S.Y.B.Sc.IT SEM III

COMPUTER NETWORKS (PUSIT303)

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UNIT III

5. Network Layer
6. Routing

5. Network Layer

Introduction

- The network layer is the third layer in the TCP/IP reference suite model.
- It is responsible for **host-to-host delivery of packets.**
- It provides service to its higher layer i.e., transport layer and receives services from its lower layer i.e., data link layer

Network Layer Services

❖Packetizing

- The **important service is to create packets from datagram received by the transport layer** at the source and decapsulate the packet at the destination.
- The **source host receives the payload from transport layer and adds a header that contains the source and destination address and extra information that is required** at the network layer and forwards the packet to the data link layer.
- The **destination host receives the network layer packet from its datalink layer, decapsulates the packet and forwards the payload to the transport layer.**
- The routers can only fragment the packet and not allowed to change any information and add fragmentation information to the packet header.

❖Routing

- This service defines that network layer needs to **find the best route to deliver the packet from source to destination.**
- So, **several algorithms and strategies are used by the network layer to find out the best route.**

❖Forwarding

- Forwarding is an **activity individual router takes when the packet arrives on one of its interfaces.**
- Routing decides about the entire path from source to destination but **forwarding is from one router to another**.
- A **routing or a forwarding table is maintained at each router** for smooth forwarding of the packets.
- When a router receives a packet from one of its attached networks, it needs to forward the packet to another attached network (in unicast routing) or to some attached networks (in multicast routing).
- The forwarding can be done on basis of destination address available in the packet header or based on labels assigned

❖Other Services

➢Error Control

- The **network layer does not directly provide error control** and it is **handled by the higher layers**.
- But it **includes checksum field that checks for corruption only in the header but not the entire packet.**
- However, the ICMP protocol which is an auxiliary network layer protocol provides some kind of error control mechanism.

Flow Control

- Flow control **regulates the amount of data a source can send without overwhelming the receiver.**
- If the upper layer at the source computer produces data faster than the upper layer at the destination computer can consume it, the receiver will be overwhelmed with data.
- To control the flow of data, the receiver needs to send some feedback to the sender to inform the latter that it is overwhelmed with data.
- The network layer in the Internet, however, **does not directly provide any flow control.**
- The datagrams are sent by the sender when they are ready, without any attention to the readiness of the receiver.

Congestion Control

- Congestion in the network causes the packet to get flooded at one area and as router cannot manage that it discards the packet.
- So, error control mechanism at higher layers cause retransmission of packet and if situation worsens then it ends up no packet reaching the destination.
- The **network layer applies several congestion policies to handle such situation**

Security

- When Internet was designed, security was not a need of the hour.
- But as data communication grew to a wider scale, the need for security emerged.
- As network layer was already designed, we **created another virtual layer to implement security called IPSec.**

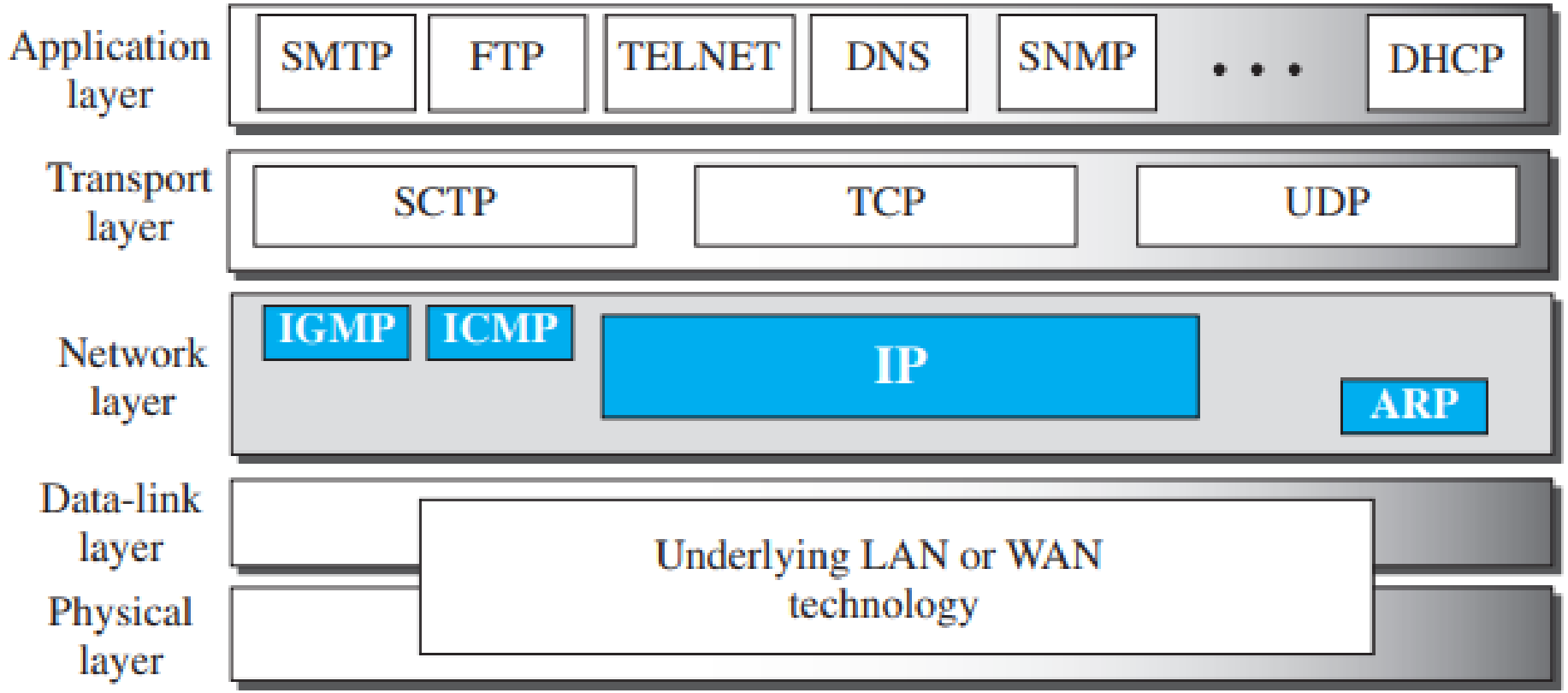
IPv4 Addresses

- **Refer Practical No. 3 PPT**

Internet Protocol

- The network layer has **one main protocol namely Internet Protocol (IP) and three auxiliary protocol** namely Internet Control Message Protocol (ICMP), Internet Group Management Protocol (IGMP) and Address Resolution Protocol (ARP).
- The **IP and ICMP** are available in **version 4 and 6**.
- The IPv4 protocol is **responsible for creation of packet, forwarding, routing and delivering the packet to the destination host**.
- The **ICMPv4** is responsible for **error handling at the network layer**.
- The **IGMP** is responsible for **multicasting in IPv4**.
- The **ARP** is responsible for **IP address to MAC address mapping** and works for the data link layer though it is a network layer protocol.

Figure 19.1 *Position of IP and other network-layer protocols in TCP/IP protocol suite*

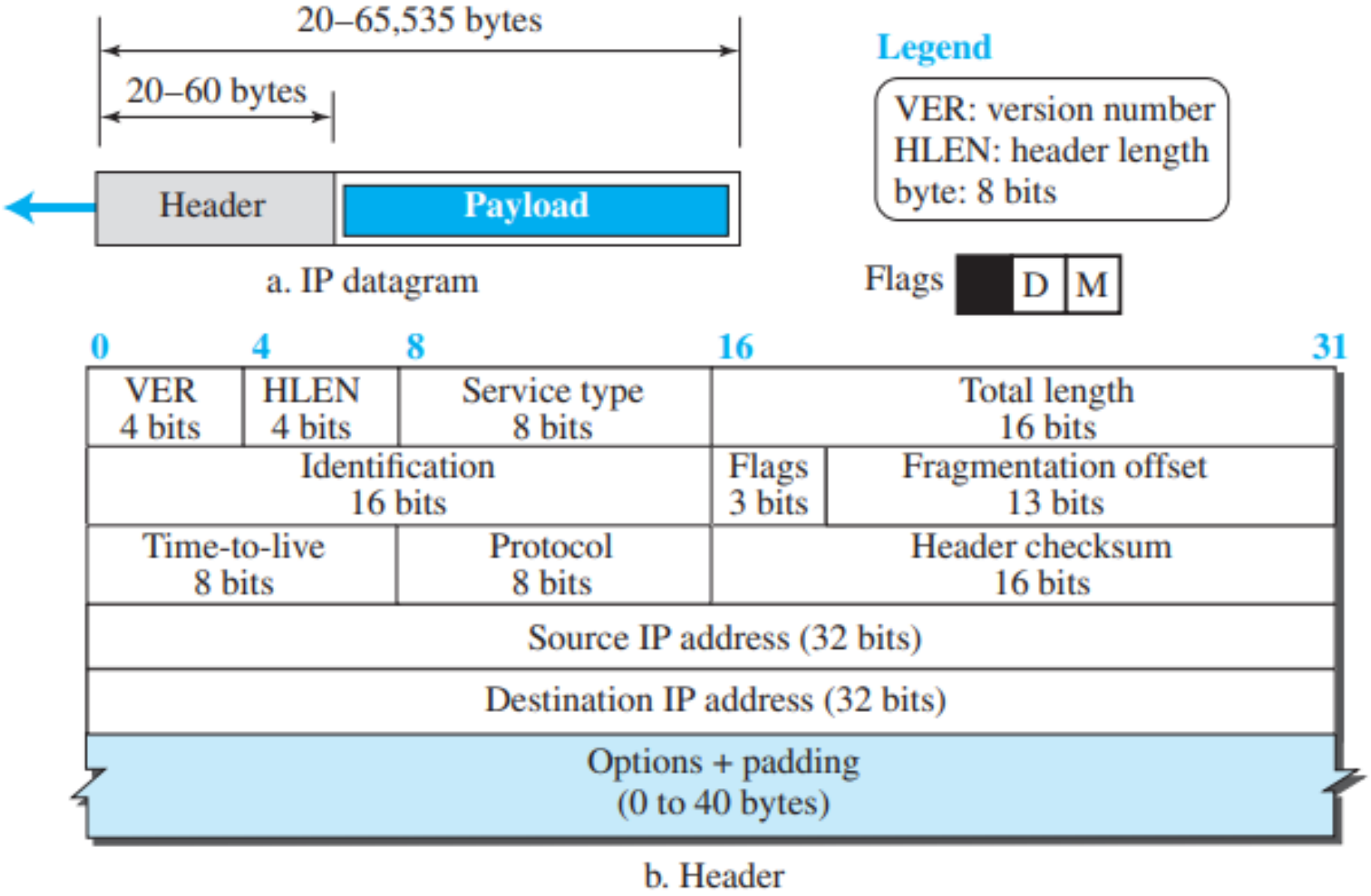


IPv4 Protocol

- IPv4 is a connectionless, unreliable protocol as each datagram is handled independently and takes a different route to reach the destination.
- The **network layer cannot handle large datagrams and so source fragments the datagram into smaller ones**.
- The **datagrams arrive out of order at destination and reassembly takes place at the destination**.
- The **intermediate routers can further fragment the datagram but cannot perform reassembly**.
- So **IPv4 handles creation, forwarding and routing of datagrams.**

Datagram Format

Figure 19.2 *IP datagram*



- **IPv4 packets** are called **datagrams**
- A **datagram** is a variable-length **packet consisting of two parts**: **header and payload (data)**
- The **header is 20 to 60 bytes in length** and **contains information essential to routing and delivery**

➢ **Version Number :** The 4-bit version number (VER) field **defines the version of the IPv4 protocol**, which, obviously, has the value of 4 i.e. version 4.

➢ **Header Length :** The field HLEN defines the **header length** which is 4-bit field and calculated by multiplying the value of this field by 4.

➢ **Service Type :** This field is of 8 bits.

- In the original design of the IP header, this field was **referred to as type of service (TOS)**, which defined **how the datagram should be handled**. In the late 1990s, IETF **redefined the field to provide differentiated services (DiffServ)**

- **1. Service Type**
- In this interpretation, the **first 3 bits are called precedence bits**. The **next 4 bits are called type of service (TOS) bits**, and the **last bit is not used.**
- **a. Precedence** is a 3-bit subfield ranging from 0 (000 in binary) to 7 (111 in binary). The **precedence defines the priority of the datagram** in issues such as congestion.
- Such as If a router is congested and needs to discard some datagrams, those datagrams with lowest precedence are discarded first.
- **b. TOS bits** is a 4-bit subfield with each bit having a special meaning.

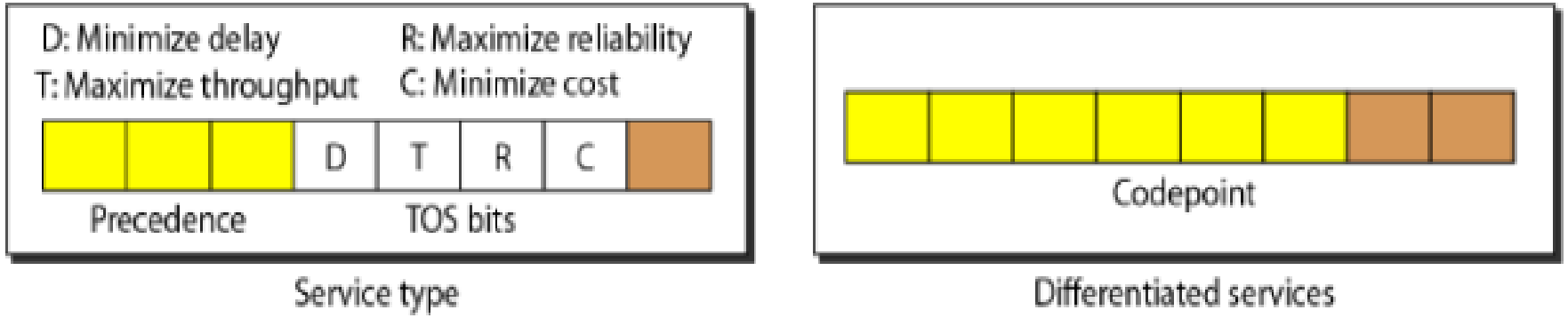
Table 20.1 *Types of service*

TOS Bits	*Description*
0000	Normal (default)
0001	Minimize cost
0010	Maximize reliability
0100	Maximize throughput
1000	Minimize delay

- **2. Differentiated Services**
- In this interpretation, the first **6 bits make up the codepoint subfield, and the last 2 bits are not used.**
- The codepoint subfield can be used in two different ways.
- **a.** When the **3 rightmost bits are 0s**, the **3 leftmost bits are interpreted the same as the precedence** bits in the service type interpretation. In other words, it is compatible with the old interpretation.
- **b.** When the **3 rightmost bits are <u>not all</u> 0s**, the 6 bits define 64 services based on the priority assignment by the Internet or local authorities according to Table

Category	Codepoint	Assigning Authority
1	XXXXX0	Internet
2	XXXX11	Local
3	XXXX01	Temporary or experiment

Figure 20.6 *Service type or differentiated services*



- **Total length :** This is a In-bit field that defines the total length **(header plus data)** of the IPv4 datagram in bytes.

- To **find the length of the data** coming from the upper layer, **subtract the header length from the total length.**

- **Identification :** The 16-bit identification field **identifies uniquely the datagram created by the source**.

- As large message is divided into smaller datagrams, each datagram belongs to the same message needs to be identified.

- **Flags :** This is a 3 bit field of which the **first bit is reserved (not used)**

- The **second bit is called the** *do not fragment* **bit**. If its *value is 1*,the machine *must not fragment* the datagram. If its *value is 0*,the datagram *can be fragmented* if required

- The **third bit is called** the ***more fragment*** bit. If its ***value is 1***, it means the ***datagram is not the last fragment*** ; there are more fragments after this one. If its ***value is 0***,it means ***this is the last fragment***

- **Fragmentation Offset :** The 13-bit field fragmentation offset defines **relative position of the fragment with respect to whole datagram**.
- **Time to live :** The time to live field **indicates the number of hops** i.e., **routers visited by the datagram**.
- When a source host sends the datagram, it **stores a number which is decremented by 1 by each router** that posses the datagram.
- If this value ,after being decremented , is **zero, the router discards the datagram**
- **Protocol :** This 8-bit field defines the higher-level protocol that used in Transport layer such as such as TCP, UDP and SCTP,etc.
- **Checksum :** This 8 bit field is used for **error detection and to protect the packet (only header)** against the corruption
- **Source Address :** This 32-bit field defines the **IP address of the source**.
- **Destination Address :** This 32-bit field defines the **IP address of the destination**

❖Fragmentation

- The network layer **cannot handle large data** and hence the **data is fragmented.**
- The **fragmentation takes place** when the when the **size of datagram is greater than maximum size of data that can be held a frame** i.e., its **Maximum Transmission Unit (MTU).**
- The data flow should not be disrupted and data received from the transport layer is fragmented.
- **Datagram is fragmented by source and intermediate routers** and **reassembly is taken care by the destination host**.
- **Three fields** namely **flag, fragmentation offset and total length** are **changed for the fragmentation process**.

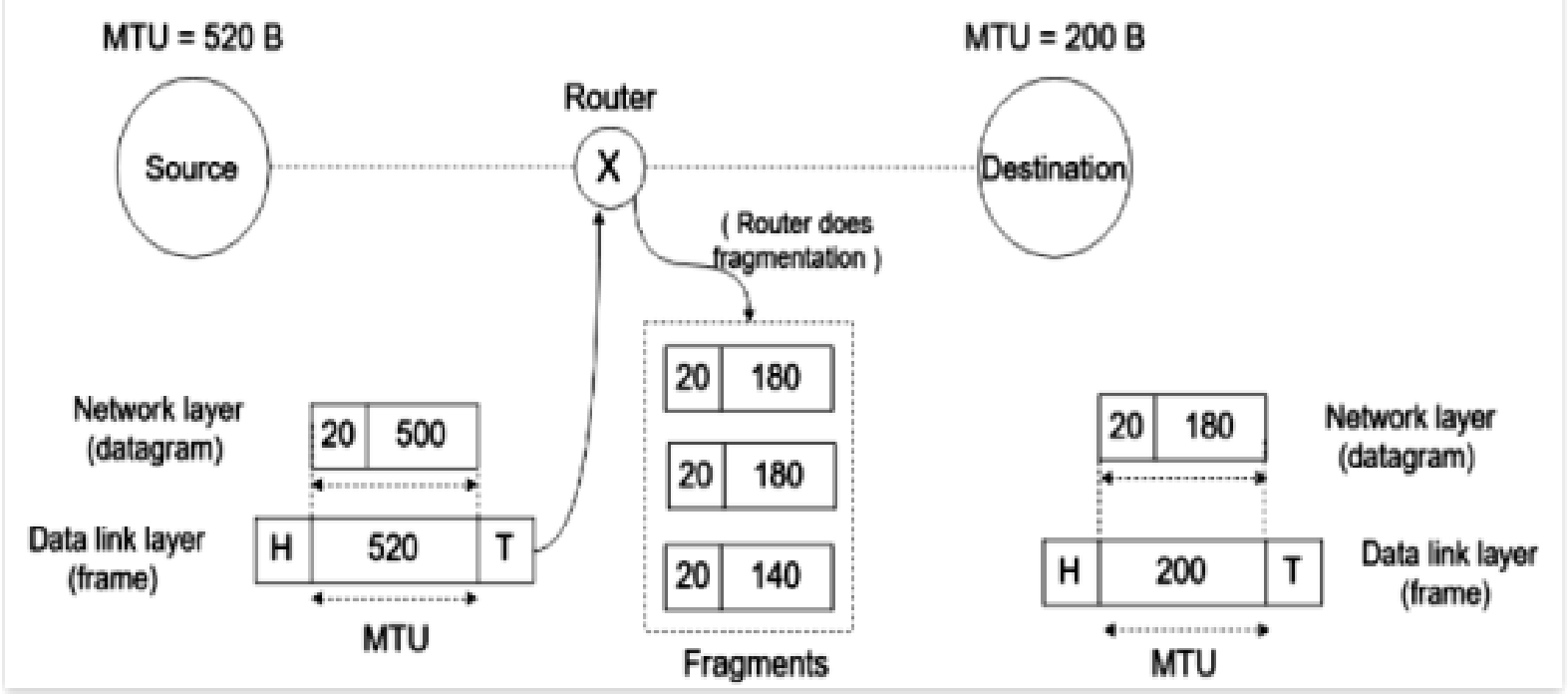


Figure 12.5– Fragmentation

- In the figure, the source creates a datagram with header size as 20 bytes and payload with 500 bytes.
- As the datagram reaches the router the, the router fragments into **3 smaller datagrams** with **header size remaining same** for all three fragments and data divided int three sizes namely **180 bytes, 180 bytes and remaining 140 bytes**.

header payload

20 | 500 → Link → 200 B

Datagram

↓

20 + 180

header payload

→ $\frac{500}{180} = 2.7 = 3$ fragment

→

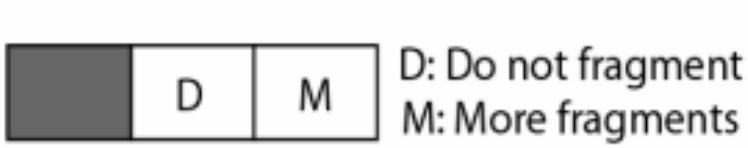
P_3	P_2	P_1
140	180	180
20	20	20

1 → [180 + 180 = 360

∴ 600 − 360

= 140]

- The flag values indicate the fragmentation status

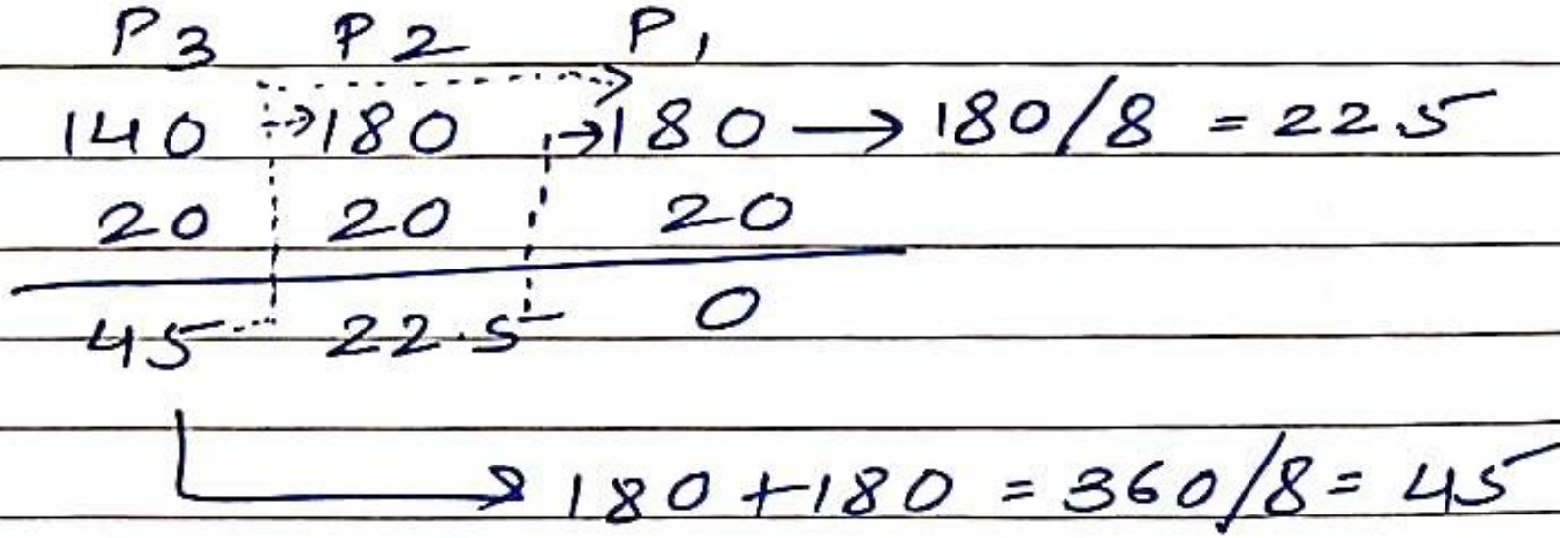


MF
1
1
0
0

- **D means do not fragment bit**. If **D =1 the router should not fragment the datagram** and in that case if router cannot handle such large datagram, then it discards it and sends an ICMP error message to source. If **D = 0 then datagram can be fragmented if required.**
- **M means more fragment bit**. If **M = 1, then it is not the last** but first or intermediate fragment. If **M = 0 then it indicates it is the last fragment**

- For the purpose of **reassembly at the destination** host identifies the **sequence of datagram from the fragmentation offset**
- So, the basic strategy involved in fragmentation is
- The offset field for **first fragment is always zero**.
- **Dividing the length of first fragment by 8 gives** offset of **second fragment.**
- **Dividing the total length of first and second fragment by 8 gives** the offset for the **third fragment**.
- Continue the same calculation for remaining fragments.

→ fragmentation offset



ARP (Address Resolution Protocol)

- **Refer Unit 2 PPT**

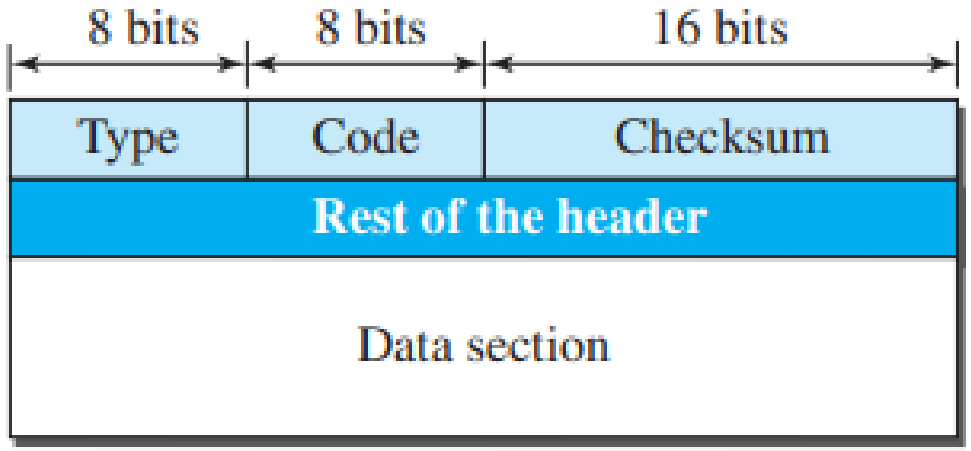
ICMP

- The **IP protocol has no error-reporting or error correcting mechanism**. The **IP protocol also lacks a mechanism for host and management queries**
- The **router may discard the datagram** because it **could not find the route to the destination or TTL field has zero value**.
- The **Internet Control Message Protocol version 4 (ICMPv4) has been designed to compensate for these deficiencies.**
- It is also a network layer protocol but the **ICMP message is encapsulated into IP datagram before sending it lower layer**.

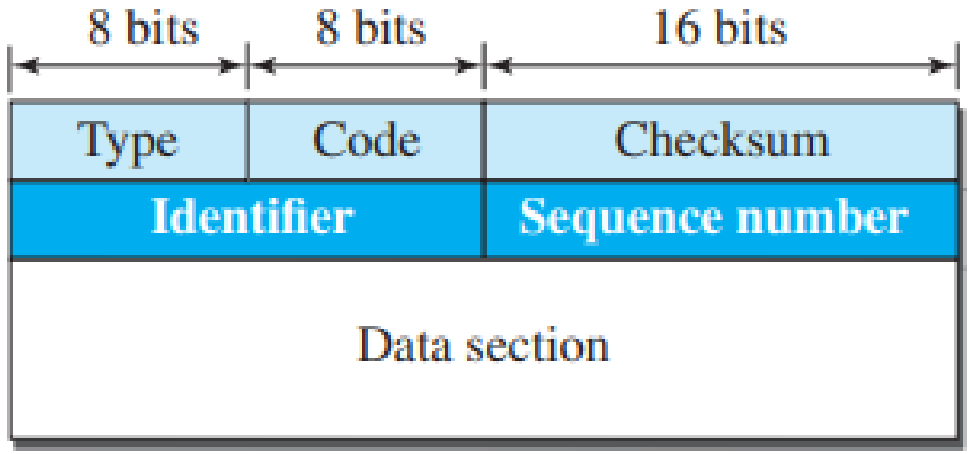
❖ICMP Messages

- ICMP messages are of **two types**: **error-reporting message and query message**
- The **error-reporting message report the errors and problems** the router and destination face while processing the datagram.
- The **query messages**, **which occur in pairs, help a host or a network manager get specific information from a router or another host**.
- For example, nodes can discover their neighbors. Also, hosts can discover and learn about routers on their network and routers can help a node redirect its messages.
- **The ICMP message has 8-byte header and variable size data section**.
- The **first 4 bytes of header are common in both types** and next four bytes are different in both.

Figure 19.8 *General format of ICMP messages*



Error-reporting messages



Query messages

Type and code values

Error-reporting messages

03: Destination unreachable (codes 0 to 15)
04: Source quench (only code 0)
05: Redirection (codes 0 to 3)
11: Time exceeded (codes 0 and 1)
12: Parameter problem (codes 0 and 1)

Query messages

08 and 00: Echo request and reply (only code 0)
13 and 14: Timestamp request and reply (only code 0)

- The **type indicates** the **type of message** and **code indicates reason for message type.**
- The **checksum** is **calculated over header and data** unlike the IPv4 where checksum is calculated for only header content.
- The **data section** in **error-reporting message carries the error occurred while processing the datagram** and in **query message** it contains **information depending on the query**.

❖Error Reporting Messages

- The **main role of ICMP is to report error** during the processing of datagram as IP is unreliable and incapable of doing so.
- ***ICMP cannot correct the errors but only informs about the errors***.
- The higher layers need to take care of the error correction.
- **Errors are reported to source** host **using the source IP address available in the header**.
- ICMP cannot directly float the error message in the network and so it **forms an error packet and encapsulates it in the IP datagram.**

- **The various error reporting message are**

- **Destination Unreachable**

- It is **sent by a router when it cannot deliver an IP datagram, the datagram is discarded** and the router or the host sends a destination unreachable message back to the source host .

Table 1. ICMP Type 3: Destination Unreachable Codes

Destination Unreachable Code	Description
0	Net is unreachable
1	Host is unreachable
2	Protocol is unreachable
3	Port is unreachable
4	Fragmentation is needed and **`Don't Fragment`** was set

Source Quench

- It is **sent by a destination host or router if it is receiving data too quickly and not able to handle the datagram**.
- When a router or a host discards a datagram due to congestion
- The message **is a request that the source slow down datagram transmission**

Redirection

- It is **sent by a router to optimize network traffic by redirecting the datagram to another router** if it receives a datagram that should have been sent to a different router.

Time Exceeded

- It is sent by a router **if the datagram has reached the maximum limit of routers through which it can travel.**
- This message is generated in 2 cases

- whenever a **router decrements a datagram with a time – to –live value to zero**, it discards the datagram and time exceeded message to original source host
- When the **final destination does not receive all of the fragments in set time**, it discards the received fragments and time exceeded message to original source host

Parameter Problem

- If a router or the destination host **discovers an ambiguous or missing value in any field of the datagram**, it discards the datagram and sends parameter problem message back to the source

❖Query Messages

- Query message are independent of IP datagram but again need to be **encapsulated in a datagram as a carrier**.
- Query message comes in pair and are **used to test the availability and activeness of router in the network.**

❖The various query messages are

❑Echo Request & Echo Reply

- It is **used to test destination accessibility and status.**
- A host sends an Echo Request and listens for a corresponding Echo Reply.

❑Timestamp Request & Timestamp Reply

- It is used to **synchronize the clocks between hosts and to estimate transit time.**

IPv6

- The IPv4 has been the reigning Internet Protocol version for several decades now even till today.
- But the **address depletion problem of IPv4 has caused IPv6** to come into picture.
- The **IPv4 is running out of room to accommodate all of the unique IP addresses** required for the world's growing number of connected devices.
- The IPv6 is the latest version of the Internet Protocol which identifies devices across the internet so they can be located.
- IPv6 is the next and the **advanced version of the internet protocol used in the network layer**.
- IPv6 provides a larger addressing space.
- The address space reserved in **IPv6 is 128 bits** as compared to only 32 bits in case of IPv4

❖IPv6 Addressing

- The **128-bit binary notation is divided into each 16-bit block** and each block represented by **four hexadecimal digits separated by colon** called the colon hexadecimal notation.

➢Notations

- Several notations have been proposed to represent IPv6 addresses when they are handled

❑Dotted Decimal Notation

- Notation is convenient for 4 byte IPv4 addresses. It seems too long for 16 byte
- **221.14.65.11.105.45.170.34.12.234.18.0.14.0.115.255**

❑Colon Hexadecimal Notation

- In this natation,128 bits are divided into eight sections, each 2 bytes in length. Two bytes in hexadecimal natation require 4 hexadecimal digits.
- **FDEC:BA98:7654:3210:ADBF:BBFF:2922:FFFF**

Zero Compression

- It can be applied to colon hex notation **if there are consecutive sections consisting of zeros only**. We can **remove all the zeros altogether and replace them with double colon**

FDEC:0:0:0:0:BBFF:0:FFFF ⟶ **FDEC::BBFF:0:FFFF**

Mixed Representation

- Sometimes we see a mixed representation of an IPv6 address: **colon hex and dotted decimal notation**
- **FDEC:14AB:2311:BBFE:AAAA:BBBB:130.24.24.18**

❖Address Types

- An IPv6 destination address can be unicast, anycast or multicast.

❑Unicast address

- **It** is meant to **configure on one interface** so that you can send and receive IPv6 packets.

❑Anycast address

- **It** is assigned to a **group of interfaces and a packet sent to an anycast address is delivered to only one of the nearest hosts.**

❑Multicast address

- **It** is **assigned to a group of interfaces and the packet is sent to all interfaces identified by the address.**

❖Advantages of IPv6 over IPv4

➢Larger Address Space

- It is 128 bit long. hence has a larger address space.

➢Better header format

- IPv6 uses a new header format in which options are separated from the base header and inserted, when needed, between the base header and the data.

➢New options

- IPv6 has new options to allow for additional functionalities.

➢Allowance for extension

- IPv6 is designed to allow the extension of the protocol if required by new technologies or applications.

Support for resource allocation

- In IPv6, the type-of-service field has been removed, but two new fields, **traffic class and flow label**, have been added to enable the source to request special handling of the packet.

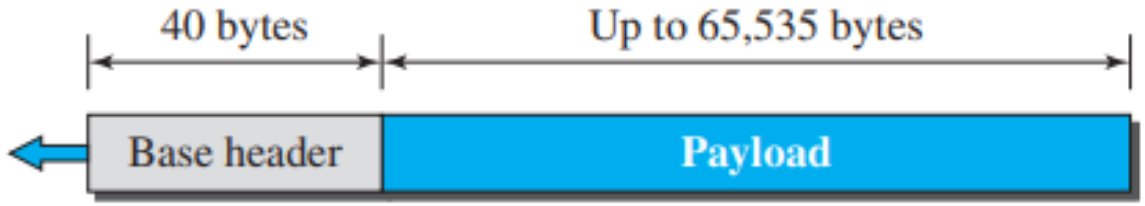
Support for more security

- The encryption and authentication options in IPv6 provide confidentiality and integrity of the packet.

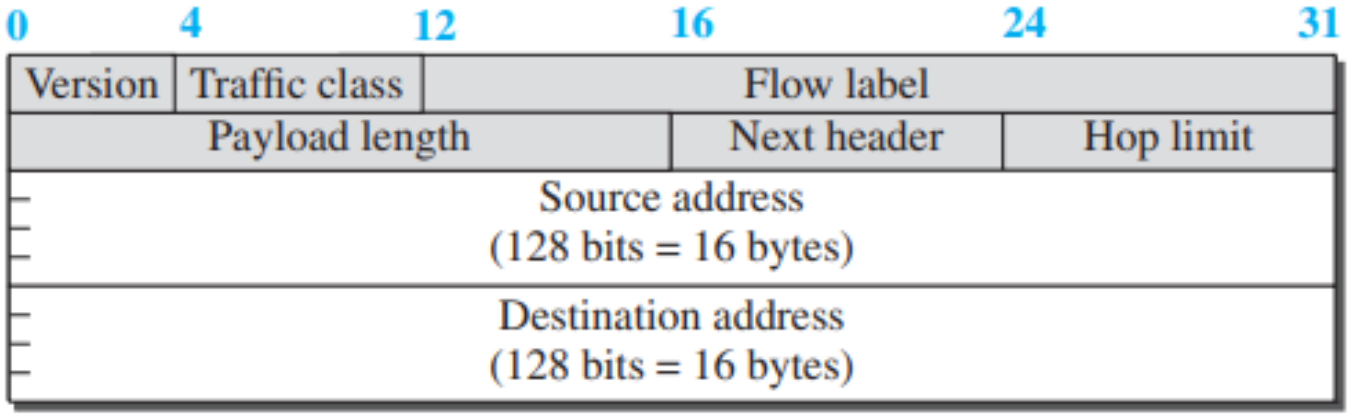
❖IPv6 Packet Format

- The IPv6 packet is **composed** of a **base header followed by the payload**.
- The **base header occupies 40 bytes**, whereas **payload can be up to 65,535 bytes of information.**

Figure 22.6 *IPv6 datagram*



a. IPv6 packet



b. Base header

- **Version :** The 4-bit version field defines the **version number** of the IP. For IPv6, the value is 6.
- **Traffic class :** The Traffic Class field indicates **class or priority of IPv6 packet. It helps routers to handle the traffic based on priority of the packet.**
- **Flow label : Flow Label field is used by source to label the packets belonging to the same flow in order to request special handling** by intermediate IPv6 routers. This makes IPv6 packet to allow IPv6 to work as a connection-oriented protocol.
- **Payload length :** Payload length is 16-bit field that indicates total size of the payload which tells **routers about amount of information a particular packet contains in its payload**.
- **Next extension header :** Next Header indicates type of extension header(if present) immediately following the IPv6 header. This **field is similar to the protocol field in IPv4**

- **Hop limit** : The 8-bit hop limit field serves the **same purpose as the TTL field in IPv4.**
- **Source and destination addresses : The source and destination address** are128-bit field and represents the address of original source and final destination.

❖Extension Header

- The length of the base header is fixed at 40 bytes. However **to give more functionality to the IP datagram**, the base header can be followed by up to six extension headers
- **Hop-by-Hop Option** – It **specifies the delivery parameters such as length of datagram, management, debugging and control information at each hop on the path** to the destination host.
- **Destination Option** – It **specifies packet delivery parameters to the final destination host. Intermediate destination devices are not permitted to access information.**
- **Source Routing** – It defines **strict source routing and loose source routing for the packet**. In **loose source routing**, **the sender specifies only some of the nodes that the packet will pass through**, while in ***strict source routing***, the ***complete set of nodes are determined before sending a packet.***

- **Fragmentation** – As **only source host can perform fragmentation**, it uses the fragment extension header to tell the destination host the size of the packet that was fragmented so that the destination can reassemble the packet.
- **Authentication** – It **provides authentication, data integrity, and anti-replay protection**. It **validates the message sender and ensures the integrity of data.**
- **Encrypted Security Payload (ESP)** –It **provides data confidentiality, data authentication, and anti-replay protection. It guards against eavesdropping**

Order	Header Type	Next Header Code
1	Basic IPv6 Header	-
2	Hop-by-Hop Option	0
3	Destination Option	60
4	Source Routing	43
5	Fragmentation	44
6	Authentication	51
7	Encrypted Security Payload	50

Table 14.3 – IPv6 Next Header Code

IPv4 vs IPv6

IPv4

- IP address is pf 32 bits (4 bytes)
- Size of the header can range from 20-60 bytes depending upon the options
- Fragmentation can be done by sender in between routers
- Fragmentation fields are present inside the header
- Checksum field is present in header
- IP sec support is optional
- Flow label field is not present

IPv6

- IP address is pf 128 bits (16 bytes)
- Size of the header is always fixed i.e. 40 bytes
- Fragmentation can be done by original sender only
- Fragmentation fields are included in options
- Checksum field is present in options
- IP sec support is in – built
- Flow label field speeds up the routing process

6. Routing

Routing

- The network layer is responsible for host-to-host delivery of packets.
- The **unicast routing governs the transmission of packet to only one destination** (one to one) whereas **multicast routing governs the transmission of packet to several destinations** (one to many).
- Unicast routing can be implemented using hierarchical routing where we route in steps

❖Unicast Routing Protocols

- A internet is a combination of networks connected by routers
- When **datagram goes from a source to a destination, it will probably pass through many routers until it reaches the router attached to the destination network**
- A router receives a **packet from one router and passes it to another router**
- The routers are able to take the decision on the basis of the information that is provided by routing table.
- The **routing table either can be a static or dynamic**
- A **static routing table is created and updated manually**
- A ***dynamic routing table is the one that is created once manually but is updated automatically whenever there is some change in the internet***

- ***Routing protocols have been developed in order to create and update dynamic routing tables***
- A ***routing protocol is a combination of rules and regulations using which routers share their information and inform each other of changes***

❖Intra and Inter-domain Routing

- An **internet today has become so huge that one routing protocol can not do the job of updating the routing table**
- Hence, the **internet is divided into smaller parts know as *Autonomous System*.**
- An ***autonomous system is a group of networks and routers connected to each other*.**
- **Routing within an autonomous system is known as interior routing or intra domain routing. *RIP and OSPF are intra domain routing protocol*.**
- **Routing between multiple autonomous systems is known as exterior routing or inter domain routing. *BGP are inter- domain routing protocol.***

❖Routing Algorithms

- **Routing algorithms are meant for determining the routing of packets in a node.**
- Several routing algorithms have been devised.

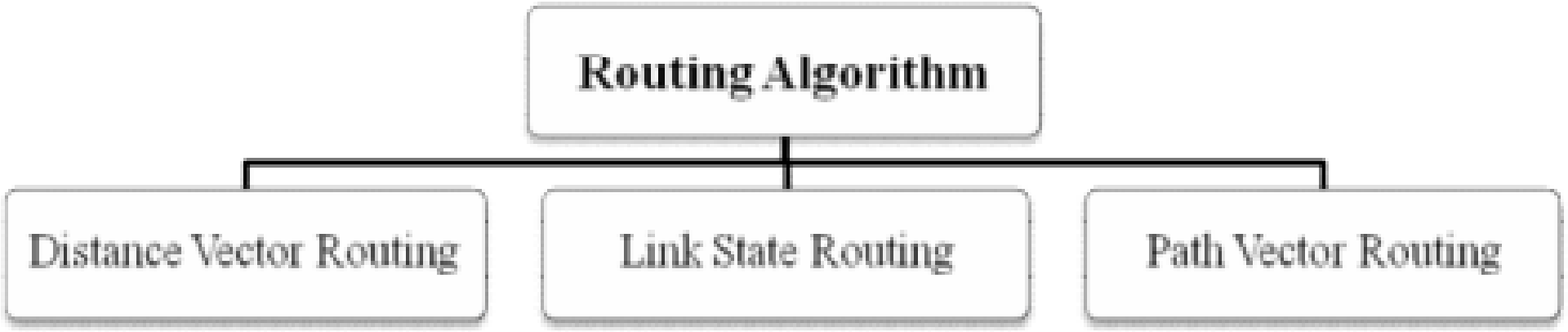


Figure 13.3 – Types of Routing Algorithms

❖Distance-vector Routing

- The distance vector protocol is the oldest routing protocol in practice. With distance vector routes are advertised based upon the following **characteristics**:
- **Distance** - How far the destination network is based upon a metric such as **hop count**.
- **Vector** - The **direction** (next-hop router or egress interface) required to get to the destination.

❖Link-state Routing

- link state routing ,**relies on each node advertising/flooding the state** (i.e. delay, bandwidth etc) of their **links to every node within the link state domain.**
- This results in each node building a complete map of the network (**shortest path tree**),

❖Path Vector Routing

- Path vector (PV) protocols, are used **across domains** aka autonomous systems.
- In a path vector protocol, a router does not just receive the distance vector for a particular destination from its neighbor; instead, **a node receives the distance *as well* as path information**

RIP (Routing Information Protocol)

- Refer Practical No. 6 PPT

OSPF (Open Shortest Path First)

- **Refer Practical No. 6 PPT**

BGP (Border Gateway Protocol)

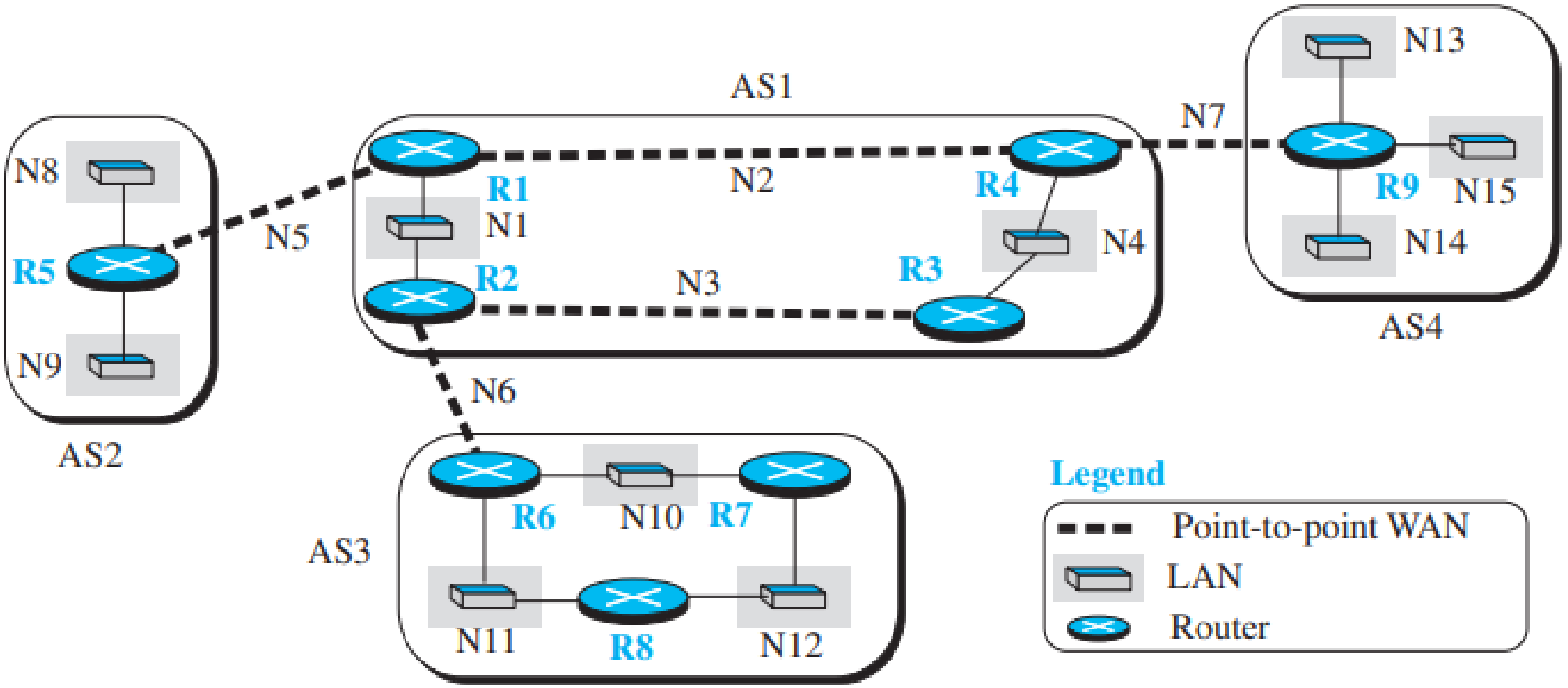
- BGP is an **exterior or inter-domain routing protocol** that **handles the job of routing between autonomous system**
- BGP is based on **path vector routing** i.e. is **uses this algorithm to initially create and update its routing table**

❖**Path Vector Routing**

- Path vector routing is **exterior routing protocol proved to be useful for inter –domain or inter-AS (Autonomous System) routing**.
- In path vector routing, a **router has a list of networks that can be reached with the path (list of ASs to pass) to reach each one**

- The figure shows the 4 autonomous system using path vector routing

Figure 20.24 *A sample internet with four ASs*



- Consider the above network with **AS1 as transient AS and AS2, AS3 and AS4 as stub AS**
- Each **AS uses intradomain protocol such as RIP or OSPF for routing internally within the AS.**
- But to know how ***to route packets to network in another AS, we require the BGP protocol.***
- There are ***two variants of BGPv4 protocol***.
- The ***external BGP (eBGP)*** is ***run on each border router*** i.e., the ***one at the edge of each AS which is connected to a router at another AS.***
- Another version is ***internal BGP (iBGP) run on all routers***.
- So, ***border routers run three protocols namely intradomain, iBGP and eBGP*** and ***other routers run two protocols namely intradomain and iBGP.***

- The border ***routers that run the eBGP are called as BGP peers or speakers.***
- The ***speaker node that speaks on behalf of the node***
- The speaker node is ***responsible for creating and updating the routing table of the respective autonomous system***