. The TTL is decremented at each router and removed from the network with a time limit exceeded error when the TTL reaches 0.
- *Upper Layer Protocol*: Value indicating transport layer protocol to which to transmit, analogous to port number in transport layer header (value 6 for TCP, 17 for UDP).
- *Header Checksum*: The header (including options) is split into words of 2 bytes (16 bits) and then the 1's complement of the sum (with carry wrapped around) is sent as the checksum.
- *Options*: Not included in version 6, the options specify information like record route taken, specify list of routers to visit, and timestamps.
- *Source and Destination IP Addresses*

3.2 Fragmentation in IPv4

- The largest possible amount of data that a link-layer frame can carry is defined by the MTU (Maximum Transmission Unit). Each link-layer protocol has its own MTU value defined.
- The solution to this is fragmentation, wherein the large IP Datagram is split into smaller datagrams, each of which is sent on a separate link layer frame.
- The receiver end reassembles the fragments in order to send to the transport layer. This is done at the host system end and not in the routers.
- The Identification, flags and offset fields help in reassembly.
- eg: A 4000 byte datagram (20 header + 3980 content) arrives at a router. The output link has MTU of 1500 bytes (20 for IP header + 1480 data). Hence the 3980 bytes of incoming data is split into 3 chunks of 1480, 1480 and 1020 bytes.
- The offset fields are set in multiples of 8 bytes. The frag flag value is 1 for all the fragments except the last one (0 indicates the end of that IP datagram).
- All the fragments have the same ID as the original IP datagram.
- Fragmentation allows for the use of multiple Link layer protocols on one path.
- Disadvantages of fragmentation:
  1. Increases complexity of routers and end systems with fragmentation and reassembly hardware/software.
  2. Vulnerable to DDoS attacks, caused by invalid fragments inserted or invalid offset values that make fragments overlap, which make the OS crash during reassembly.

3.3 IPv4 Addressing

- IPv4 addresses are 32 bits long. They are written as 4 groups of 8 bits, each group converted to base 10 and written as a separate number separated by a dot (.)
- This notation is called the dotted decimal notation. eg: The IP Address `11000001 00100000 11011000 00001001`, it is written as `193.32.216.9` .
- Every interface on every host and router on the internet should have a globally unique IP Addresses (except for those behind NAT).
- One portion of an IP Address is decided by the **subnet** to which that interface is connected. A subnet is a collection of computers
- The IP Address consists of 2 parts: a subnet identifier and a host identifier. The first n bits of the IP Address are subnet ID, and the last $32 - n$ bits are the host ID.

- To determine the subnets, detach each interface from its host or router, creating islands of isolated networks, with interfaces terminating the end points of the isolated networks. Each of these isolated networks is called a subnet.
- In every subnet, the addresses `0.0.0.0` and `255.255.255.255` are reserved as broadcast addresses.

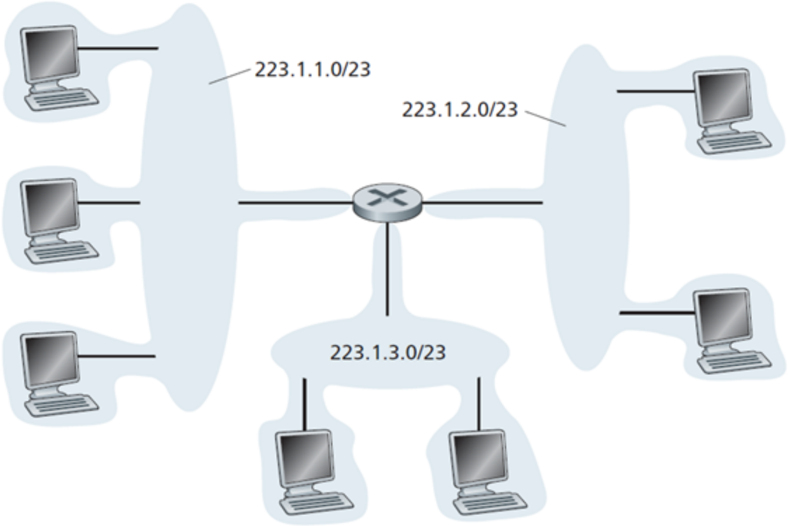


Figure 7: Subnet Addresses

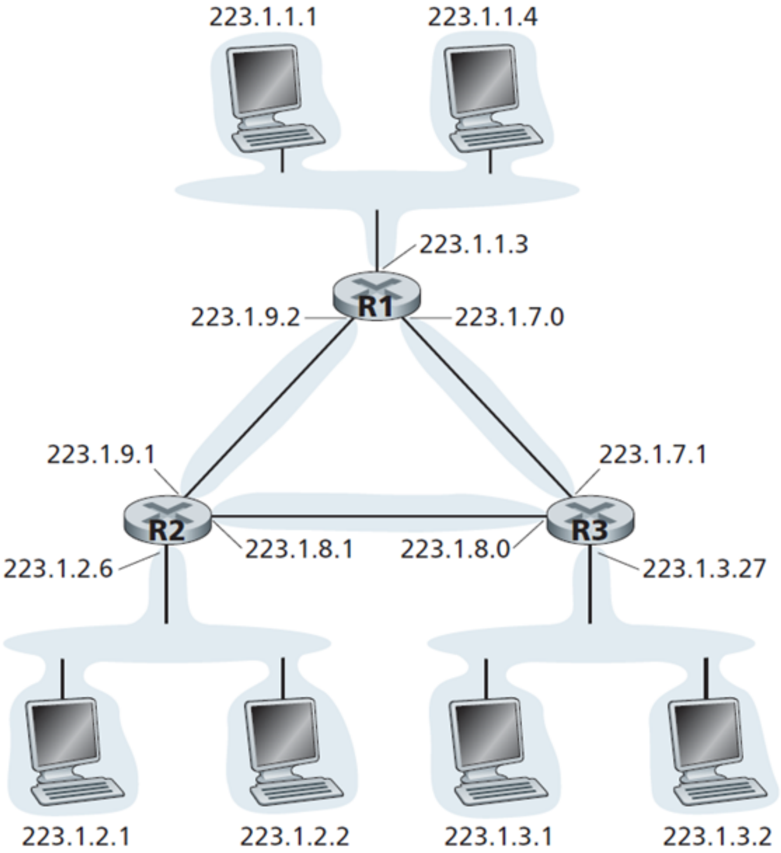


Figure 8: Routers connecting 6 subnets

- The notation *a.b.c.d/x* is called **Classless Inter-Domain Routing** or CIDR. The x is called the subnet mask, and indicates that the first x bits of the IP Address are the subnet identifier.
- The previous type of IPv4 addressing was called **classful addressing**. Classes A, B and C were defined as having subnet identifiers of size 8, 16 and 24 bits respectively.
- Class A Addresses have the first octet in range 1-126, Class B addresses have range 128-191 and class C addresses have range 192-223.
- The classful addressing scheme led to inefficient use of a limited number of IP Addresses. (eg: if a company with 2000 hosts is allocated a Class B address then there are $65536 - 2000 = 63534$ unused IP Addresses in that block which cannot be used by another organization).
- Organizations obtain blocks of IP addresses from their respective ISPs. ISPs in turn obtain larger address blocks from the *Internet Corporation for Assigned Names and Numbers* (ICANN).
- ICANN handles IP address allocation as well as DNS server management and domain name allocations/disputes. ICANN allocates addresses to regional internet registries like APNIC (Asia Pacific), LACNIC (Latin America & Caribbean), ARIN (North America), RIPE (Europe) and AFRINIC (Africa).

4 Dynamic Host Configuration Protocol (DHCP)

- This is an **application-layer** protocol that is used by host machines on a network to get IP Addresses and other details such as the DNS server's IP Address and the IP Address of the first hop router (aka the *default gateway*).
- DHCP can be configured to give the same IP address to a machine each time it connects to a network, or different **temporary** IP Addresses each time.
- Properties of DHCP:
  1. **Client-Server Protocol**: The DHCP server (often integrated into the router) maintains a list of free IP Addresses from which new ones are allocated and to which the unused ones return.
  2. **Plug-and-Play Protocol**:It automates the process of IP address configuration that would otherwise have to be done manually for each system by the network admin.

4.1 4-step Process (DORA)

- *Step 1*: **Discovery**
  - The newly connected host searches for a DHCP server to provide it information. It does this by sending a UDP segment to **port 67 on the server**, with the IP datagram having source IP as `0.0.0.0` and destination address as `255.255.255.255`.
  - The destination address `255.255.255.255` indicates that the UDP segment is to be sent to all the hosts on the network, in a process called *broadcasting*.
- *Step 2*: **Offer**
  - A DHCP server receiving a broadcast discovery message replies with a message containing an IP Address, the transaction ID of the discovery message and a lease time that indicates the validity of the offered IP Address.
  - This message is also broadcast to all hosts in the network. It is sent to **UDP Port 68** on the client.
- *Step 3*: **Request**
  - The client chooses one of the offers, and sends a request message back to the server from which that offer was received.
- *Step 4*: **Acknowledgement**

- The DHCP server replies to the request with an acknowledgement message that confirms the information sent in the offer message.

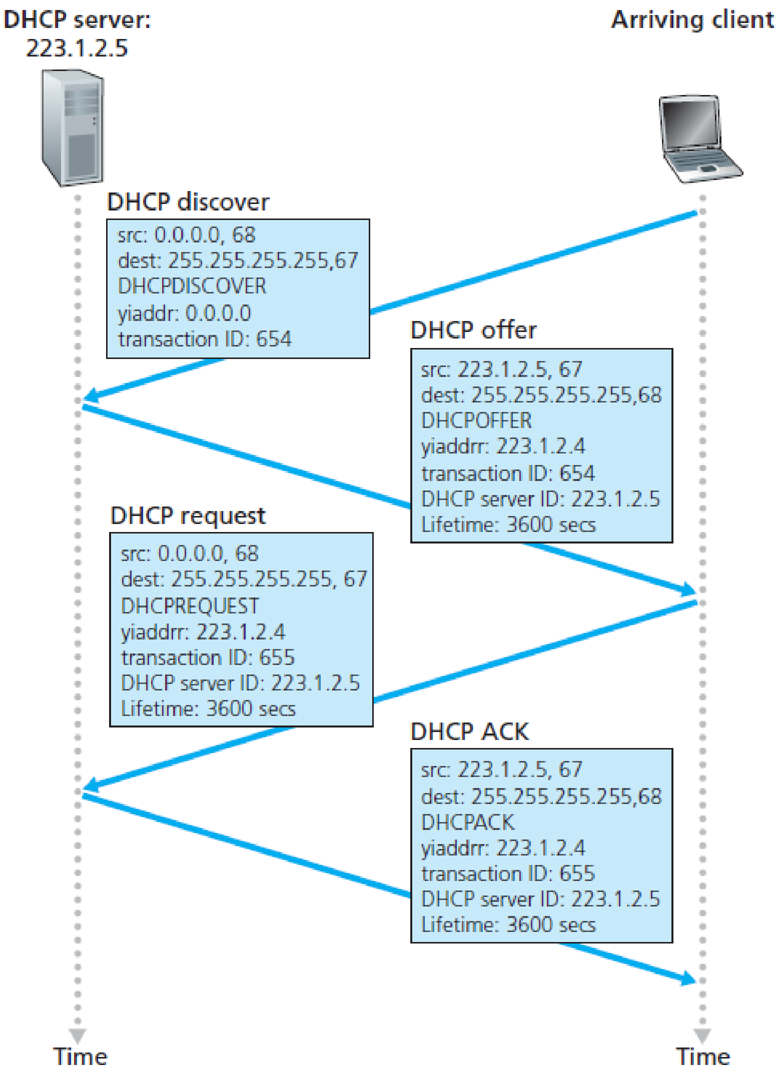


Figure 9: DHCP Client-Server Interaction

5 Network Address Translation (NAT)

- NAT is a technology that is used to map one IP Address space to another, by modifying network address information in the IP header of packets while they are in transit across a traffic routing device.
- This technique avoid the need to assign a new unique IP address to every host that joins a network, in case a network is moved or the ISP is changed.
- In the face of IPv4 address exhaustion, NAT is now commonly used to conserve the IP address space.
- A NAT-enabled router translates the private address of the host in the local network, to the address of the router interface that is exposed to the outside internet or WAN.
- As all hosts in the local network appear to have the same IP Address, they are distinguished based on port numbers.

- The following are the controversial aspects of NAT as raised by the IETF:
  - The use of port numbers for addressing hosts within a private network is in opposition to the requirement that port numbers be used to address application-layer processes running on a host.
  - Routers should only be restricted to managing layer 3 addresses (IP Addresses) and below. But the manipulation of IP Addresses as well as port numbers (which are layer 2 information) is in opposition to this.
  - To solve the shortage of IPv4 addresses, IPv6 is meant to be used instead of NAT.
  - NAT requires network applications to be coded differently. In particular NAT affects P2P applications like file sharing and voice call applications, as these require the setup of a direct TCP connection between 2 peers. (eg: if a peer B is behind a NAT, it cannot act as a server to accept TCP connections from A. A instead requests an intermediate C to tell B to start a TCP connection with A directly. This hack is called **connection reversal**).

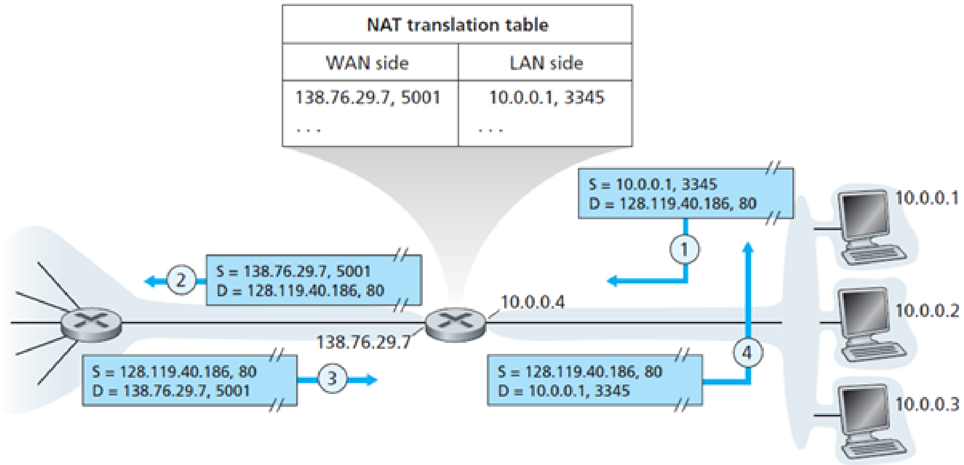


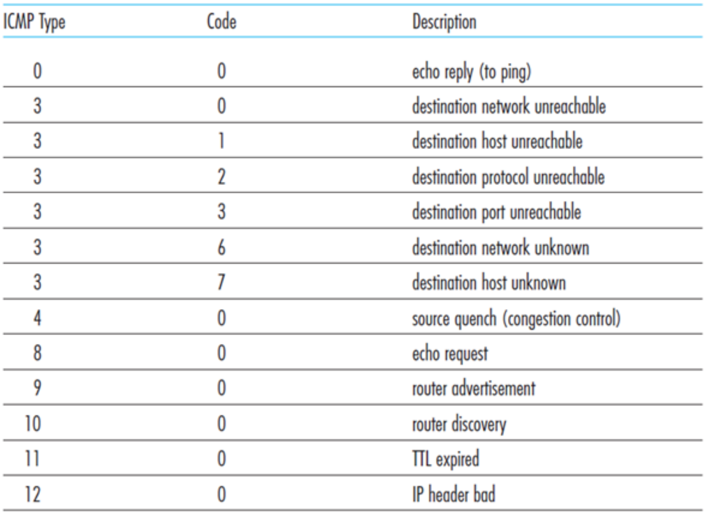
Figure 10: Working of NAT

6 Internet Control Message Protocol (ICMP)

- ICMP is the network layer's error reporting and information delivery service.
- It acts as an intermediary above the network layer, and ICMP messages are carried as IP Payloads (like TCP or UDP segments).
- ICMP messages have a type field, a code field and contain the first 8 bytes of the IP datagram that generated that error.
- The `ping` program sends out type 8 code 0 (echo request) messages and receives type 0 code 0 (echo response) messages in case of a successful delivery. The `ping` program is used as a network diagnostic tool.
- The source quench message (type 4 code 0) is a form of congestion control that is implemented at the network layer. It is sent out by a congested router to a host to tell that host to reduce its transmission rate.

6.1 Traceroute

- `traceroute` is a program that is used to determine the path taken by IP Datagrams between 2 hosts on the internet. It makes use of ICMP messages



ICMP Type	Code	Description
0	0	echo reply (to ping)
3	0	destination network unreachable
3	1	destination host unreachable
3	2	destination protocol unreachable
3	3	destination port unreachable
3	6	destination network unknown
3	7	destination host unknown
4	0	source quench (congestion control)
8	0	echo request
9	0	router advertisement
10	0	router discovery
11	0	TTL expired
12	0	IP header bad

Figure 11: ICMP type and code information

- The sending host sends out IP datagrams that carry UDP segments having invalid port numbers, and contain TTL values of 1, 2, 3, ..., n.
- The n^{th} router receiving the n^{th} datagram sees that the TTL has just expired. It sends back an ICMP message with type 11 code 0 indicating TTL expired.
- The TTL expired message contains the IP Address and name of the router. The source estimates the round trip time of that ICMP message from the timer, and the name/address of the router from the ICMP message.
- The `traceroute` sender stops sending the IP datagrams when it receives an ICMP message of type 3 code 3 (unreachable port), as the UDP segment that was sent contains an invalid port number.
- The client program must be able to isntruct the OS to generate IP datagrams with specific TTL values, and must be aware of the incoming ICMP messages.

7 Internet Protocol v6 (IPv6)

- IPv6 aims to solve the address space exhaustion problem that is a part of IPv4 due to its limited number of addresses (2^{32}) and the increasing number of hosts on the internet.
- IPv6 also included enhanced addressing capabilities as well as other features that were learned from the experience of implementing IPv4.

7.1 Features of IPv6

- *128-bit addresses*, and a new class of addresses called *anycast* addresses that allow datagrams to be transmitted to any one of a group of hosts (eg: to send an HTTP GET to the nearest of a number of mirror sites that contain a given document.)
- **Flow labelling and priority** is a new feature of IPv6 that enables labeling of packets belonging to particular flows for which the sender requests special handling, such as a non-default quality of service or real-time service. (eg: audio/video is treated as a flow, but file transfer or e-mail may not).
- IPv6 **removes** the responsibility of **fragmentation and reassembly** from the routers and puts it only on the end systems. In case an incoming IPv6 datagram is too large to be forwarded over the next link, an ”Datagram too large” ICMP message is sent back and the sender resends the datagram in smaller chunks.

- As transport layer and link layer protocols compute data checksums, the redundancy of a **header checksum was removed** from IPv4.
- The **options field** of IPv4 is **removed**, but the "next header" field in the IPv6 format points to the options that can be the next header in the IPv6 datagram just like TCP or UDP segments.

7.2 IPv6 Datagram Format

- *Version*: 4 bit version number (1010 in this case)
- *Traffic Class*: 8 bits, similar to the Type of Service field in IPv4
- *Flow Label*: 20 bits to identify the flow.
- *Payload Length*: 16 bits to indicate the length of the data field in the datagram (after the 40 byte header)
- *Next Header*: The upper layer protocol to which the data must be delivered (value of 6 indicates TCP, 17 indicates UDP).
- *Hop Limit*: Similar to a TTL field.
- *Source, Destination IP Addresses*: 128 bit IP Addresses.

7.3 IPv6 Addressing

- IPv6 Addresses are written as 8 groups of 4 hexadecimal digits each, separated by a colon (:). This is called the *colon hexadecimal* notation.
- In each section of 4 hex digits, the leading zeros can be ignored (eg: 0A12 can be written as A12, 00FF can be written as FF and 0002 can be written as 2)
- Consecutive sections of zeros can be compressed into the double colon symbol (::). This compression can be applied only once, and can be applied anywhere on the address.

7.3.1 Types of IPv6 Addresses

- **Unicast Address**: Identifies a single interface on a router/host machine.
- **Anycast Address**: It defines a group of computers that share a single address. A packet with an anycast address is delivered to the most reachable member of that group. Anycast addresses are allocated from the unicast block.
- **Multicast Address**: All members of the group of computers receive a copy of a packet that is sent to a multicast address.

7.4 Interface ID

- The Interface ID of a router or host interface is configured from its manufacturer-supplied MAC address (Layer 2 address). The MAC address is 48 bits in length, written as 6 groups of 2 hex digits each.
- This is done by first inverting the 7th bit from the left of the MAC address (1 to 0 or 0 to 1).
- Following this, the result of the above operation is split into 2 groups, the hexadecimal digits FFFE added in between to get a 64-bit Interface ID.
- eg: For the given MAC address `F5-A9-23-14-7A-D2`, the corresponding Interface ID is written as `F7A9:23FF:FE14:7AD2`
- If the physical address is not given as a 48-bit MAC address but instead as a 64-bit EUI address (Extended Unique Identifier), then the process is simply to invert the 7th bit from the left.
- eg: Given the EUI `F5-A9-23-EF-07-14-7A-D2`, the interface ID is `F7A9:23EF:0714:7AD2`

7.5 Unspecified Address

- The address `::/128` (128 0s) is called the unspecified address.
- The unspecified address is used during bootstrap when a host does not know its own address and wants to send an inquiry to find it. Since any IPv6 packet needs a source address, the host uses this address for this purpose.
- The unspecified address cannot be used as a destination address.

7.6 Loopback Address

- The address `::1/128` is called the loopback address.
- The loopback address is used to create datagrams that do not enter the network but only go till the link layer, and then loop back till the application layer.
- Loopback addresses are used for diagnostic purposes to test functionalities of network applications.

7.7 Unique Local Unicast Address

- The prefix for this block is `FC00::/7`.
- The 8th bit indicates whether the address is allocated locally or by an authority. The next 40 bits are randomly selected by the site. The random block reduces the chances of duplication of these addresses.
- The next 16 bits are the subnet ID and the next 64 bits, are the Interface ID.
- The unique local unicast address is used for *site-level* addressing. They are not routable on the global internet.

7.8 Link-Local Unicast Address

- Link-local addresses have the prefix `FE80::/10`.
- The remaining 54 bits are 0, and the next 64 bits are the Interface ID.
- Link local addresses are used only within a single link or a network segment. They are also not routable on the global internet.

7.9 Global Unicast Address

- This consists of a 48-bit **global routing prefix**, a 16-bit **subnet ID** and a 64-bit **interface ID**
- The subnet ID indicates which subnet of the network the host belongs to. The first subnet has an ID of 0000, the second has ID 0001 and so on.

7.10 Autoconfiguration

- The host first creates a link local address for itself as described above (`FE80::` followed by 54 zeros and the 64 bit interface id).
- The host verifies the uniqueness of the link-local address by sending out a *neighbour solicitation* message, waiting for the reply in the form of a *neighbour advertisement* message. If the link-local address is not unique, the procedure fails and the host must use DHCP to get an IPv6 address.
- The host sends a *router solicitation* message, and waits for a *router advertisement* message. The router advertisement message contains the 48-bit global routing prefix and the 16-bit subnet ID. From these 2 and the 64-bit interface ID, the global unicast address of the host is generated.
- If the router cannot help with the process of autoconfiguration, then this is informed by setting a flag bit in the router advertisement message.

7.11 Renumbering

- Renumbering is a scheme that allows the global routing prefix (first 48 bits of the IPv6 address) to change.
- This is useful when a network's service provider changes. The router now advertises this new routing prefix, but allows the use of the old prefix for a short while before disabling it.
- Therefore for a short period during transition, the network has two valid global routing prefixes.
- One issue with renumbering is the working of DNS which must also be made aware of the new routing prefixes and associate those with the domain names. A next generation DNS protocol is being created to provide support for this.

7.12 Transition between IPv4 and IPv6

7.12.1 Dual Stack Approach

- In this approach, all IPv6 nodes also have a complete IPv4 implementation inside. These nodes have both IPv4 and IPv6 addresses, and they can create both types of datagrams.
- In order to know whether a neighbouring system is IPv4 or IPv6 capable, DNS is used. DNS returns an IPv4 address for an IPv4 compatible machine and likewise for IPv6. This means that the node issuing the request itself must be IPv6 compatible, or else DNS will only return IPv4 addresses.
- In the below figure, since the nodes C and D are IPv4 compatible only, the extra information carried in IPv6 headers coming from B (eg: flow labels) is removed and not sent to the other IPv6 compatible nodes E and F.

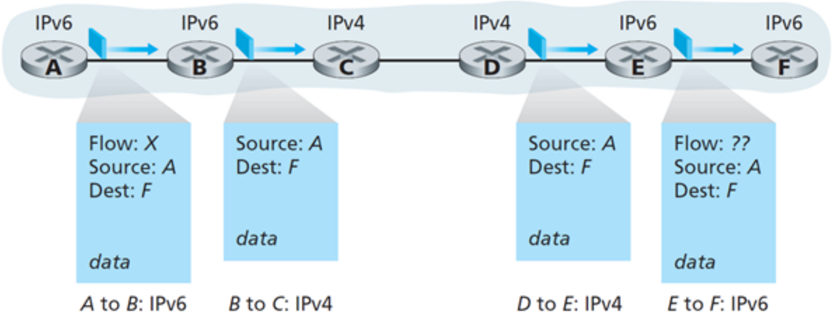


Figure 12: Dual Stack Approach

7.12.2 Tunnelling

- If an IPv6 node is connected to another IPv6 node via only an IPv4 node, the intervening IPv4 node is viewed as a tunnel.
- Through this tunnel, the entire IPv6 datagram is attached as data of an IPv4 datagram and sent across the IPv4 node, to the IPv6 node where it is decapsulated to get the actual IPv6 datagram.
- The IPv4 datagram is addressed to the IPv6 node at the other end of the tunnel. It is routed among the IPv4 nodes till it reaches there.
- The IPv6 node at the end of the tunnel must check the incoming IPv4 datagram to see if ti contains a valid IPv6 datagram addressed to it.
- Upon receipt of such an IPv6 datagram it can route it through the IPv6 network like any other datagram.

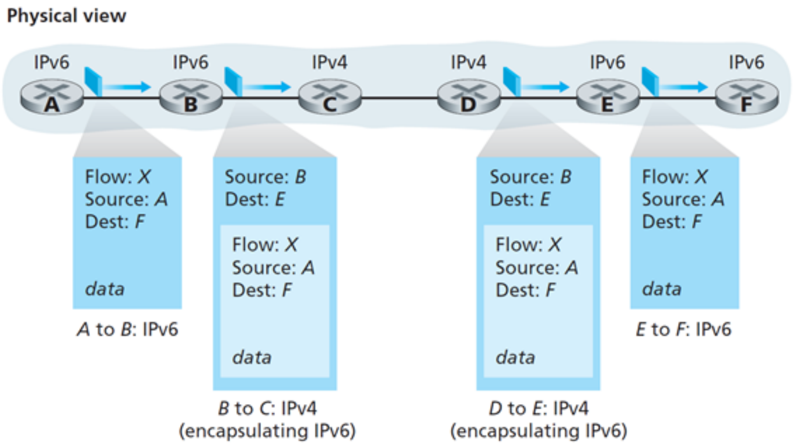


Figure 13: Tunnelling

8 Introduction to Routing Algorithms

- The primary types of routing protocols are Interior Gateway Protocols and Exterior Gateway Protocols.
- Interior Gateway Protocols are used for exchanging routing information between gateways (commonly routers) *within* an autonomous system (for example, a system of corporate local area networks).
- The types of IGPs are **Distance-Vector** and **Link-State** routing protocols.
- Exterior Gateway Protocols are used for exchanging routing information *between* autonomous systems of routers.

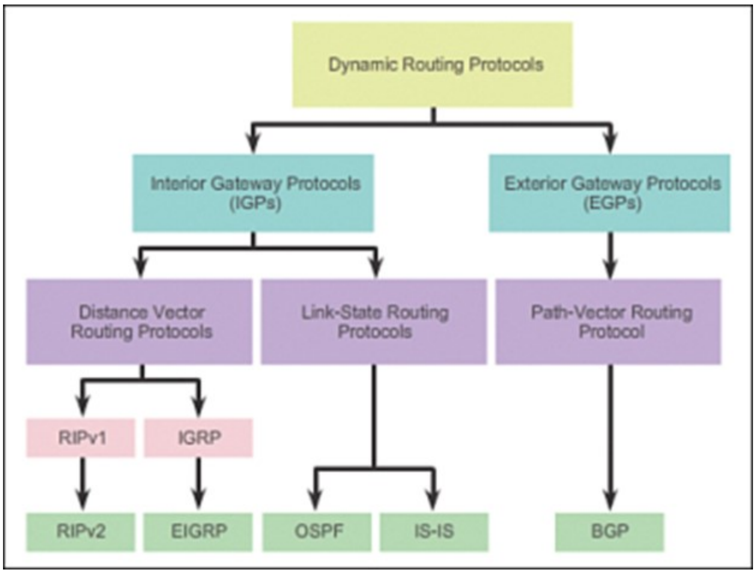
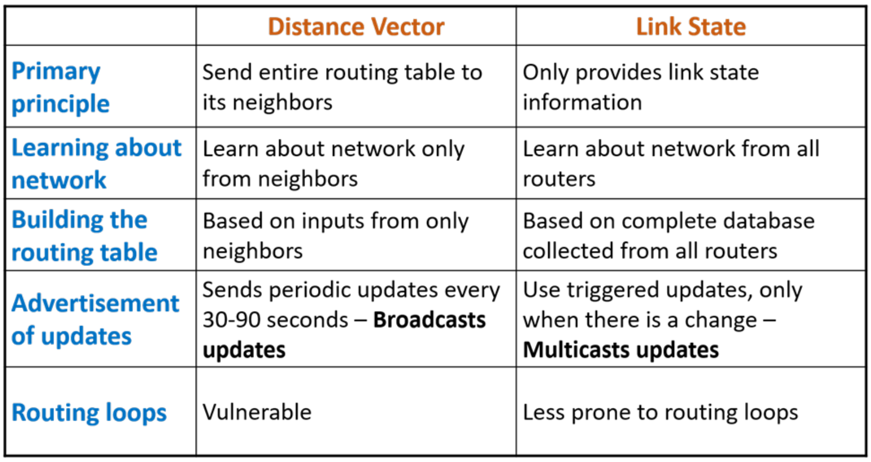
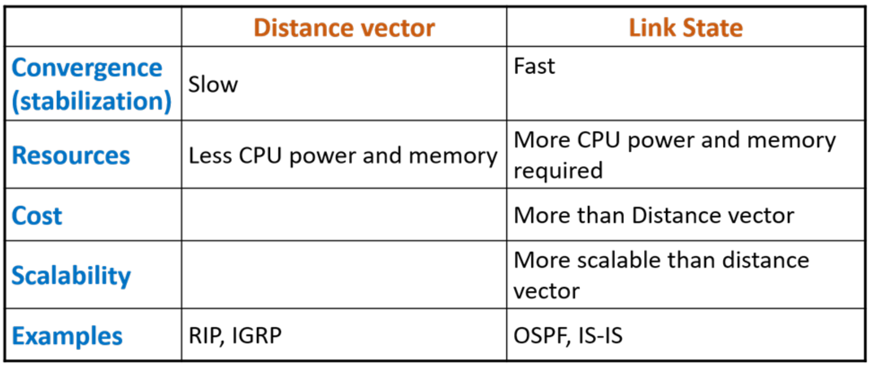

Dynamic Routing Protocols
Interior Gateway Protocols (IGPs)
Exterior Gateway Protocols (EGPs)
Distance Vector Routing Protocols
Link-State Routing Protocols
Path-Vector Routing Protocol
RIPv1
IGRP
RIPv2
EIGRP
OSPF
IS-IS
BGP

Figure 14: Classification of Routing Algorithms

8.1 Comparison between Distance-Vector and Link-State



	Distance Vector	Link State
Primary principle	Send entire routing table to its neighbors	Only provides link state information
Learning about network	Learn about network only from neighbors	Learn about network from all routers
Building the routing table	Based on inputs from only neighbors	Based on complete database collected from all routers
Advertisement of updates	Sends periodic updates every 30-90 seconds – **Broadcasts updates**	Use triggered updates, only when there is a change – **Multicasts updates**
Routing loops	Vulnerable	Less prone to routing loops



	Distance vector	Link State
Convergence (stabilization)	Slow	Fast
Resources	Less CPU power and memory	More CPU power and memory required
Cost		More than Distance vector
Scalability		More scalable than distance vector
Examples	RIP, IGRP	OSPF, IS-IS