Chapter 6
Network Layer

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Objectives

- Role of routers in wide area networks
- Services provided to the transport layer
- Routers
- Routing algorithms
- Internet protocol suite

Limitations of data link layer

- Just moving frames from one end of a wire to the other
- Have a limitation of number of hosts per a network segment
- Difficult in interconnecting many heterogeneous networks

Roles of network layer

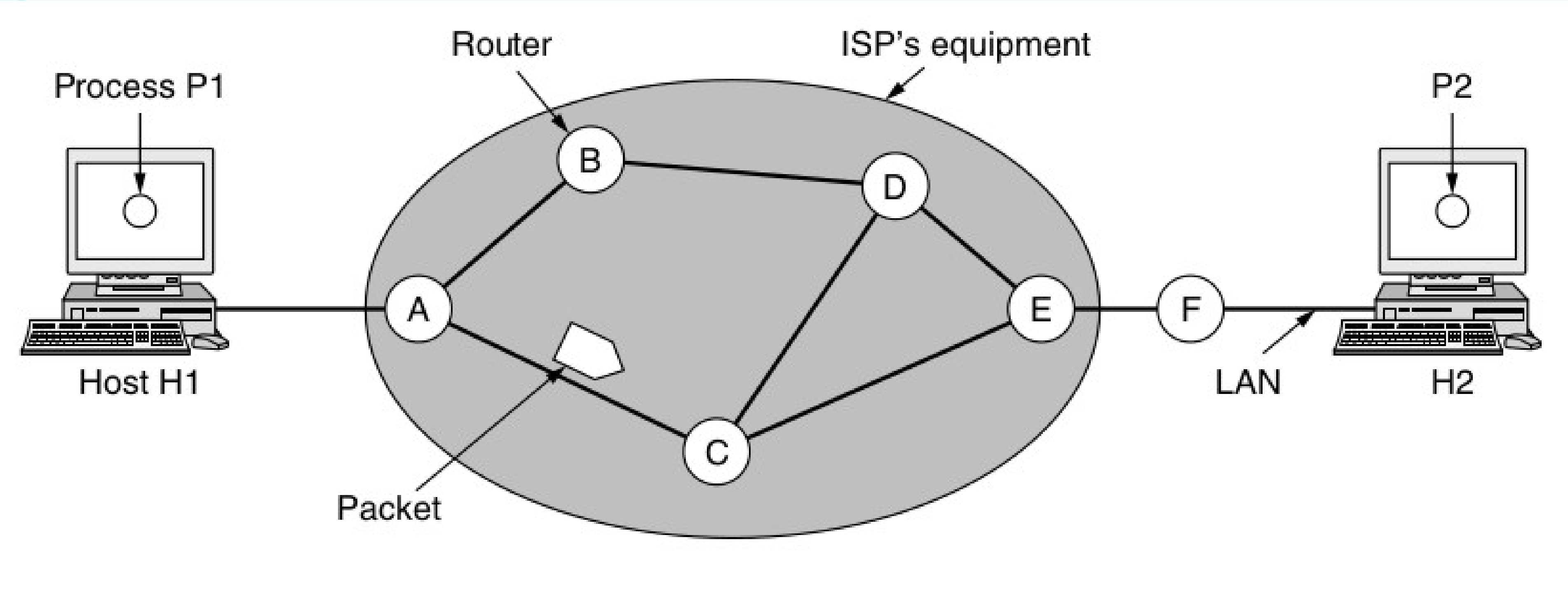
- Provide a host-to-host transmission in a WAN consisting of many heterogeneous LANs
- Moving a packet from one host to another host via many intermediate links
- Find appropriate routes for packets to avoid congestion

Network Layer Design Issues

- Store-and-Forward Packet Switching
- Services Provided to the Transport Layer
- Implementation of Connectionless Service
- Implementation of Connection-Oriented Service
- Comparison of Virtual-Circuit and Datagram Subnets

Network Layer Design Issues

Store-and-Forward Packet Switching



The environment of the network layer protocols

Network Layer Design Issues

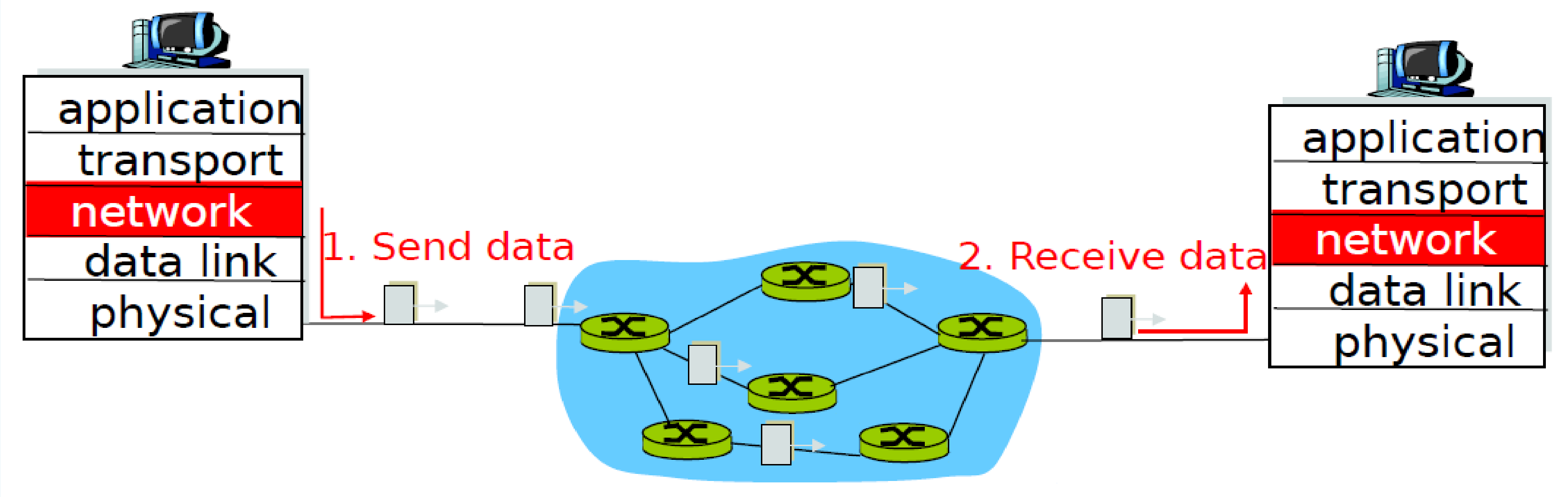
Services Provided to the Transport Layer

- Services need to be carefully designed with the following goals in mind
  - The services should be independent of the router technology.
  - The transport layer should be shielded from the number, type, and topology of the routers present
  - The network addresses made available to the transport layer should use a uniform numbering plan, even across LANs and WANs.
- Two services provided to the transport layer
  - Connectionless service
  - Connection-oriented service

Network Layer Design Issues

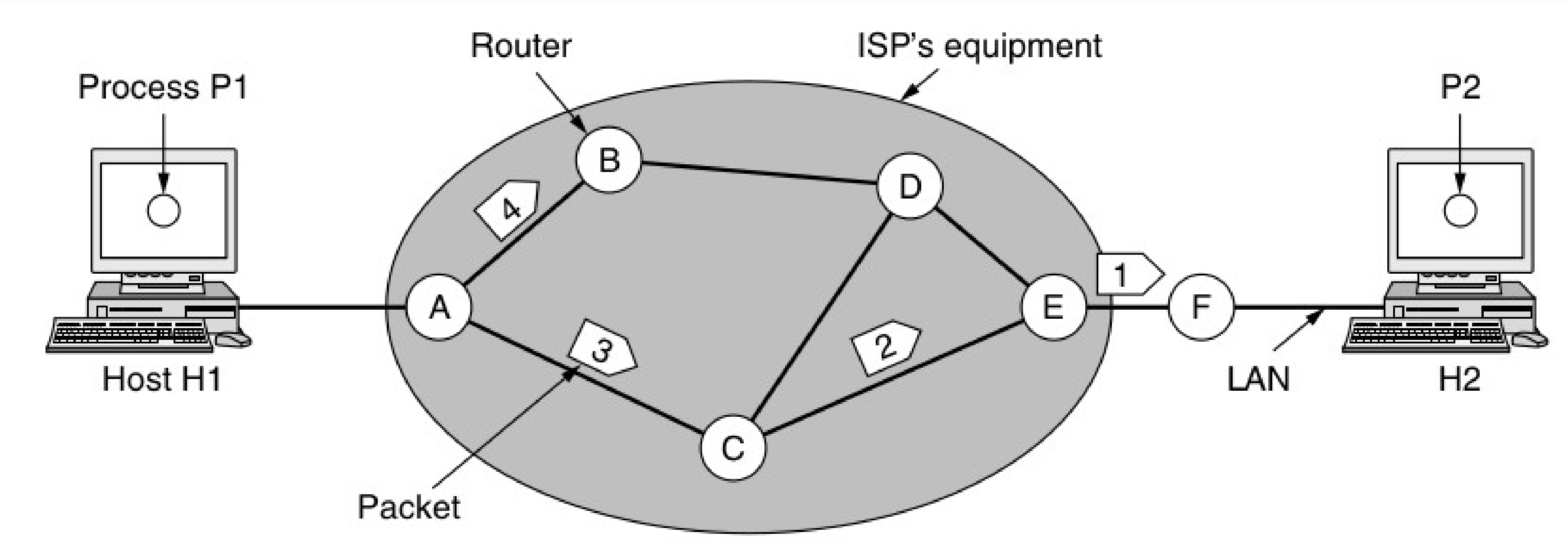
Implementation of Connectionless Service

- Packets frequently called *datagrams* and network called a *datagram network*
- No need to establish a path from the source router to the destination router before sending packets
- Data segmented in to packets that are independently sent in the network through different paths to the same destination



Network Layer Design Issues

Implementation of Connectionless Service



A's table (initially)		A's table (later)		C's table		E's table	
A	–	A	–	A	A	A	C
B	B	B	B	B	A	B	D
C	C	C	C	C	–	C	C
D	B	D	B	D	E	D	D
E	C	E	B	E	E	E	–
F	C	F	B	F	E	F	F
Dest.	Line						

Routing within a diagram subnet

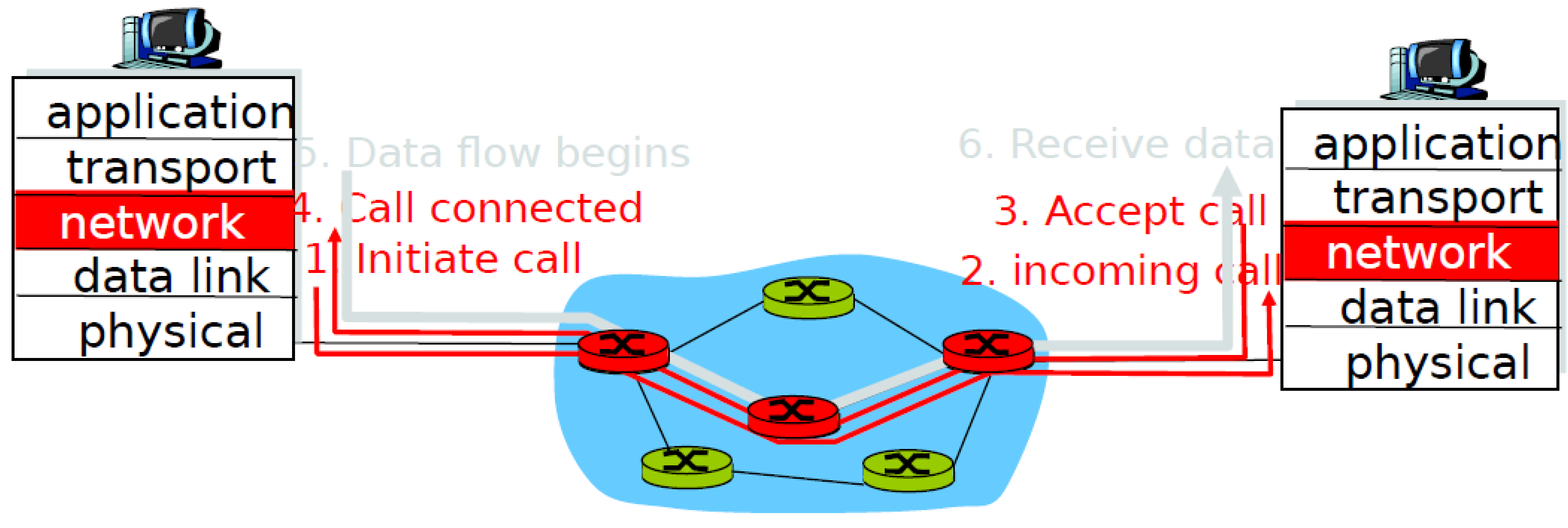
Network Layer Design Issues

Implementation of Connection-Oriented Service

- A path from the source router all the way to the destination router established before any data packets can be sent
- This connection called a *virtual circuit*, and the network called a *virtual-circuit network*
- When a connection established, *a route* from the source to the destination chosen as part of the connection setup and stored in tables inside the routers.
- Established route is used for all traffic flowing over the connection
- When the connection is released, the virtual circuit is terminated.
- Each packet carries *an identifier* telling which virtual circuit it belongs to

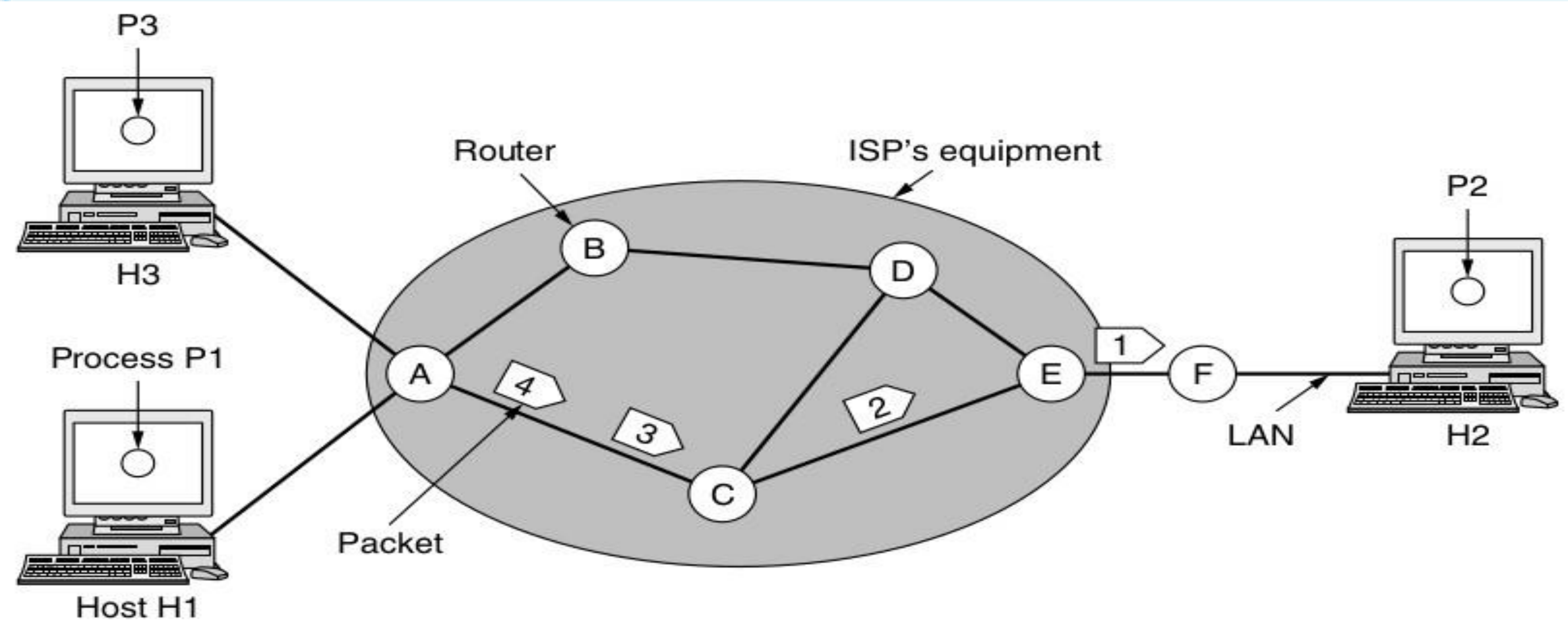
Network Layer Design Issues

Implementation of Connection-Oriented Service



Network Layer Design Issues

Implementation of Connection-Oriented Service



A's table

In		Out	
H1	1	C	1
H3	1	C	2

C's table

A	1	E	1
A	2	E	2

E's table

C	1	F	1
C	2	F	2

Routing within a virtual-circuit subnet

Network Layer Design Issues

Comparison of Virtual-Circuit and Datagram Subnets

Issue	Datagram subnet	Virtual-circuit subnet
Circuit setup	Not needed	Required
Addressing	Each packet contains the full source and destination address	Each packet contains a short VC number
State information	Routers do not hold state information about connections	Each VC requires router table space per connection
Routing	Each packet is routed independently	Route chosen when VC is set up; all packets follow it
Effect of router failures	None, except for packets lost during the crash	All VCs that passed through the failed router are terminated
Quality of service	Difficult	Easy if enough resources can be allocated in advance for each VC
Congestion control	Difficult	Easy if enough resources can be allocated in advance for each VC

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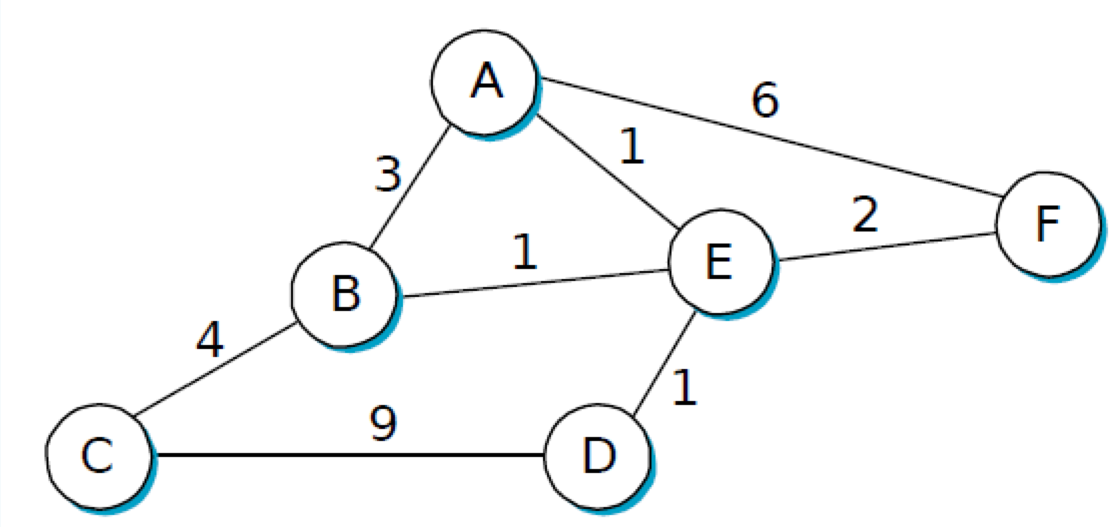
Routing Algorithms

Routing Algorithms

- A part of the network layer software responsible for deciding which output line an incoming packet should be forwarded
- In datagram network: routing made for every data packet since the best route may have changed since last time
- In virtual circuits network: routing decisions are made only when a new virtual circuit established
- Two process in inside a router
  - ✓ Handling each incoming packet: look up the outgoing line in the routing tables – forwarding process
  - ✓ Filling in and updating the routing tables

- Objective: Choosing an appropriate route (a chain of router) through an internetwork from sender host to destination host

- Need to model the network as a graph
  - ✓ Nodes: Routers, switches or sub networks
  - ✓ Edges: network links
  - ✓ Costs on each edge: Cost for transmitting data via the edge



- Cost of a route is the sum of edges costs on the route
- If there is no route between two nodes, the cost of route is infinite

Routing Algorithms

General objective

- Finding a route quickly and exactly
- Being able to adapt to the change of network topology
- Being able to adapt to the change of network traffic
- Being able to avoid network congestion
- Low cost in computing

Routing Algorithms

Types

- Centralized routing: There is a NIC (Network Information Center) responsible for calculating and updating routing table for all routers in the network
- Distributed routing: Each router has to calculate and update its routing table
  - ✓ Routers need to exchange routing information
- Static routing: A router can't update its routing table when network topology is changed
  - ✓ Usually network administrator will create and update routing table manually
- Dynamic routing: Routing table will be updated automatically by the router when there is a network topology change

Routing Algorithms

Finding shortest path with Dijkstra algorithm

- Objective: Finding shortest paths from one source node to all other destination nodes in a network
- Being an optimized algorithm – centralized routing algorithm
- Call
  - ✓ S: Source node (predefined)
  - ✓ N: Set of nodes which shortest path (from S) found
  - ✓ D_i: Cost of a shortest path from node S to node i
  - ✓ l_{ij}: Cost of edge connecting node i and node j; ∞ if no edge between i and j
  - ✓ P_i: Parent node of node i

Routing Algorithms

Finding shortest path with Dijkstra algorithm

- Step 1: Initial step

  $N=\{S\}; Ds=0;$

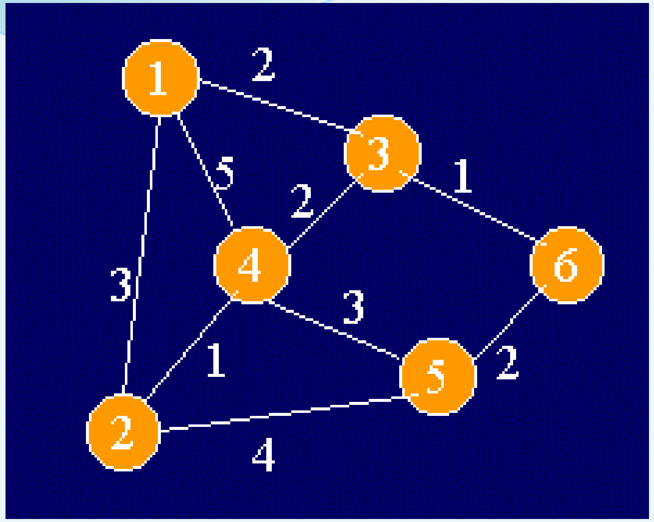
  $\forall i \neq S: Di=l_{si}$, $P_i=S$

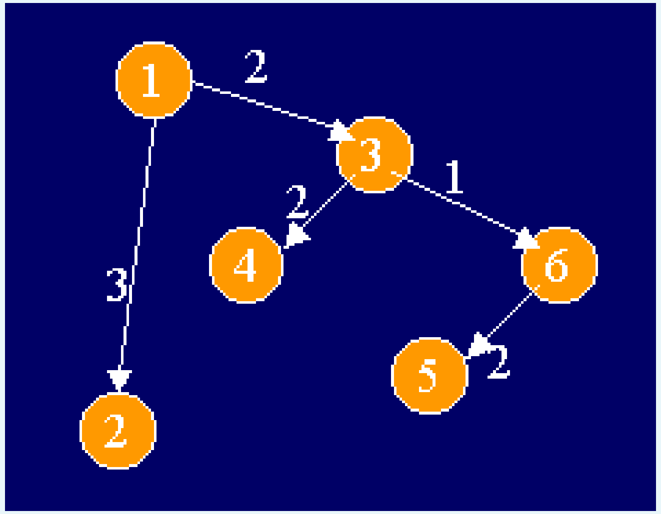
- Step 2 Finding a neighborhood nodes
  - Find node $i \notin N$: $Di= \min (Dj)$ với $j \notin N$
  - Add node **i** into the set N
  - If N contains all node of the graph then stop the algorithm. Otherwise do step 3

- Step 3: Recalculating cost of shortest paths
  - ✓ For each node $j \notin N$, recalculate $Dj= \min\{ Dj, D\mathbf{i}+ l\mathbf{i}j\}$; $Pj=i$;
  - ✓ Return to step 2

Routing Algorithms

Finding shortest path with Dijkstra algorithm





Lần lặp	N	D_2	D_3	D_4	D_5	D_6	P_2	P_3	P_4	P_5	P_6
Khởi tạo	{1}	3	2	5	∞	∞	1	1	1	1	1
1	{1,3}	3	**2**	4	∞	3	1	1	3	1	3
2	{1,3,2}	**3**		4	7	3	1		3	2	3
3	{1,3,2,6}			4	5	**3**			3	6	3
4	{1,3,2,6,4}			**4**	5				3	6	
5	{1,3,2,6,4,5}				**5**					6	

Routing Algorithms

Finding shortest path with Fulkerson algorithms

- Objective: Finding shortest paths from all nodes to a destination node
- Being an optimized algorithm – distributed routing algorithm
- Call
  - ✓ d: Destination node (predefined)
  - ✓ Di: Cost of a shortest path from node i to node d
  - ✓ Ci: Child node of node i

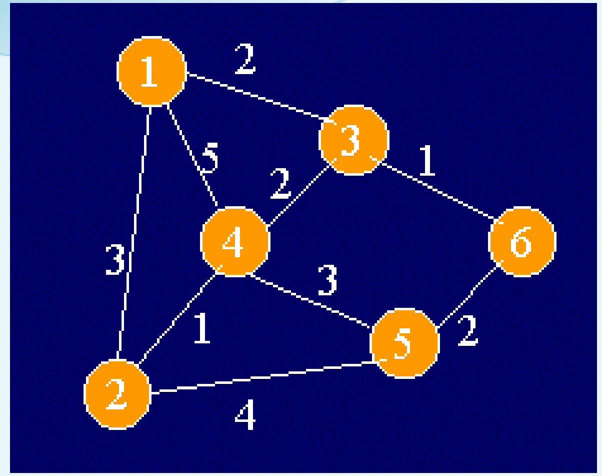
Routing Algorithms

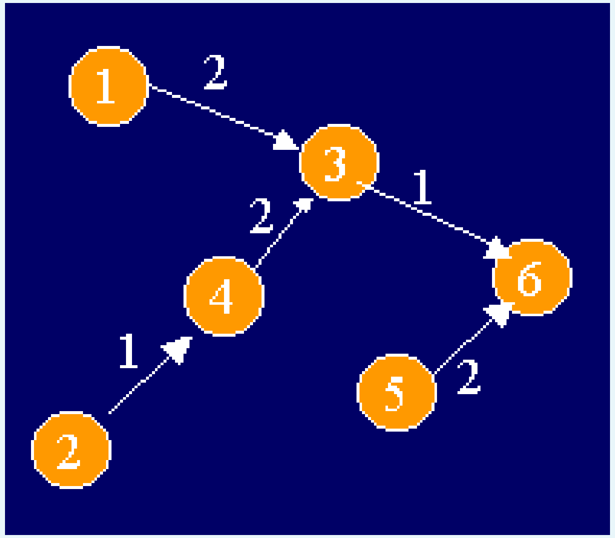
Finding shortest path with Fulkerson algorithms

- Step 1: initial step
  - – $D_d = 0$;
  - – For every $\forall i \neq d$: assign $D_i = \infty$; $C_i = -1$;
- Step 2: Update cost of shortest from i to d
  - ✓ $D_i = \min\{ l_{ij} + D_j \}$ với $\forall j \neq i \Rightarrow C_i = j$;
  - ✓ Repeat step 2 until no Di changed

Routing Algorithms

Finding shortest path with Fulkerson algorithms





Lần lặp	D_1	D_2	D_3	D_4	D_5	C_1	C_2	C_3	C_4	C_5
Khởi tạo	∞	∞	∞	∞	∞	-1	-1	-1	-1	-1
1	∞	∞	**1**	**3**	**2**	-1	-1	**6**	**3**	**6**
2	**3**	**4**	1	3	2	**3**	**4**	6	3	6
3	3	4	1	3	2	3	4	6	3	6

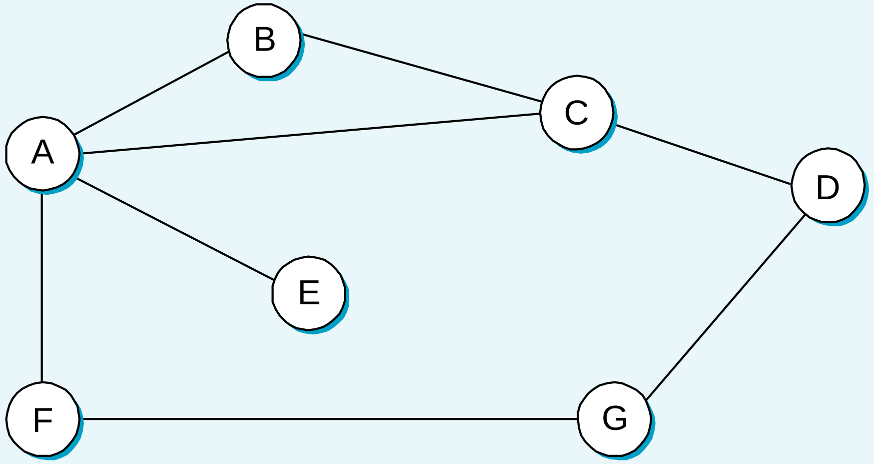
Routing Algorithms

Distance Vector

- Each router maintains a routing table containing one entry for each router in the network.
  - ✓ Entry [destination, Next hop, Cost]
- Cost is distance – hops
- Each router is supposed to know costs of links connecting to its neighborhood
- Cost of a broken/down link is infinite
- A router exchange its routing table with neighborhood periodically
- A router will update its routing table with new shorter routes learned from routing tables of its neighborhood

Routing Algorithms
Distance Vector

Initially, each node will assigns 1 for cost of the link to a neighborhood, and ∞ for links to other router



	Distance to nodes						
	A	**B**	**C**	**D**	**E**	**F**	**G**
A	0	1	1	∞	1	1	∞
B	1	0	1	∞	∞	∞	∞
C	1	1	0	1	∞	∞	∞
D	∞	∞	1	0	∞	∞	1
E	1	∞	∞	∞	0	∞	∞
F	1	∞	∞	∞	∞	0	1
G	∞	∞	∞	1	∞	1	0

Routing Algorithms
Distance Vector

	Distance to nodes						
	A	B	C	D	E	F	G
A	0	1	1	∞	1	1	∞
B	1	0	1	∞	∞	∞	∞
C	1	1	0	1	∞	∞	∞
D	∞	∞	1	0	∞	∞	1
E	1	∞	∞	∞	0	∞	∞
F	1	∞	∞	∞	∞	0	1
G	∞	∞	∞	1	∞	1	0

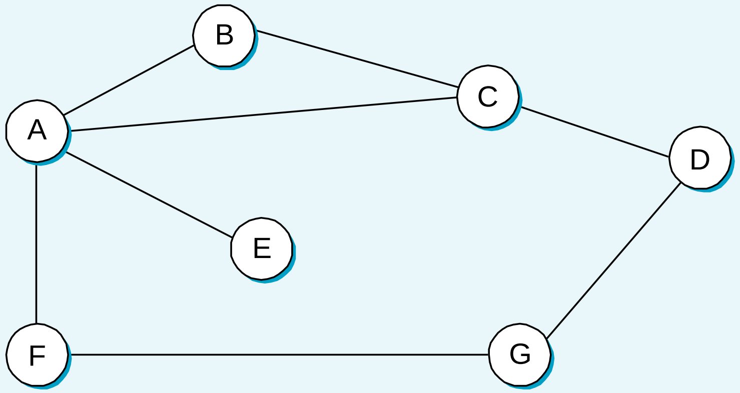
Each router sends its routing table to its neighbor

Dest	Cost	Next hop
B	1	B
C	1	C
D	∞	-
E	1	E
F	1	F
G	∞	-

A's routing table

Dest	Cost	Next hop
B	1	B
C	1	C
D	2	C
E	1	E
F	1	F
G	2	F

Routing tables after routers get enough information



	Distance to nodes						
	A	**B**	**C**	**D**	**E**	**F**	**G**
A	0	1	1	2	1	1	2
B	1	0	1	2	2	2	3
C	1	1	0	1	2	2	2
D	2	2	1	0	3	2	1
E	1	2	2	3	0	2	3
F	1	2	2	2	2	0	1
G	2	3	2	1	3	1	0

Routing Algorithms

Distance Vector

- When a router send its routing table to all its neighborhoods ?
  - ✓ Periodically, for example: every 30 seconds
  - ✓ When its routing table is modified
- How to know a neighborhood is alive ?
  - ✓ Send a hello message periodically
  - ✓ Receive routing table sent by neighborhood
- What a router do when one of its a link is down ?
  - ✓ Set the cost of route containing the link to infinite and send its routing table to all its neighborhoods
  - ✓ Problem of convergence

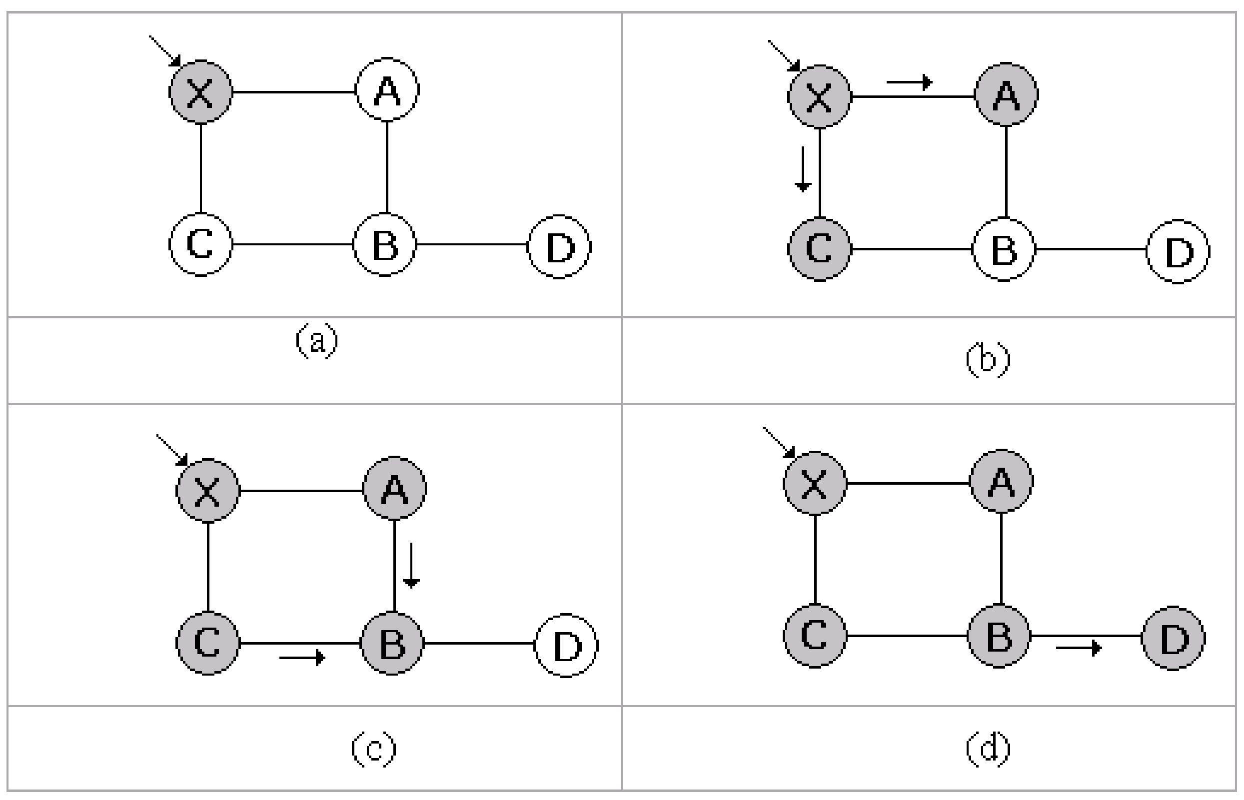
Routing Algorithms

Link State Routing

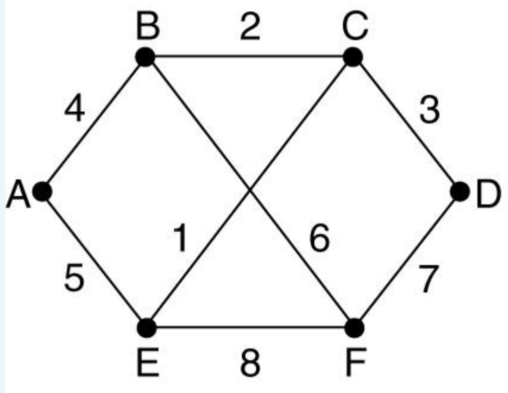
Each router must do the following:

1. Discover its neighbors, learn their network address.
2. Measure the delay or cost to each of its neighbors.
3. Construct a packet telling all it has just learned.
4. Send this packet to all other routers.
5. Compute the shortest path to every other router.

Reliable flooding protocol to send link state to all Routers



Building Link State Packets (LSP)



(a)

Link State Packets

A	B	C	D	E	F
Seq.	Seq.	Seq.	Seq.	Seq.	Seq.
Age	Age	Age	Age	Age	Age
B 4	A 4	B 2	C 3	A 5	B 6
E 5	C 2	D 3	F 7	C 1	D 7
	F 6	E 1		F 8	E 8

(b)

Routing Algorithms

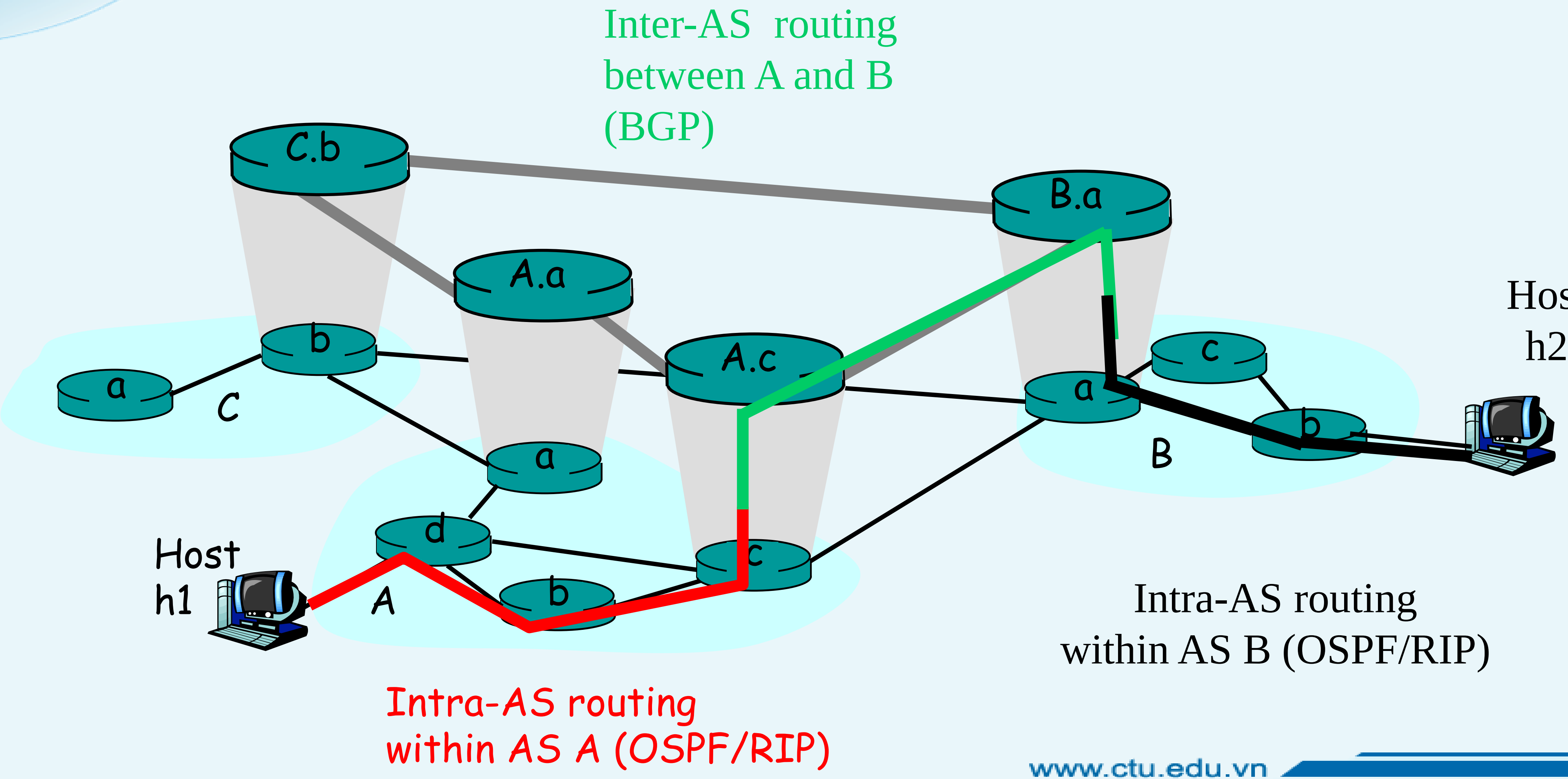
Hierarchical routing

- As networks grow in size
  - ✓ Router's routing tables grow proportionally
  - ✓ Router's memory consumed ever-increasing tables
  - ✓ CPU time needed to scan routing tables and more bandwidth needed to send status reports about them

  => Routing will have to be done hierarchically
- When hierarchical routing is used
  - ✓ the routers divided into domains
  - ✓ Each router knows how to route within its own domain but knows nothing about the internal structure of other domains

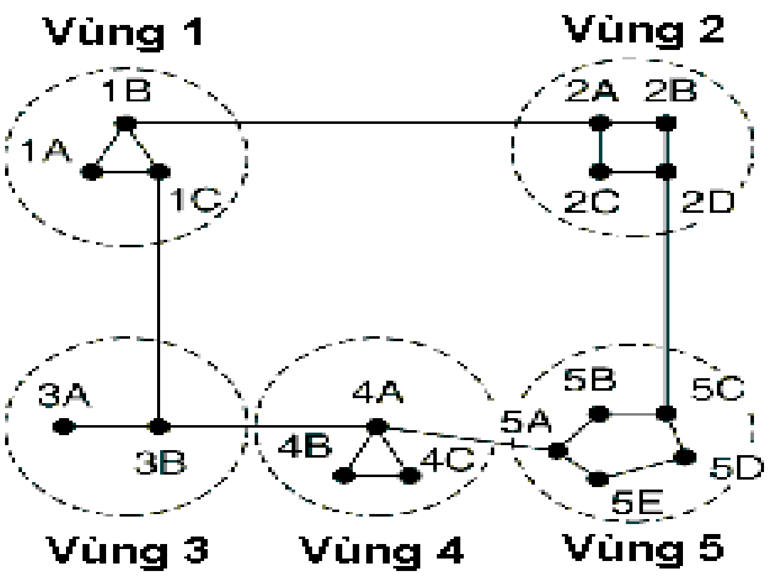
Routing Algorithms

Hierarchical routing



Routing Algorithms

Hierarchical routing



(a)

Bảng vạch đường đầy đủ của nút 1A

Đích	Lối ra	Chi phí
1A	–	–
1B	1B	1
1C	1C	1
2A	1B	2
2B	1B	3
2C	1B	3
2D	1B	4
3A	1C	3
3B	1C	2
4A	1C	3
4B	1C	4
4C	1C	4
5A	1C	4
5B	1C	5
5C	1B	5
5D	1C	6
5E	1C	5

(b)

Bảng vạch đường phân cấp của host 1A

Đích	Lối ra	Chi phí
1A	–	–
1B	1B	1
1C	1C	1
2	1B	2
3	1C	2
4	1C	3
5	1C	4

(c)

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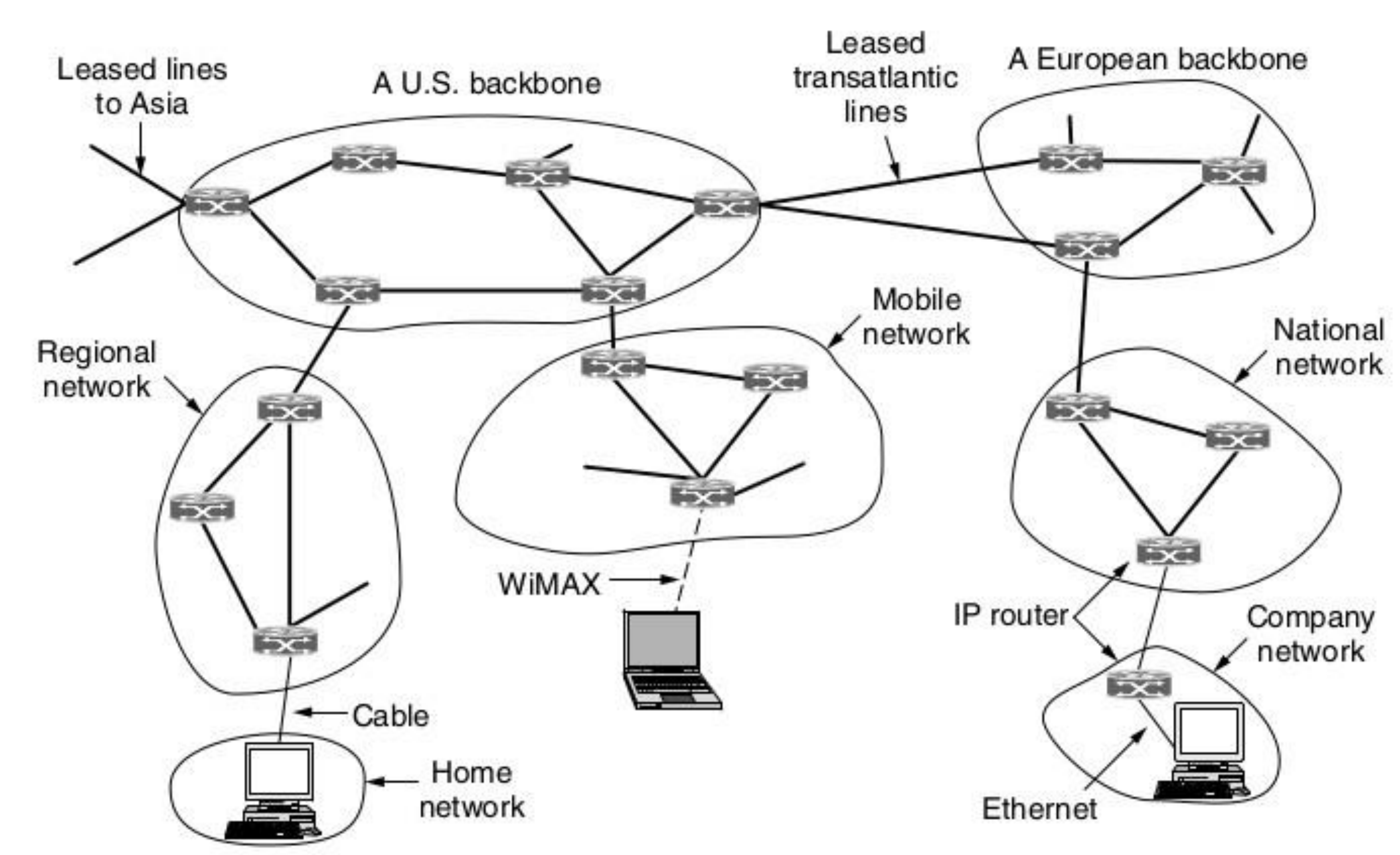
Internetworking & Internet Protocol Suite

Internetworking

- An internetwork: a collection of individual networks, connected by intermediate networking devices, that functions as a single large network
- Component networks are inhomogeneous: different in hardware, software and protocols
- Objective: to allow a user in a network to communicate with other users in the other networks

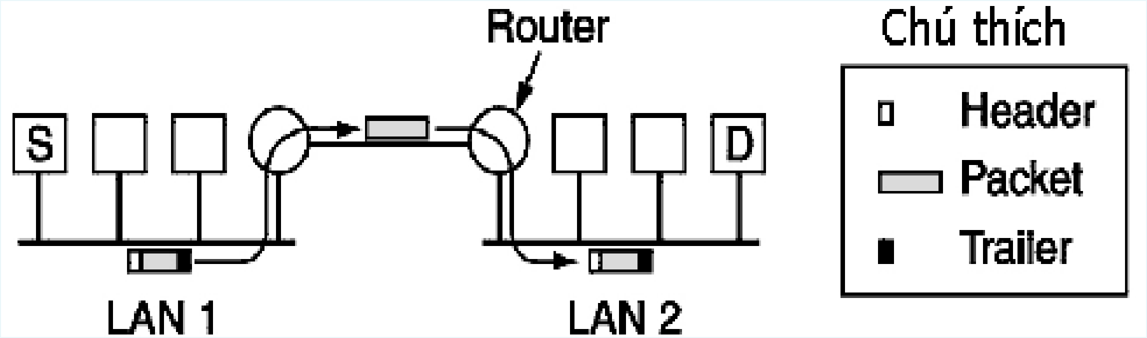


Internetworking

- At physical layer:
  - ✓ Individual networks interconnected by using Repeaters or HUBs.
  - ✓ Repeaters or HUBs simply transmit raw bits from one network segment to others network segments
- At data link layer:
  - ✓ Switches or Bridges used.
  - ✓ They analyze the frame’s MAC address and forward it to the other network segment.
  - ✓ Reformat the frame
- At network layer: Routers used.
- At transport layer and application layer: Gateways used

Internetworking

- Two routers interconnected by a point-to-point link
- Host S wants to send a packet to host D
- S creates a frame containing the packet and sends the frame onto LAN1



- When the frame arrives at router R1, the router will
  - ✓ Unpack the frame, retrieve the packet, find the destination address of the frame, search in its routing table for the route to the destination
  - ✓ Decide to forward the packet to port connecting to R2;
  - ✓ Create a frame containing the packet and send the frame to router R2

Internet Protocol Suite

History

- Developed in the years of the '70s of the 20th century in a project of Defense Advanced Research Projects Agency (DARPA)
- DARPA project led to the development of protocols for internetworking
- In september1969: the first packet-switched network was placed in UCLA and was supervised by Kleinrock.
- In Dec of 1969: ARPAs network expanded to include three different nodes throughout the United States: The Stanford analysis Institute (SRI), The University of California city, and thus the University of Utah
- 1971 : Fifteen sites connected to the young ARPANET
- In December 1974, RFC 675 – Specification of Internet Transmission Control Program, term **internet** used as a shorthand for internetworking

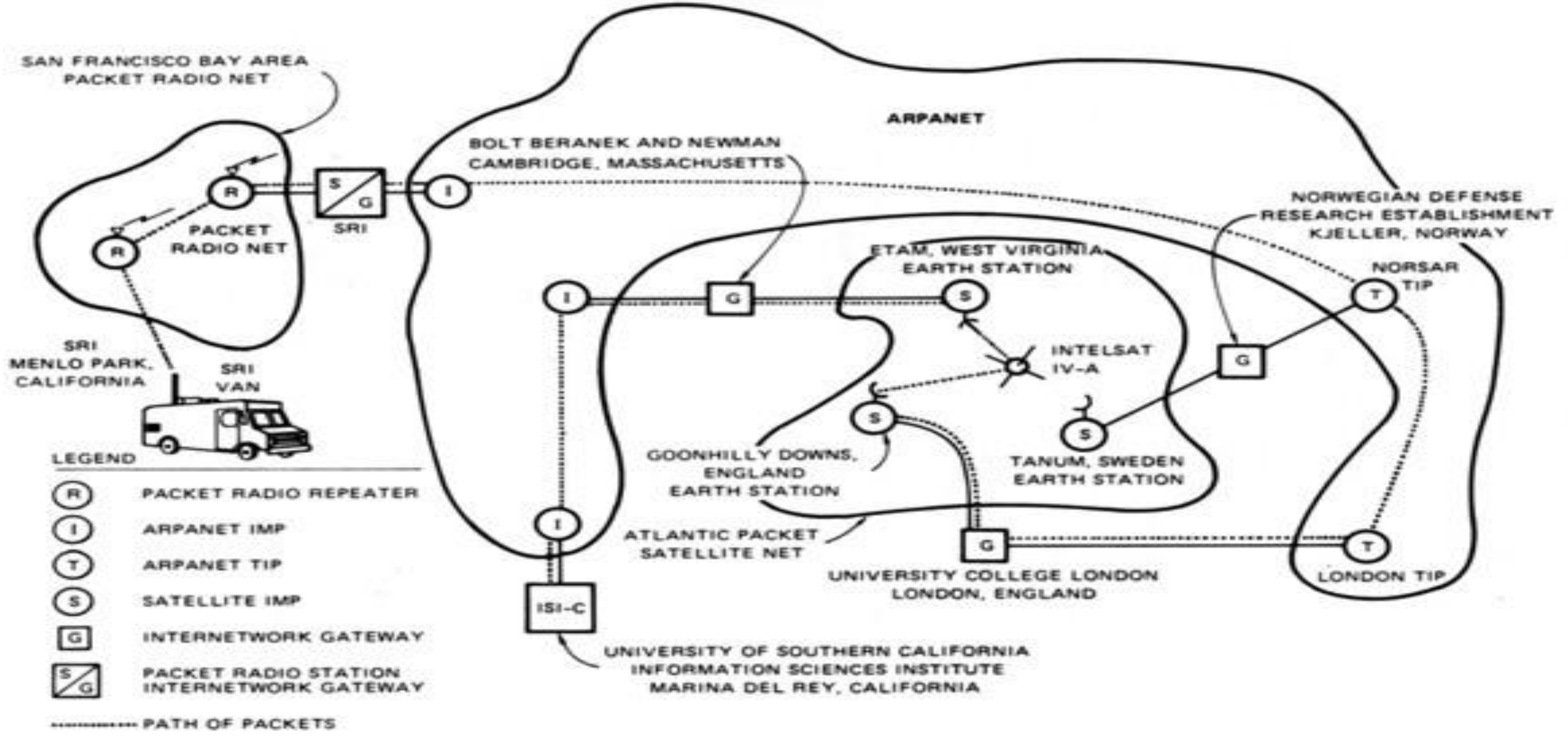
Internet Protocol Suite

History

- In 1982, the Internet Protocol Suite (TCP/IP) was standardized, which permitted worldwide proliferation of interconnected networks.
- In 1986, TCP/IP network access expanded again when the National Science Foundation Network (NSFNET) provided access to supercomputer sites in the United States from research and education organizations, first at 56 kbit/s and later at 1.5 Mbit/s and 45 Mbit/s.
- In 1990, The ARPANET was decommissioned
- By 1995, The Internet was fully commercialized in the U.S.
- In 1997, Vietnam was connected to Internet

Internet Protocol Suite

History

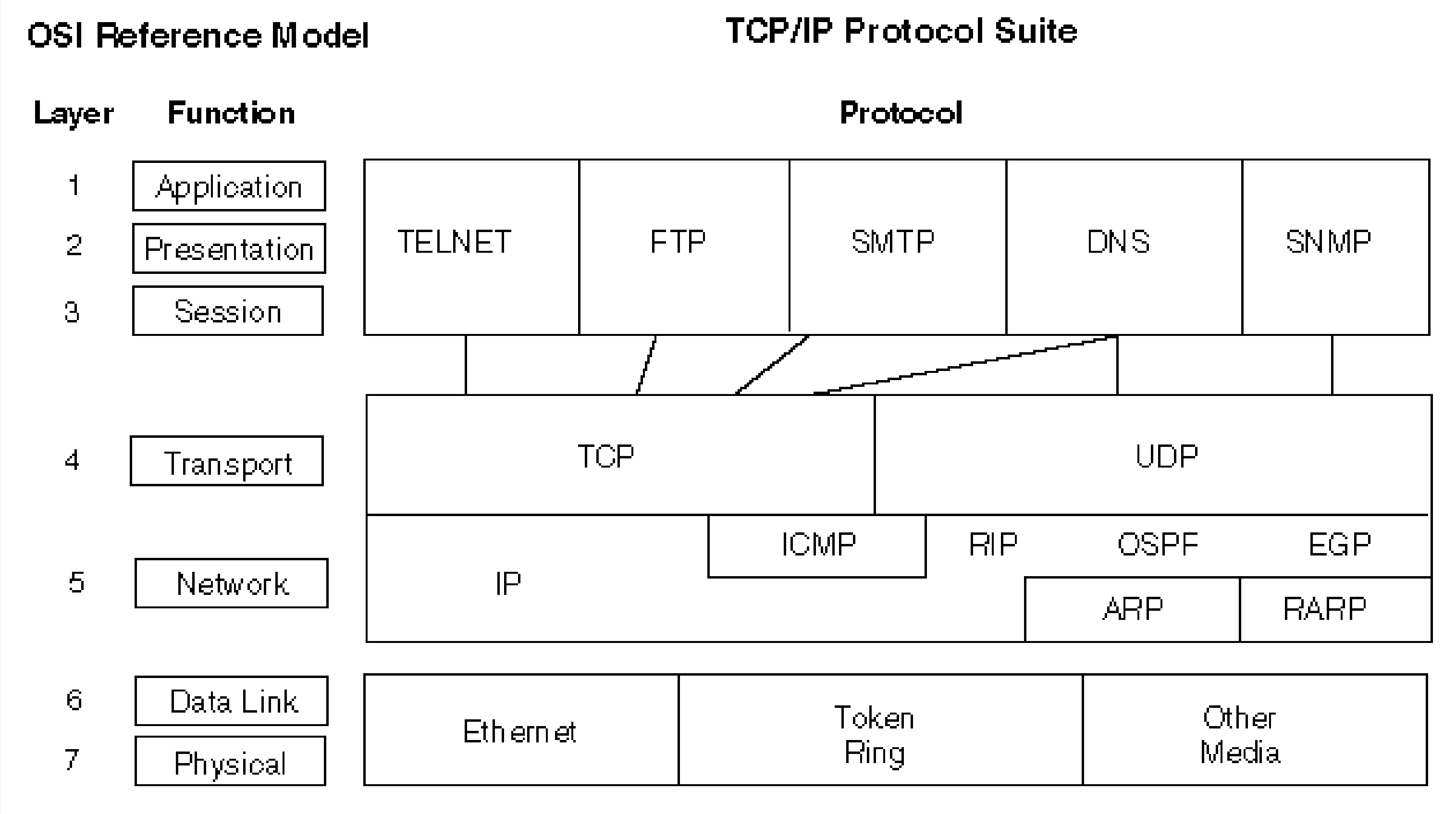


Internet Protocol Suite

TCP/IP

The heart of Internet; A set of communication protocols

- Layer 3: Internet Protocol
- Layer 4: TCP (Transmission Control Procotol); UDP (User Datagram Protocol)
- Layer 7: SMTP, FTP, TELNET, HTTP,…



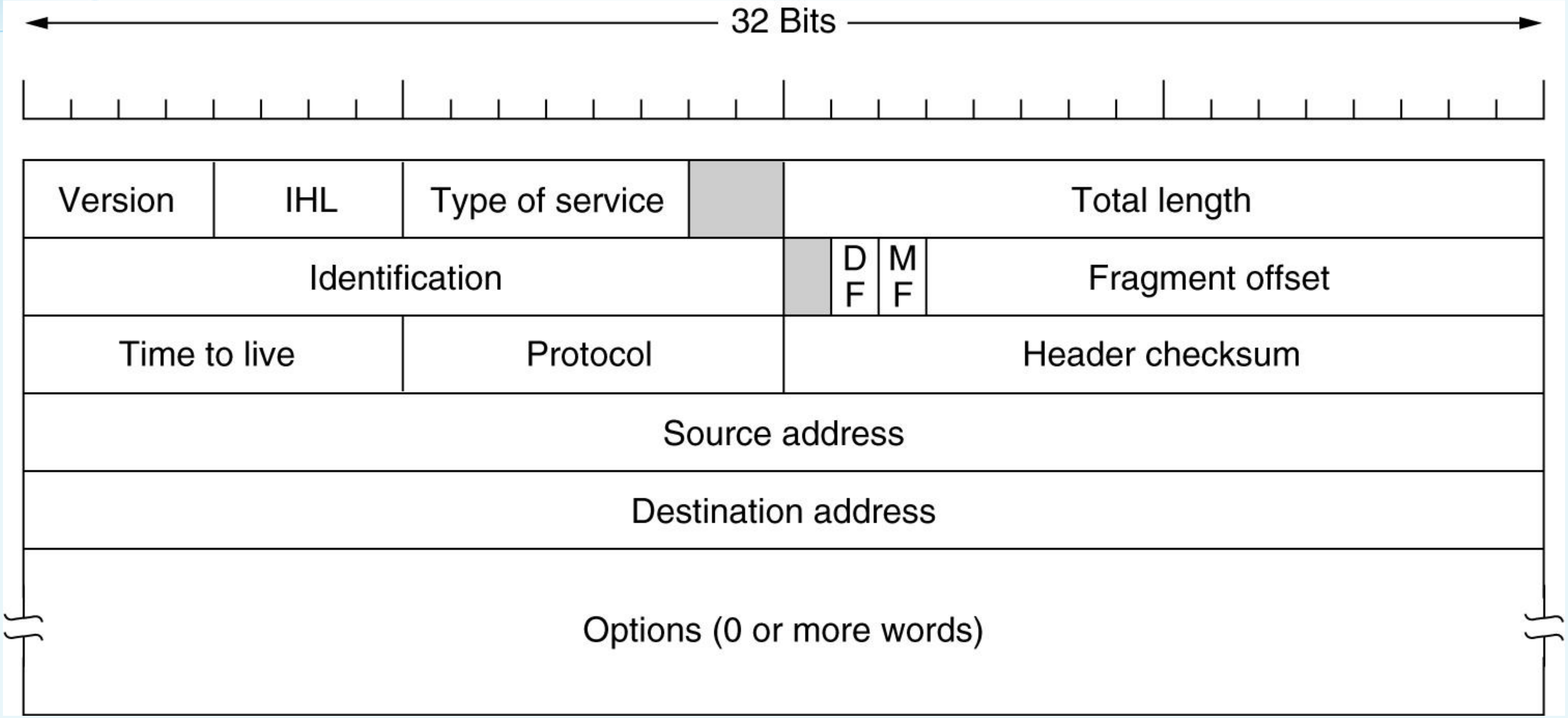
Internet Protocol Suite

IP

- A protocol at the Network layer
- Define the addressing scheme and packet exchange methods in an internetwork
- Specified in RFC 791 (Request For Comments)
- Two main functions
  - ✓ Providing a connectionless communication to exchange datagram packets between hosts in an internetwork
  - ✓ Breaking up packets into fragments and recombining the fragments back into original packet to support data link layer with different sizes of frames

Internet Protocol Suite

IPV4 packet format



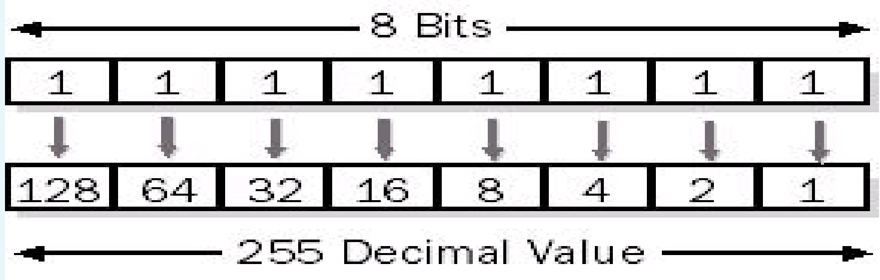
Internet Protocol Suite

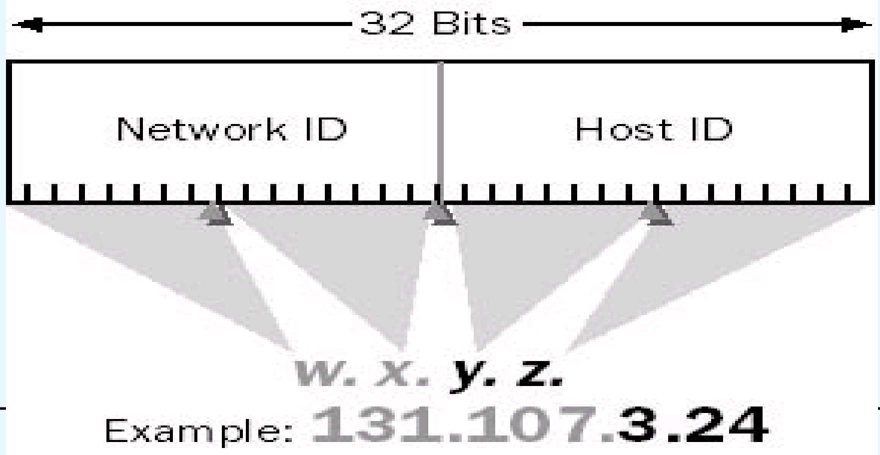
IPV4 address

- A 32-bit number that uniquely identifies a network interface on a machine.
- An IPv4 address typically written in decimal digits, formatted as four 8-bit fields separated by periods.
- Each 8-bit field represents a byte of the IPv4 address.
- Example:

  10101100.00010010.11001000.00000010

  172 . 18 . 200 . 2
- An IP address consist of 2 parts:
  - ✓ Network ID and Host ID





Internet Protocol Suite

IPV4 address

32 Bits

Class			Range of host addresses
A	0	Network / Host	1.0.0.0 to 127.255.255.255
B	10	Network / Host	128.0.0.0 to 191.255.255.255
C	110	Network / Host	192.0.0.0 to 223.255.255.255
D	1110	Multicast address	224.0.0.0 to 239.255.255.255
E	1111	Reserved for future use	240.0.0.0 to 255.255.255.255

Internet Protocol Suite

Special IPV4 address

- *Network Address*: an IP address where all bits in host identifier part are 0, used to identify a network
  - ✓ Example: 10.0.0.0; 172.18.0.0 ; 192.1.1.0
- *Broadcast address*: an IP address where all bits in host identifier part are 1, used to refer to all host in a network; not assigned to a host
  - ✓ Example: 10.255.255.255, 172.18.255.255, 192.1.1.255

Internet Protocol Suite

Special IPV4 address

- **Loopback Network**: 127.0.0.0 used locally in each host.
  - ✓ Each host assigned the loopback IP address 127.0.0.1: used to check IP protocol
- *Private Network Addresses:* for LANs not directly connected to Internet
  - ✓ Network of class A: 10.0.0.0
  - ✓ Networks of class B: 172.16.0.0 → 172.32.0.0
  - ✓ Networks of class C: 192.168.0.0 → 192.168.254.0

Internet Protocol Suite

Special IPV4 address

- *Netmask*: An IP address where all bits in network identifier part are 1 and, all bits in host identifier part are 0.
  - ✓ Used to determine Network ID from an IP address

    Network ID = IP & Netmask
  - ✓ Three standard netmasks
    - For networks of class A: 255.0.0.0
    - For networks of class B: 255.255.0.0
    - For networks of class C: 255.255.255.0
  - ✓ Example:

    Netmaks = 255.255.0.0 and IP address 191.2.2.41

    => Network ID = 191.2.2.41 & 255.255.0.0 = 191.2.0.0

Internet Protocol Suite

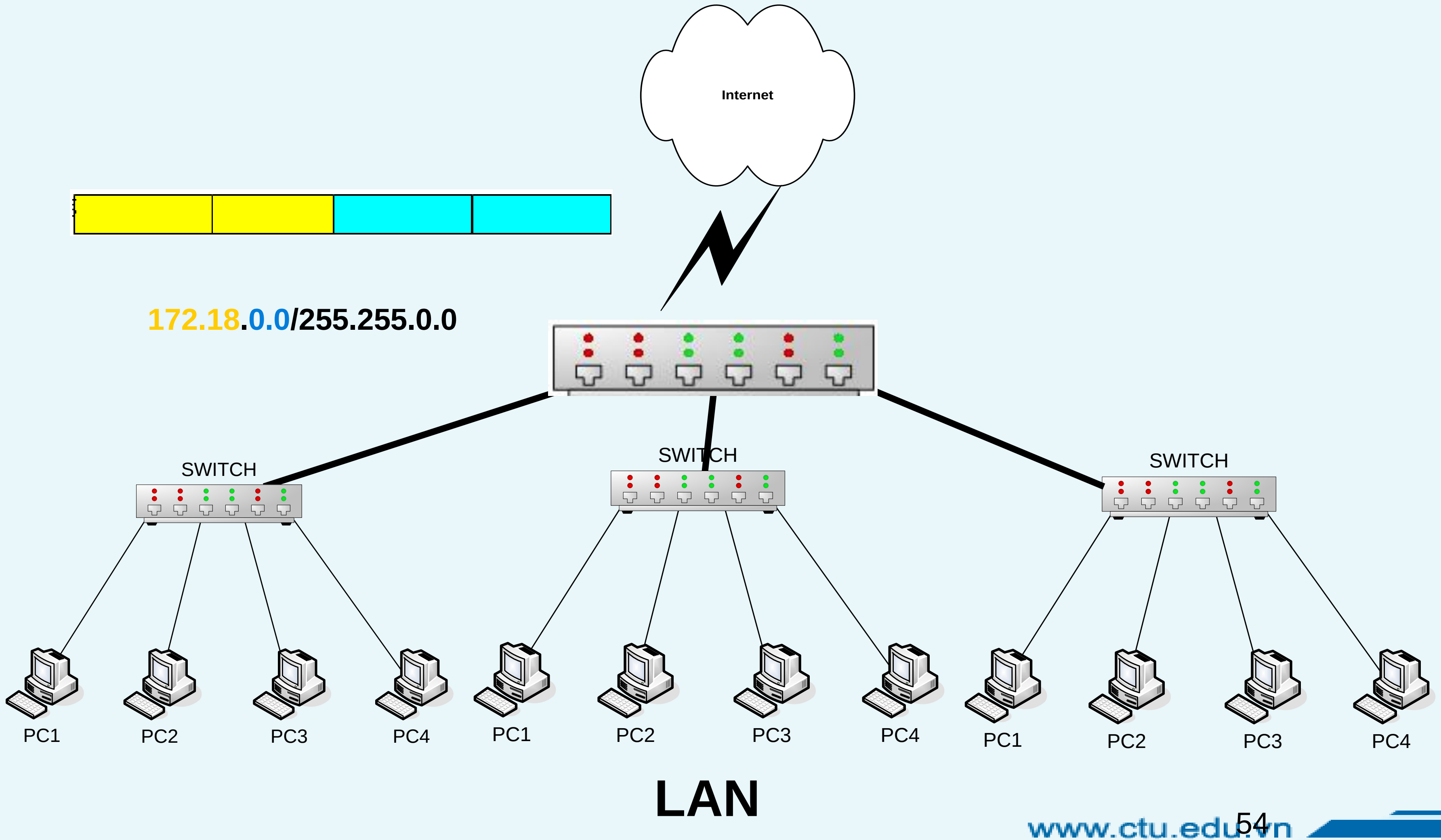
Subnetting

- A solution allowing the block of addresses to be split into several parts:
  - ✓ for internal use as multiple networks (subnets)
  - ✓ while still acting like a single network to the outside world.
- Benefits
  - ✓ *Simplify administration*: subnets managed as independents network and more efficient
  - ✓ Be able to change the internal structure of the network without affecting the external network.
    - An organization continue to use the IP addresses allocated without requesting new address block

- Benefits
  - ✓ *Strengthening the security of the system*: Subnetting allow an organization to design his network as an internetwork of subnets while outside networks still see it is a single network
  - ✓ *Isolating the traffic flow on the network*: With the help of the routers, network traffic can be kept to the lowest level

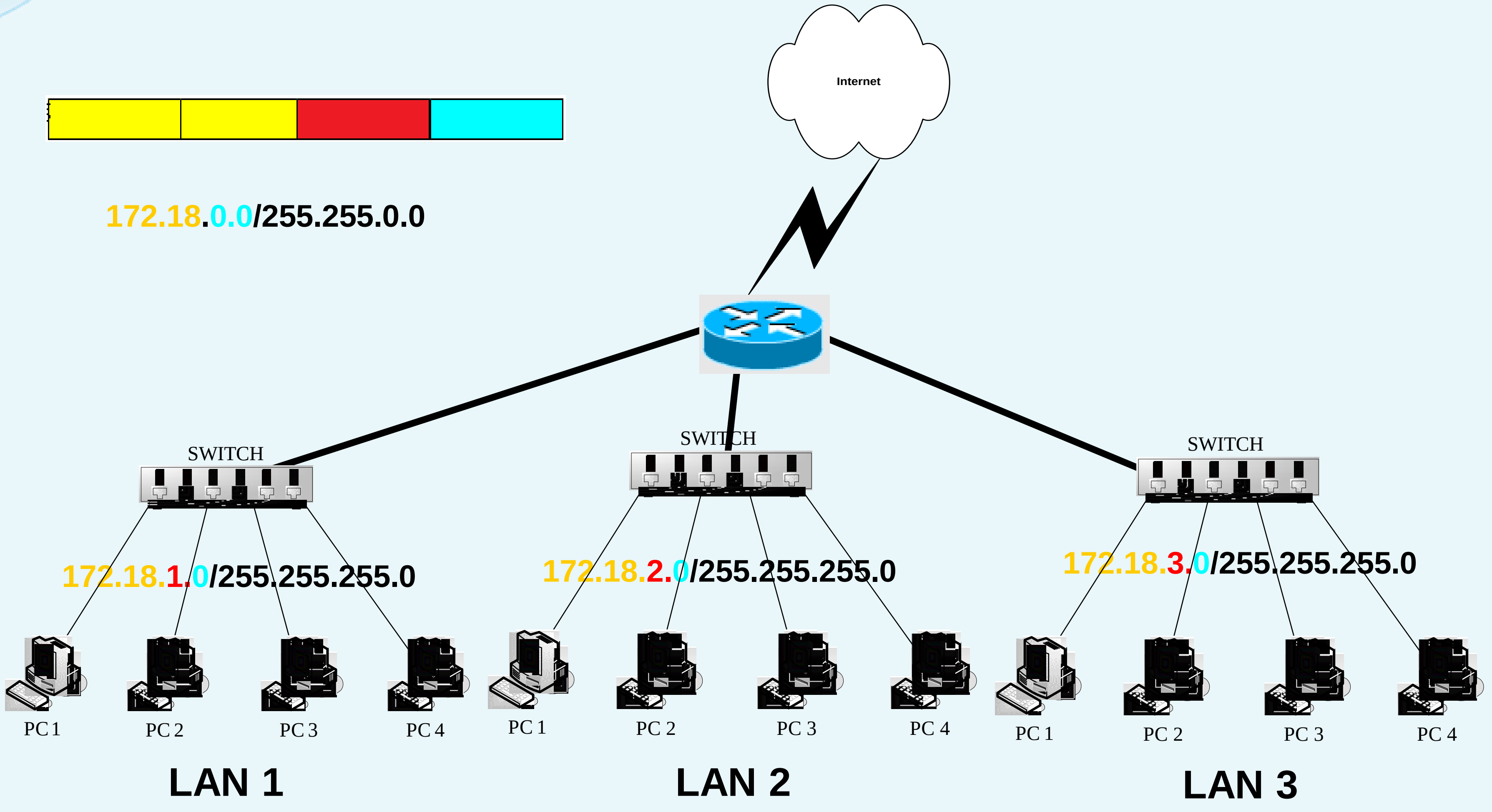
Internet Protocol Suite

Subnetting

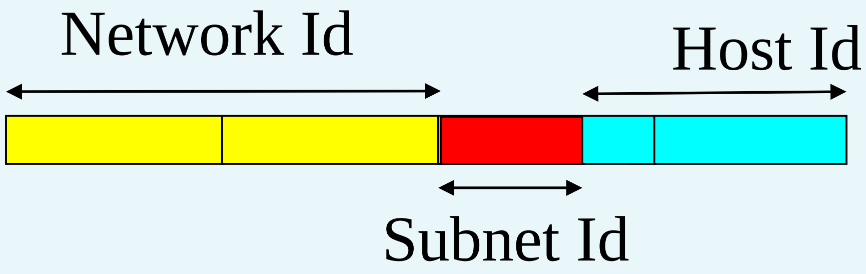


Internet Protocol Suite

Subnetting

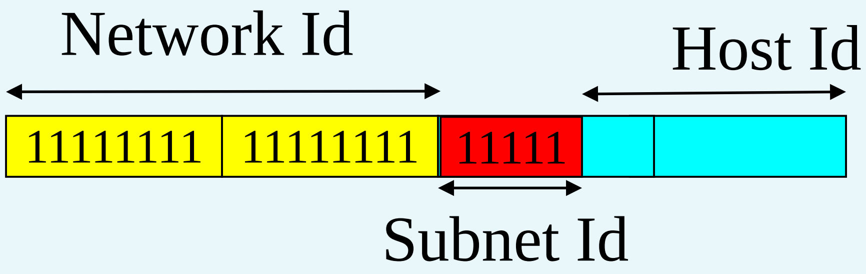


- Network Identifier of original network address remains unchanged
- Host Identifier of original network address is divided into two parts:
  - ✓ Subnet Identifier
  - ✓ Host Identifier



- Subnetmask is an IP address where all bits in network identifier part and all bits in subnet identifier part are 1, and all bits in host identifier are 0

Subnetwork Address = IP & Subnet mask



- Number of bits of subnet id determines the number of subnets
- Example: 4 bits in subnet id → 24=16 subnets

Given a network address of class C: 192.168.1.0 / 255.255.255.0.

- ✓ Using 2 bits for subnet identifier part
- ✓ Subnetmask is 255.255.255.192
- ✓ List of subnetwork addresses

IP address	Represented in decimal	Represented in binary			
Original network	192.168.1.0	1100 0000	1010 1000	0000 0001	0000 0000
Subnet 1	192.168.1.0	1100 0000	1010 1000	0000 0001	0000 0000
Subnet2	192.168.1.64	1100 0000	1010 1000	0010 0001	0100 0000
Subnet3	192.168.1.128	1100 0000	1010 1000	0000 0001	1000 0000
Subnet4	192.168.1.192	1100 0000	1010 1000	0000 0001	1100 0000

Steps in subnetting

- Determine the required number of subnets, e.g **N**
- Represent the number **(N+1)** in binary.
  - ✓ The number of bits used to represent **(N+1)** is also the number of bits reserved for Subnet identifier part.
- For example, N=6 → N+1=7 ~ 111 (B) → Need 3 bits for Subnet identifier part
- Create subnetmask
- List all subnetwork addresses corresponding to the subnetmask
- Choose N addresses from the above list to assign to N subnetworks

Internet Protocol Suite

Steps in subnetting

```
Address:    192.168.1.0            11000000.10101000.00000001 .00000000
Netmask:    255.255.255.0 = 24     11111111.11111111.11111111 .00000000
Wildcard:   0.0.0.255              00000000.00000000.00000000 .11111111
=>
Network:    192.168.1.0/24         11000000.10101000.00000001 .00000000 (Class C)
Broadcast:  192.168.1.255          11000000.10101000.00000001 .11111111
HostMin:    192.168.1.1            11000000.10101000.00000001 .00000001
HostMax:    192.168.1.254          11000000.10101000.00000001 .11111110
Hosts/Net:  254                    (Private Internet)

Subnets

Netmask:    255.255.255.192 = 26   11111111.11111111.11111111.11 000000
Wildcard:   0.0.0.63               00000000.00000000.00000000.00 111111

Network:    192.168.1.0/26         11000000.10101000.00000001.00 000000 (Class C)
Broadcast:  192.168.1.63           11000000.10101000.00000001.00 111111
HostMin:    192.168.1.1            11000000.10101000.00000001.00 000001
HostMax:    192.168.1.62           11000000.10101000.00000001.00 111110
Hosts/Net:  62                     (Private Internet)
```

Internet Protocol Suite

Steps in subnetting

```
Network:     192.168.1.64/26       11000000.10101000.00000001.01 000000 (Class C)
     Broadcast:  192.168.1.127          11000000.10101000.00000001.01 111111
     HostMin:    192.168.1.65           11000000.10101000.00000001.01 000001
     HostMax:    192.168.1.126          11000000.10101000.00000001.01 111110
              Hosts/Net:  62                     (Private Internet)

Network:     192.168.1.128/26      11000000.10101000.00000001.10 000000 (Class C)
     Broadcast:  192.168.1.191          11000000.10101000.00000001.10 111111
     HostMin:    192.168.1.129          11000000.10101000.00000001.10 000001
     HostMax:    192.168.1.190          11000000.10101000.00000001.10 111110
              Hosts/Net:  62                     (Private Internet)

Network:     192.168.1.192/26      11000000.10101000.00000001.11 000000 (Class C)
     Broadcast:  192.168.1.255          11000000.10101000.00000001.11 111111
     HostMin:    192.168.1.193          11000000.10101000.00000001.11 000001
     HostMax:    192.168.1.254          11000000.10101000.00000001.11 111110
              Hosts/Net:  62                     (Private Internet)
```

Bài 1: Cho địa chỉ mạng 192.168.1.0. Hãy phân mạng này thành 10 mạng con để gán cho 10 phòng máy tính. Định địa chỉ cho 10 máy tính của phòng 1 và phò ng 2

Bài 2: Cho địa chỉ mạng 172.16.0.0 được chia mạng con với subnetmask=255.255.255.0. Gán mỗi phòng 1 mạng con. Hãy định địa chỉ cho 10 máy tính ở phòng 1 và 2

Lưu ý: Trình bày kết quả theo dạng

– Phân bố mạng con

+ Phòng 1: Địa chỉ mạng con/subnetmask

….

+ Phòng 10: Địa chỉ mạng con/subnetmask

– Phòng 1:

+ Máy 1: IP

+ Máy 2: IP

+ Máy 3: IP …

+ Máy 10: IP

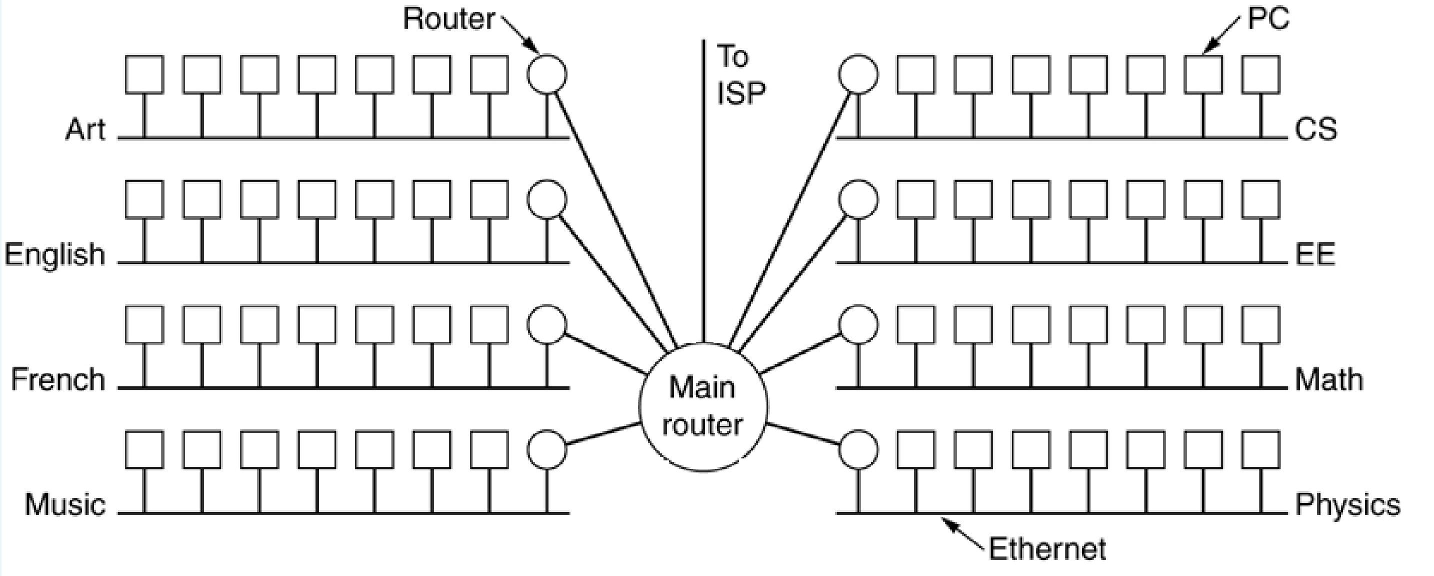
Bài 3: Mạng máy tính của một tổ chức có sơ đồ như hình bên dưới. Hãy xác định số lượng mạng con tối thiểu của mạng này. Giả sử tổ chức này sử dụng một địa chỉ mạng IP 180.10.0.0. Hãy giúp xác định:

a) Mặt nạ mạng con

b) Gán địa chỉ mạng cho các mạng con

c) Gán địa chỉ IP cho các Interface của router

d) Gán 10 địa chỉ IP cho phòng máy tính Art và Physics



Internet Protocol Suite

Classless Inter-Domain Routing method (CIDR)

- Developed to resolve the lack of IP addresses
- No need to classify the networks into class A, B, or C
- Network identify part: the first 13→ 27 bits
- An IP address consists of two parts
  - ✓ 32 bits of a traditional IP address
  - ✓ Number of bits used for network identify
  - ✓ Example: 206.13.01.48/25

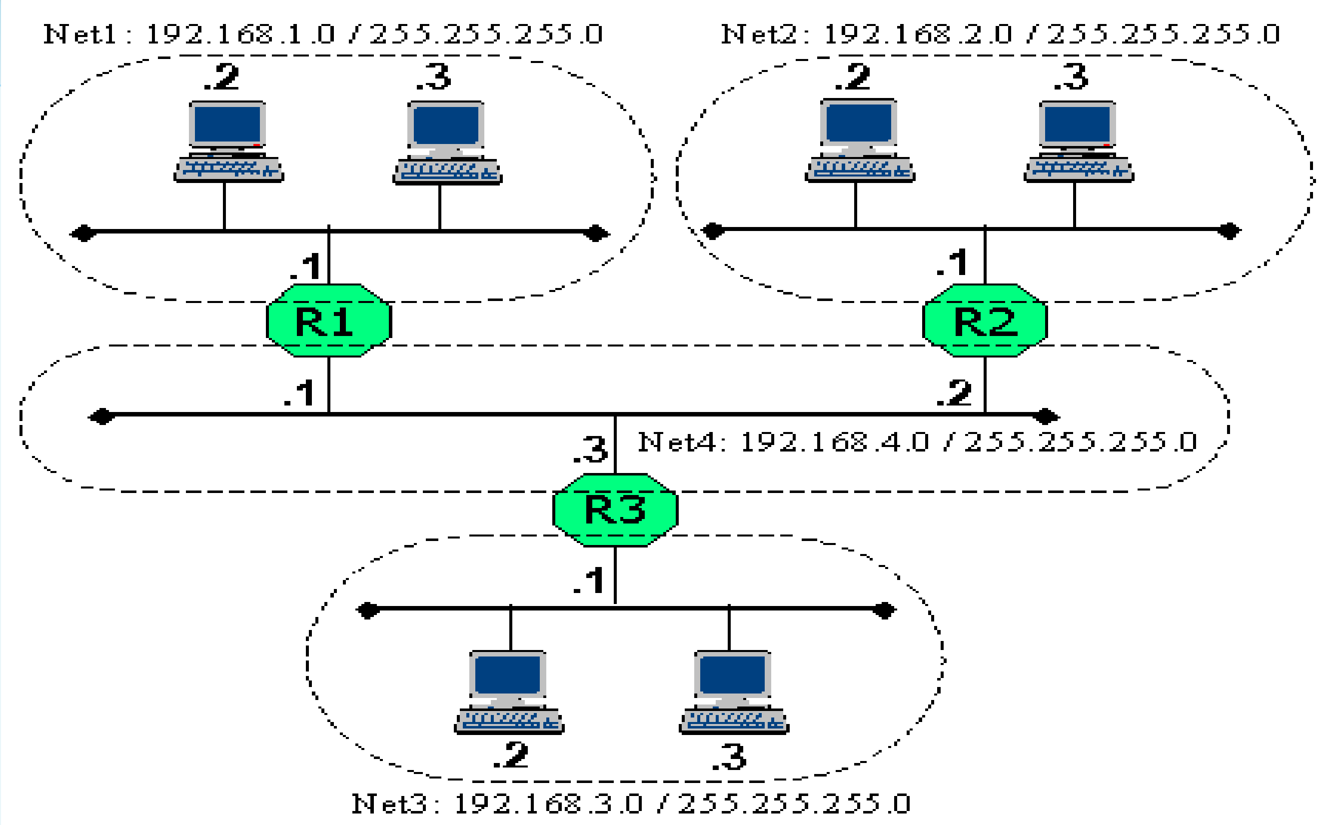
Internet Protocol Suite

Classless Inter-Domain Routing method (CIDR)

CIDR Prefix	Fraction of Class B or C nets	Dotted decimal	Host Addresses
/28	1/16 C	255.255.255.240	16 hosts
/27	1/8 C	255.255.255.224	32 hosts
/26	1/4th C	255.255.255.192	64 hosts
/25	1/2 C	255.255.255.128	128 hosts
/24	1 Class C	255.255.255.0	256 hosts
/23	2 C's	255.255.254.0	512 hosts
/22	4 C's	255.255.252.0	1,024 hosts
/21	8 Class C	255.255.248.0	2,048 hosts
/20	16 C's	255.255.240.0	4,096 hosts
/19	32 C's	255.255.224.0	8,192 hosts
/18	64 C's	255.255.192.0	16,384 hosts
/17	128 Class C	255.255.128.0	32,768 hosts
/16	1 B or 256 C's	255.255.0.0	65,536 hosts
/15	2 B's or 512 C's	255.254.0.0	131,072 hosts
/14	4 B's or 1024 C's	255.252.0.0	262,144 hosts
/13	8 B's or 2048 C's	255.248.0.0	524,288 hosts

Internet Protocol Suite

Routing in IP protocol



192.168.3.3 - Routing table

Network/Netmask	NextHop	Interface
192.168.3.0/255.255.255.0	local	local
default	192.168.3.1	local

R1-Routing table

Network/Netmask	NextHop	Interface
192.168.1.0/255.255.255.0	local	local
192.168.2.0/255.255.255.0	192.168.4.2	192.168.4.1
192.168.3.0/255.255.255.0	192.168.4.3	192.168.4.1
192.168.4.0/255.255.255.0	local	local

R2-Routing table

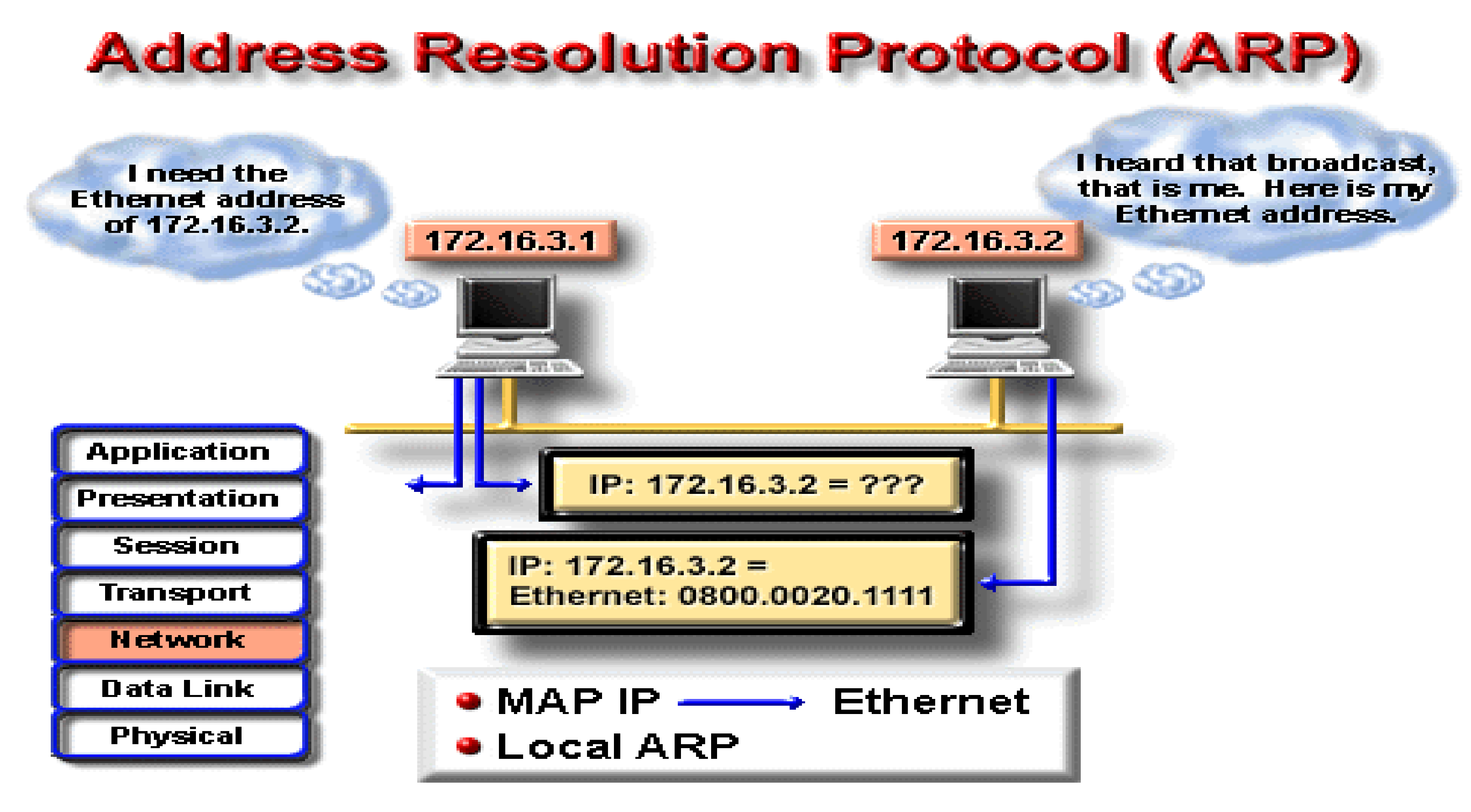
Network/Netmask	NextHop	Interface
192.168.1.0/255.255.255.0	192.168.4.1	192.168.4.2
192.168.2.0/255.255.255.0	local	local
192.168.3.0/255.255.255.0	192.168.4.3	192.168.4.2
192.168.4.0/255.255.255.0	local	local

R3-Routing table

Network/Netmask	NextHop	Interface
192.168.1.0/255.255.255.0	192.168.4.1	192.168.4.3
192.168.2.0/255.255.255.0	192.168.4.2	192.168.4.3
192.168.3.0/255.255.255.0	local	local
192.168.4.0/255.255.255.0	local	local

Internet Protocol Suite

ARP - Address Resolution Protocol



ARP - Address Resolution Protocol

```
C:\WINDOWS\system32\cmd.exe
C:\Documents and Settings\Giaovien1>arp -a

Interface: 192.168.0.62 --- 0x10003
  Internet Address      Physical Address      Type
  192.168.0.3           00-0c-76-ad-32-dc     dynamic
  192.168.0.33          00-0c-76-15-a2-49     dynamic
  192.168.0.34          00-10-dc-71-93-52     dynamic
  192.168.0.35          00-0c-76-26-43-08     dynamic
  192.168.0.36          00-10-dc-41-df-c6     dynamic
  192.168.0.37          00-10-dc-c1-34-85     dynamic
  192.168.0.38          00-10-dc-71-96-21     dynamic
  192.168.0.39          00-10-dc-f3-42-b1     dynamic
  192.168.0.40          00-10-dc-72-7a-a5     dynamic
  192.168.0.41          00-10-dc-72-7a-ad     dynamic
  192.168.0.43          00-0c-76-26-43-c0     dynamic
  192.168.0.44          00-0c-76-26-43-be     dynamic
  192.168.0.46          00-0c-76-26-43-92     dynamic
  192.168.0.48          00-10-dc-41-c3-96     dynamic
  192.168.0.49          00-10-dc-c1-5d-8d     dynamic
  192.168.0.50          00-10-dc-c1-38-47     dynamic

C:\Documents and Settings\Giaovien1>_
```

Internet Protocol Suite

RARP – Reverse Address Resolution Protocol

- Mapping MAC addresses to IP addresses
- Used in systems supporting diskless workstations
- Diskless workstations need to get IP addresses to communicate with the server
- The server maintains a table mapping MAC addresses to IP addresses
- On receiving an RARP request, the server searches in mapping table for the IP address correspond to the MAC address in RARP request and return the address to the workstation

Internet Protocol Suite

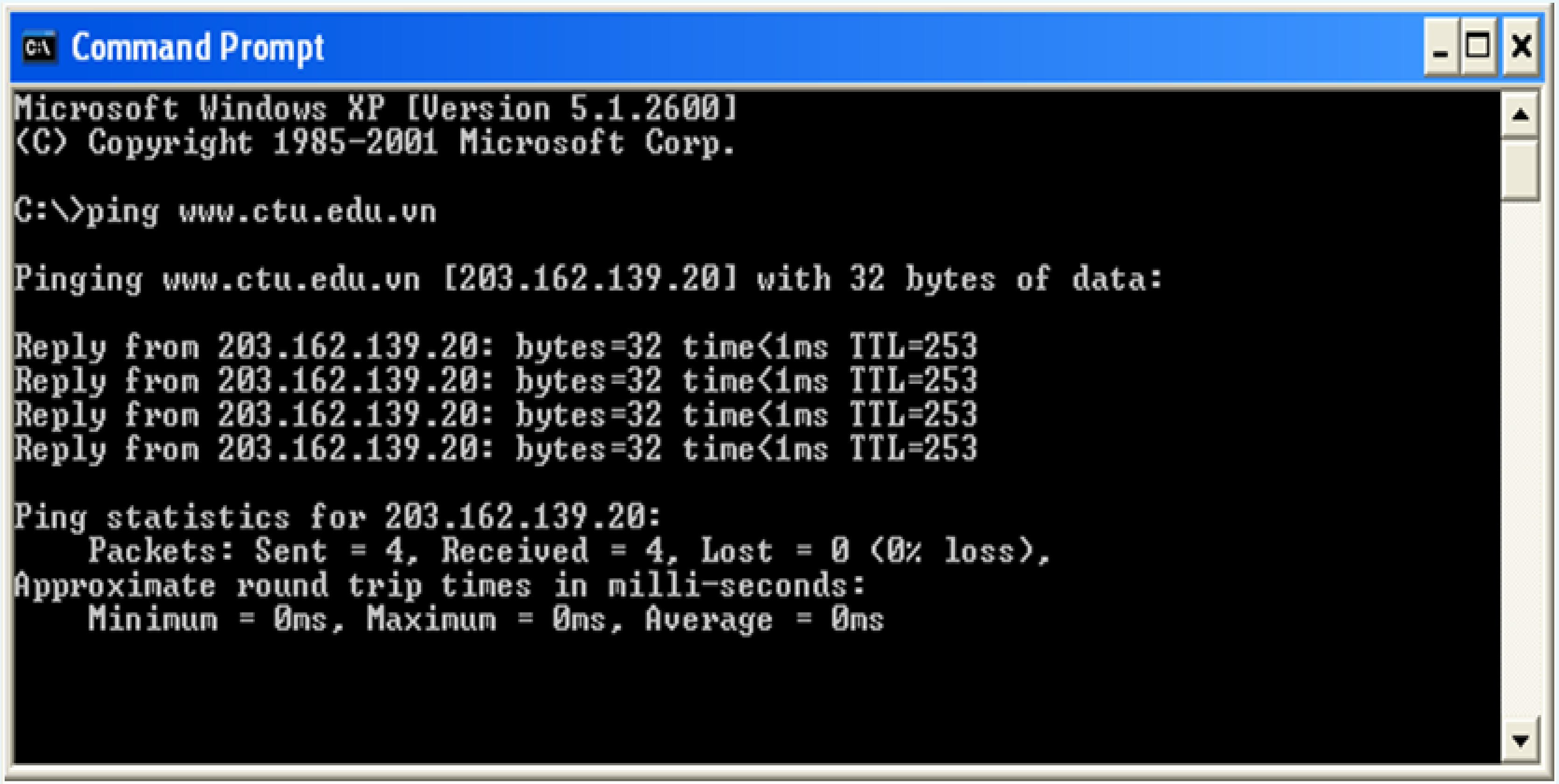
Internet Control Message Protocol (ICMP)

- Messages of ICMP are transmitted in IP packets
- Used to transmit error messages or control information

Message type	Description
Destination unreachable	Packet could not be delivered
Time exceeded	Time to live field hit 0
Parameter problem	Invalid header field
Source quench	Choke packet
Redirect	Teach a router about geography
Echo request	Ask a machine if it is alive
Echo reply	Yes, I am alive
Timestamp request	Same as Echo request, but with timestamp
Timestamp reply	Same as Echo reply, but with timestamp

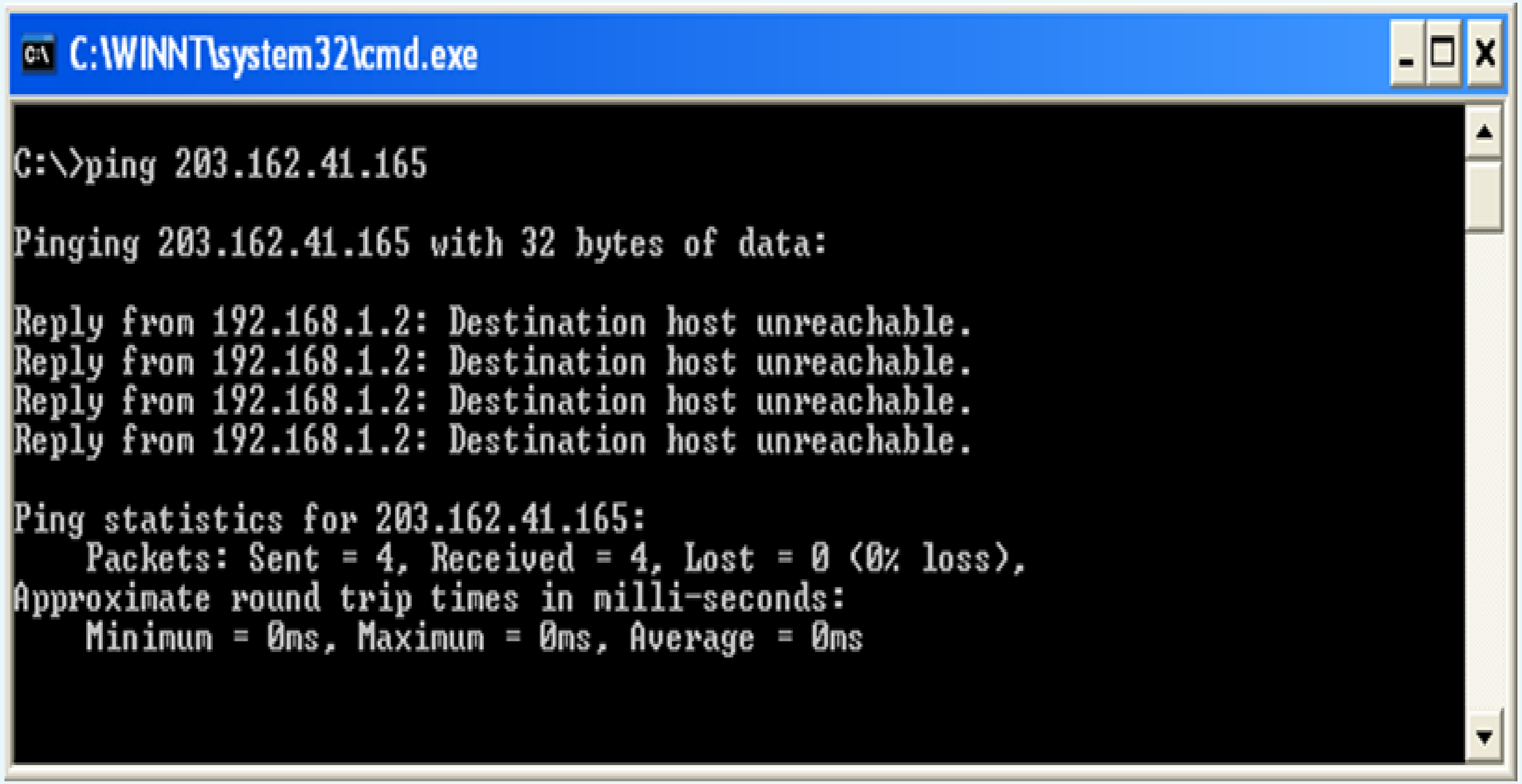
Internet Protocol Suite

Internet Control Message Protocol (ICMP)



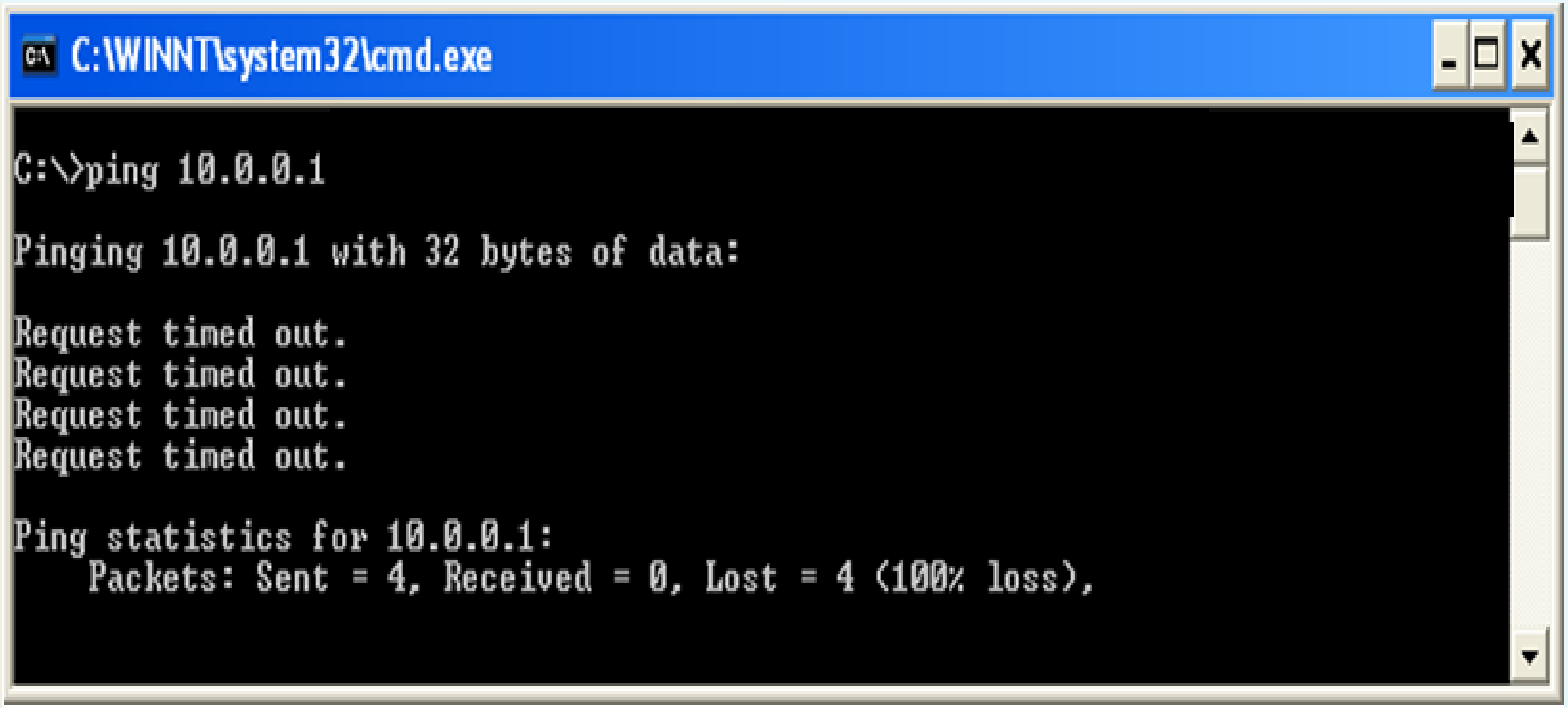
Internet Protocol Suite

Internet Control Message Protocol (ICMP)



Internet Protocol Suite

Internet Control Message Protocol (ICMP)



Internet Protocol Suite

Subnetting Cheat Chart

Which subnet is host 192.168.1.1/26 in?

- /26 isn’t the standard mask for Class C IP addresses; /24 is.
- To get to 26 from 24 you need to add 2.
- Tick two places across the top row to see that the subnets go up in increments of 64

Subnetting Cheat Chart

	Bits	128	64	32	16	8	4	2	1
Subnets		✓	✓						
128	✓								
192	✓								
224									
240									
248									
252									
254									
255									

- You are allowed to start with subnet 0, and the last subnet will be whatever /26 is.
  - ✓ To work that out, tick two down the Subnets column

Which subnet is host 192.168.1.1/26 in?

192.168.1.0 <= **Host 192.168.1.1 is in this subnet**
192.168.1.64
192.168.1.128
192.168.1.192

Which subnet is host 192.168.1.100/26 in?
192.168.1.0
192.168.1.64 <= **Host 192.168.1.1 is in this subnet**
192.168.1.128
192.168.1.192

Subnetting Cheat Chart

	Bits	128	64	32	16	8	4	2	1
Subnets		✓	✓						
128	✓								
192	✓								
224									
240									
248									
252									
254									
255									

Internet Protocol Suite

Subnetting Cheat Chart

Which subnet is host 192.168.1.100/27 in?

- To get to 27 from 24 you need to add 3
- Tick three places across the top row
  - ✓ The subnets go up in increments of 32
  - ✓ Start at zero and end at 224.

192.168.1.0
192.168.1.32
192.168.1.64
192.168.1.96 <= **Host 192.168.1.100 is in this subnet**
192.168.1.128
192.168.1.160
192.168.1.192
192.168.1.224

Subnetting Cheat Chart

	Bits	128	64	32	16	8	4	2	1
Subnets		✓	✓	✓					
128	✓								
192	✓								
224	✓								
240									
248									
252									
254									
255									

Internet Protocol Suite

Subnetting Cheat Chart

Which subnet is host 192.168.1.210/28 in?

- To get to 28 from 24 you need to add 4
- Tick four places across the top row
  - ✓ Subnets go up in increments of 16
  - ✓ Start at zero and end at 240
- Apply jumping whenever you have a small increment and a high IP address
  - ✓ Find a number you can use to jump, but stay in the increment count

Subnetting Cheat Chart

	Bits	128	64	32	16	8	4	2	1
Subnets		✓	✓	✓	✓				
128	✓								
192	✓								
224	✓								
240	✓								
248									
252									
254									
255									

192.168.1.0

192.168.1.16 <=**Apply a jump here to 160.**

192.168.1.160 <=**Resume the 16 increment count.**

192.168.1.176

192.168.1.192

192.168.1.208 <=**Host 192.168.1.210 is in this subnet.**

192.168.1.224

Internet Protocol Suite

Subnetting Cheat Chart

Which subnet is host 200.100.100.250/29 in?

- To get to 29 from 24 you need to add 5
- Tick five places across the top row
  - ✓ Subnets go up in increments of 8
  - ✓ Start at zero and end at 248

Subnetting Cheat Chart

	Bits	128	64	32	16	8	4	2	1
Subnets		✓	✓	✓	✓	✓			
128	✓								
192	✓								
224	✓								
240	✓								
248	✓								
252									
254									
255									

200.100.100.0
200.100.100.8 <=Jump to 80.
200.100.100.80 <=Jump to 160.
200.100.100.160 <=Add another 80.
200.100.100.240 <=Back to adding 8 increments.
200.100.100.248 <=Host 200.100.100.250 is here.

Exercises:

1. 220.20.10.199/27 in? What is the broadcast address?
2. Which subnet is host 199.99.10.87/28 in? What is the broadcast address?
3. Which subnet is host 200.99.30.171/29 in? What is the first host, last host, and broadcast address?
4. Which subnet is host 172.16.100.100/17 in?
5. Which subnet is host 172.16.200.100/17 in?
6. Which subnet is host 128.160.22.111/18 in?
7. Which subnet is host 130.160.222.1/18 in?
8. Which subnet is host 140.60.212.12/19 in?
9. Which subnet is host 160.160.160.160/20 in?

Exercises:

10. Which subnet is host 190.1.150.110/21 in? What is the first host, last host, and broadcast address?
11. Which subnet is host 191.100.15.1/22 in?
12. Which subnet is host 128.100.19.11/23 in?
13. Which subnet is host 136.10.40.111/24 in?
14. Which subnet is host 186.30.30.41/25 in?
15. Which subnet is host 150.130.20.121/26 in?
16. Which subnet is host 131.60.50.1/27 in?
17. Which subnet is host 142.160.40.35/28 in?
18. Which subnet is host 128.10.10.54/29 in?

Exercises:

19. Which subnet is host 10.10.10.54/9 in? What is the first host, last host, and broadcast address?
20. Which subnet is host 20.100.11.11/10 in?
21. Which subnet is host 40.50.101.121/12 in?
22. Which subnet is host 120.150.1.2/14 in?
23. Which subnet is host 10.10.14.25/16 in?
24. Which subnet is host 10.23.4.2/18 in?
25. Which subnet is host 14.40.140.85/22 in?
26. Which subnet is host 90.10.22.17/29 in?
27. Which subnet is host 100.100.210.46/28 in?

Exercises:

27. Which subnet mask applied to 192.168.1.0 will generate two subnets and 126 hosts-per-subnet?
28. Which subnet mask applied to 192.168.1.0 will generate four subnets and 62 hosts-per-subnet?
29. Which subnet mask applied to 200.18.2.0 will generate eight subnets and 30 hosts-per-subnet?
30. Which subnet mask applied to 221.1.22.0 will generate 16 subnets and 14 hosts-per-subnet?
31. Which subnet mask applied to 198.10.122.0 will generate 30 subnets and 6 hosts-per-subnet?
32. Which subnet mask applied to 210.100.12.0 will generate two hosts-per-subnet?
33. Which subnet mask applied to 172.16.0.0 will generate four subnets? How many hosts-per-subnet will this leave you?
34. Which subnet mask applied to 172.20.0.0 will generate 32 subnets? How many hosts-per-sub-net will this leave you?

Internet Protocol Suite

Subnetting Cheat Chart

Exercises:

35. Which subnet mask applied to 132.30.0.0 will generate as close as possible to 60 subnets each supporting up to 1000 hosts?
36. Which subnet mask applied to 190.100.0.0 will generate 128 subnets each supporting at least 500 hosts?
37. Which subnet mask applied to 191.40.0.0 will generate 512 subnets each supporting up to 100 hosts?
38. Your boss hands you subnet 10.0.0.0/21 and asks you to work out how many subnets and hostsper- subnet this will generate. What do you tell her?

Subnetting Cheat Chart

	Bits	128	64	32	16	8	4	2	1
Subnets		✓	✓	✓	✓	✓	✓		
128	✓								
192	✓								
224	✓								
240	✓								
248	✓								
252	✓								
254									
255									
Powers of Two	Subnets	Hosts Minus 2							
2	✓	✓							
4	✓	✓							
8	✓	✓							
16	✓	✓							
32	✓	✓							
64	✓	✓							
128		✓							
256		✓							
512		✓							
1024		✓							
2048									
4096									
8192									
16384									

Exercises:

39. You have taken over a network from another network designer. You can see that 10.0.0.0/23 has been allocated. How many subnets and hosts-per-subnet has this generated?
40. You have taken over a network from another network designer. You can see that 10.0.0.0/17 has been allocated. How many subnets and hosts-per-subnet has this generated?

Internet Protocol Suite

IPv6

- The latest version of Internet Protocol
- Layer 3 Internet Protocol version 6
- Intended to replace IPv4
- Became a draft standard in December 1998
- Formally become Internet Standard on 14 July, 2017

Internet Protocol Suite

IPv6

- Better Security
- Larger address space: 128-bit vs 32-bit length address
- More efficient IP header (fewer fields and no checksum)
- Built-in IP Mobility

- IPv6 address:
  - a 128-bit address broken up into eight different sections separated by a colon
  - Each section made up of 16 bits.
  - 1111:AABB:CCDD:0001:0123:4567:8901:ABCD
- This address can be divided into 3 section: as an **organizational prefix**, the **subnet**, and **the device IDs**

Example address

1111:AABB:CCDD:0001:0123:4567:8901:ABCD

We can break it out into the following parts:

- Organizational Prefix (48 bits): 1111:AABB:CCDD
- Subnet ID (16 bits): 0001
- Device IDs (64 bits): 0123:4567:8901:ABCD

1111:AABB:CCDD	0001	**0123:4567:8901:ABCD**
Organizational Prefix (48 bits)	Subnet ID	Device IDs (64 bits)

Example address

1111:AABB:CCDD:0001:0123:4567:8901:ABCD

We can break it out into the following parts:

- Organizational Prefix (48 bits): 1111:AABB:CCDD
- Subnet ID (16 bits): 0001
- Device IDs (64 bits): 0123:4567:8901:ABCD

1111:AABB:CCDD	0001	**0123:4567:8901:ABCD**
Organizational Prefix (48 bits)	Subnet ID	Device IDs (64 bits)

Internet Protocol Suite

IPv6 address

- How many devices are there in the network with an IP schema like this?
- In the above example:
  - 16-bit section for subnetting: provide us with the capability to have more than **65,000** subnets and,
  - And 64 bits for actual IP addresses: **quintillions** of unique device IDs in the IP range

- ***How to assign the individual device ID numbers for all of the computers, servers, and devices on our network?***

  1. Start with number 1 and go up from there.
  2. Calculate out the old IPv4 addresses into hex and use this as the last 32 bits of the address

- Then utilize ID numbers in combination with the organizational prefix and the subnet ID to create a static IPv6 address

  E.g., An IPv4 192.168.1.5 factors out to C0A8:0105

  IPv6: 1111:AABB:CCDD:0001:0:0:C0A8:0105

Internet Protocol Suite

IPv6 address Simplified

- The IPv6 address:
  - **1111:AABB:CCDD:0001:0000:0000:C0A8:0105**

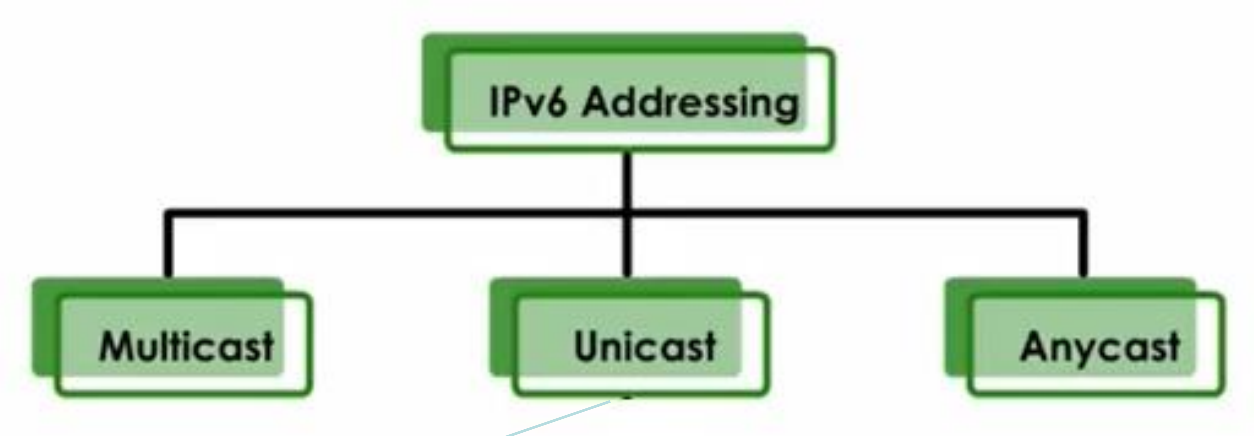
1. Dropping leading zeroes from any group.
   - For example: 1111:AABB:CCDD:**1:0:0**:C0A8:105

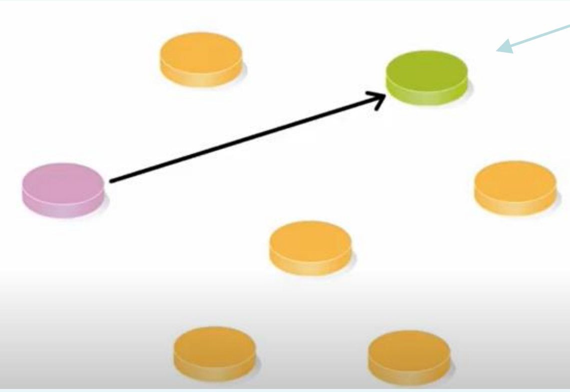
- 2. Using a pair of colons (::) to represent a string of consecutive groups with a value of zero
  - For example: 1111:AABB:CCDD:1::C0A8:105

- 3. pair of colons can not used more than one time within an IP address

Internet Protocol Suite

Type of IPv6 address

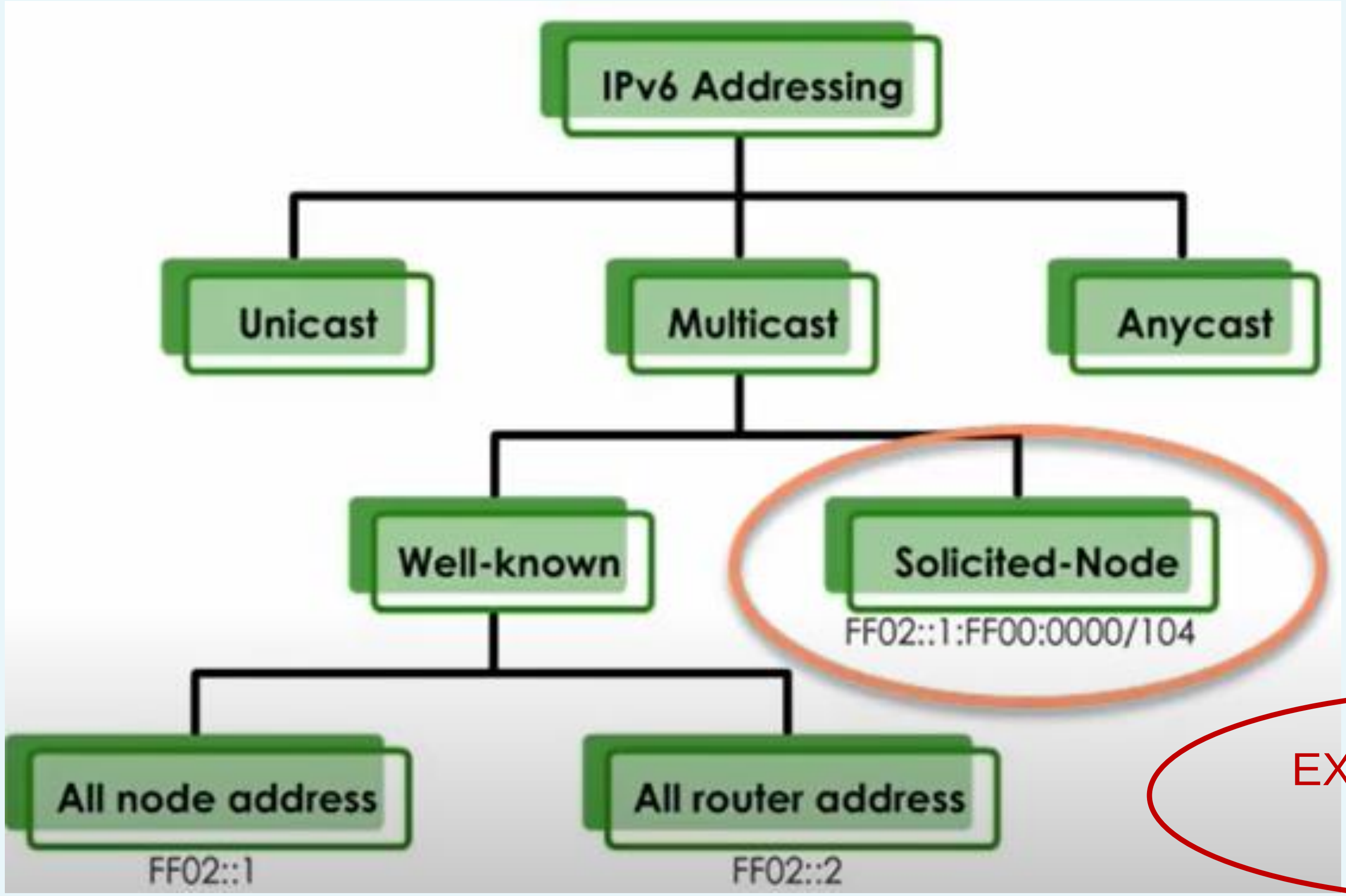




- One-to-one association between two individual devices
- Each unicast destination address uniquely identifies a single receiver on a network

Internet Protocol Suite

Type of IPv6 address



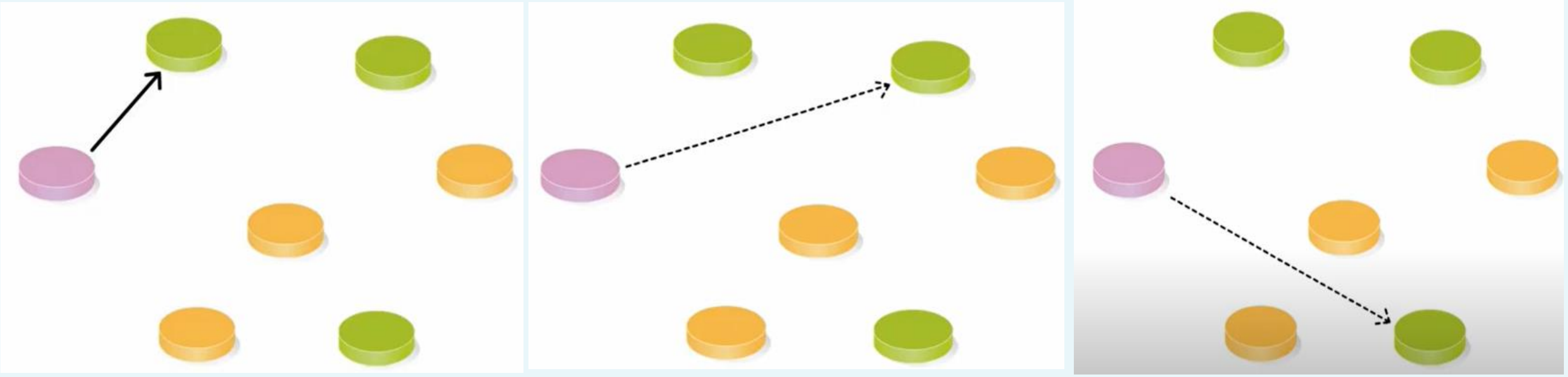
EX: ICMPv6: NDP to find MAC

- One-to-many communication

Internet Protocol Suite

Type of IPv6 address

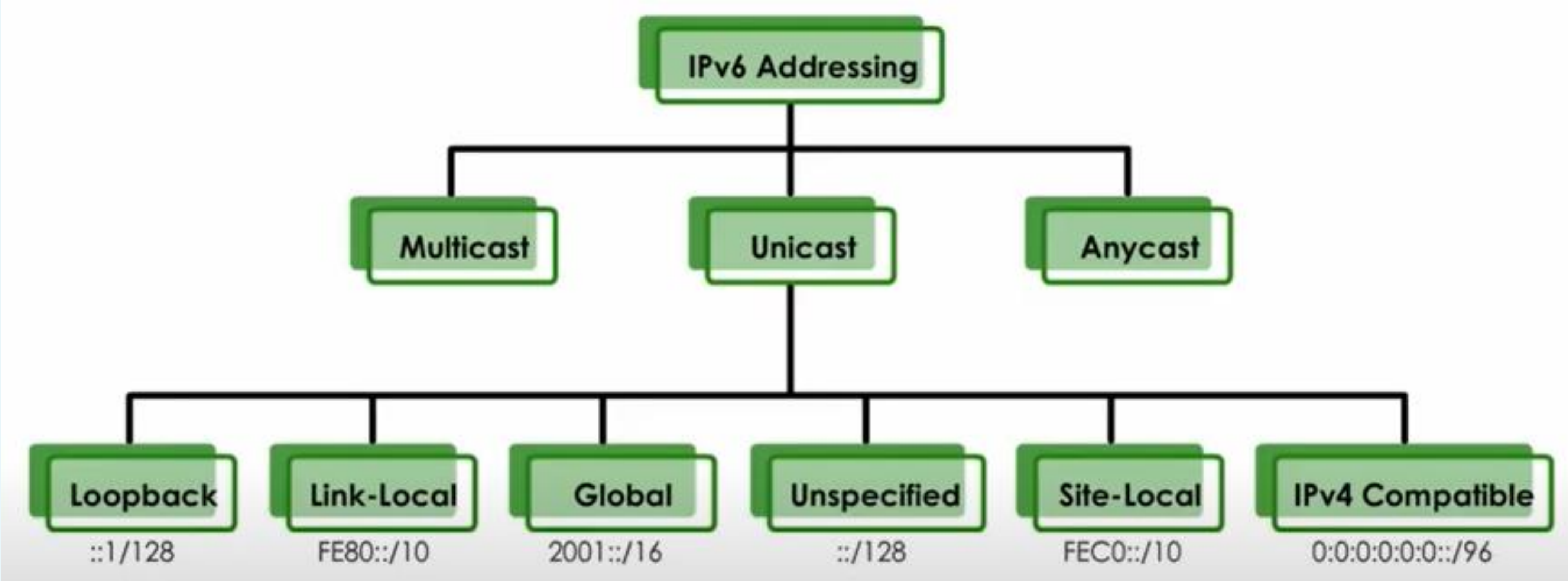
- One-to-nearest any association
- Typically used by routers
- The address can be assigned to a group of routers



Internet Protocol Suite

Type of IPv6 address

- Several types of unicast for different purposes



Internet Protocol Suite

Type of IPv6 address

Loopback

::1/128

- ::1/128,corresponding to 127.0.0.0/8 in IPv4
  - ::1/128 is short for 0:0:0:0:0:0:0:1
- It is used to send packet(s) back to their source
  - primary for testing

Link-Local

FE80::/10

- FE80::/10 address block is IPv6 link-local addresses, corresponding to 169.254.0.0/16 in IPv4.
- A link-local address is valid only for communications on a local network segment.
- Routers do not forward packets with link-local addresses.

Internet Protocol Suite

Type of IPv6 address

Global

2001::/16

- Similar to IPv4 public IP addresses.
- Global unicast IPv6 prefixes that are being currently allocated by IANA are 2000::/3
  - They all start with 001
  - At this point, unique global unicast IPv6 address starts with 2001
  - For example: 2001:4860:4860::8888

Unspecified

::/128

- ::/128 is much like 0.0.0.0 in IPv4.
- ::/128 is typically used as a source address when a unique address has not yet been determined.
- ::/128 is never assigned to an interface or used as a destination address.
- In terms of routing, ::/128 indicates the default route much like 0.0.0.0 with subnet mask of 0.0.0.0 in IPv4.

DHCP client

Internet Protocol Suite

Type of IPv6 address

Site-Local

FEC0::/10

- Site-local addresses are equivalent to IPv4 private addresses.
- IPv6 site-local addresses always begin with FEC0
- Site-local addresses have been replaced with unique local address (ULA).

Site-Local

FEC0::/10

Unique Local

FC00::/7

- IPv6 Unique Local Address (ULA) block: FC00::/7
- Used inside a private site or organization.
- They are routable only within private networks.

Internet Protocol Suite

Type of IPv6 address

IPv4 Compatible

0:0:0:0:0:0::/96

- IPv4 compatible addresses are assigned to devices that handle both IPv4 and IPv6.
- They start with 96-bit zeroes, followed by the 32-bit IPv4 address.
- The structure and format:

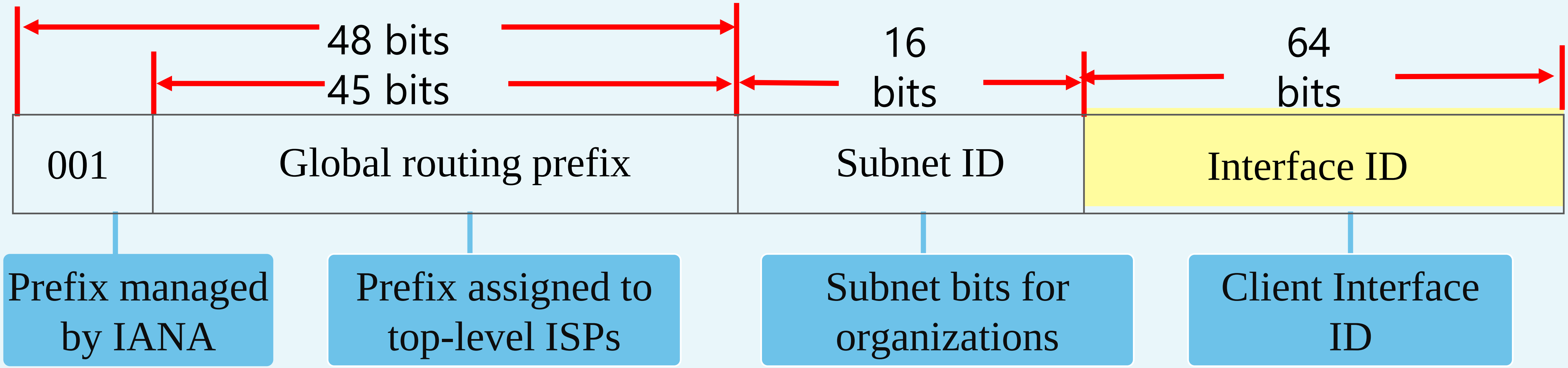
0:0:0:0:0:0 **123.25.135.1**

IPv4 compatible address = :: 123.25.135.1
= :: 7B19:8701

Internet Protocol Suite

Type of IPv6 address: Global unicast addresses

- Similar to IPv4 public IP: used when a host want to used Internet
- Routable on the IPv6 Internet
- Currently always starts with 2001::/3

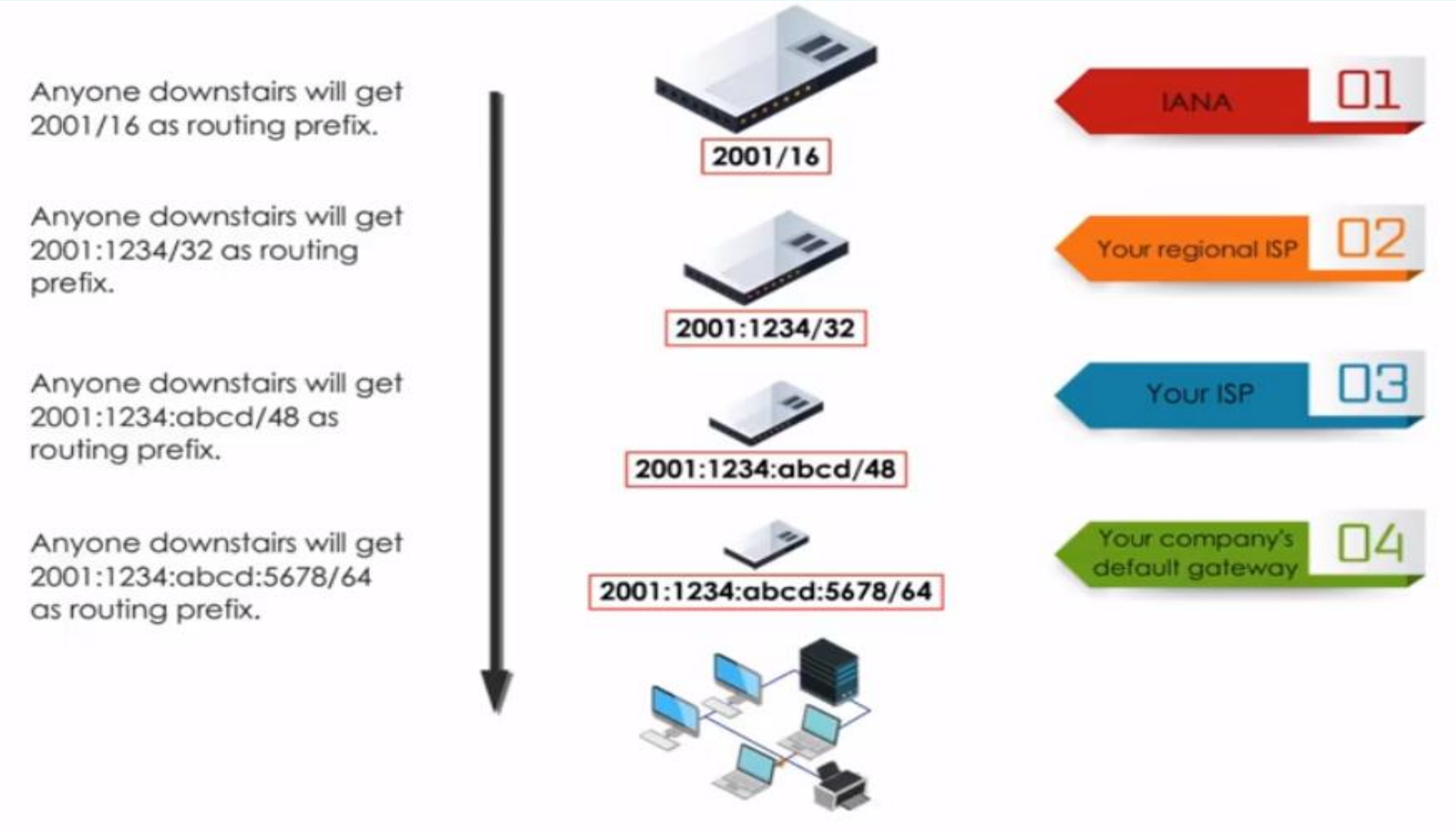


Internet Protocol Suite

Type of IPv6 address: Global unicast addresses

How does devices get global unicast address?

The first 64-bit part (Global routing prefix and subnet ID): comes from default gateway

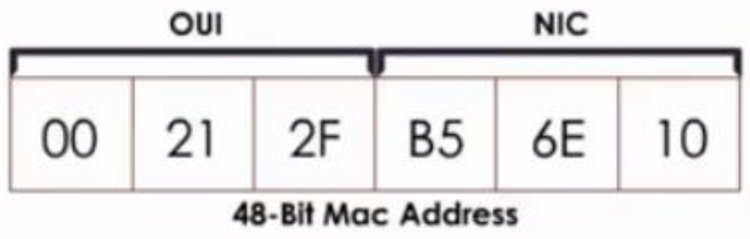


Internet Protocol Suite

Type of IPv6 address: Global unicast addresses

How does devices get global unicast address?

- The second 64-bit part generated by the device: typically derived from device's MAC address



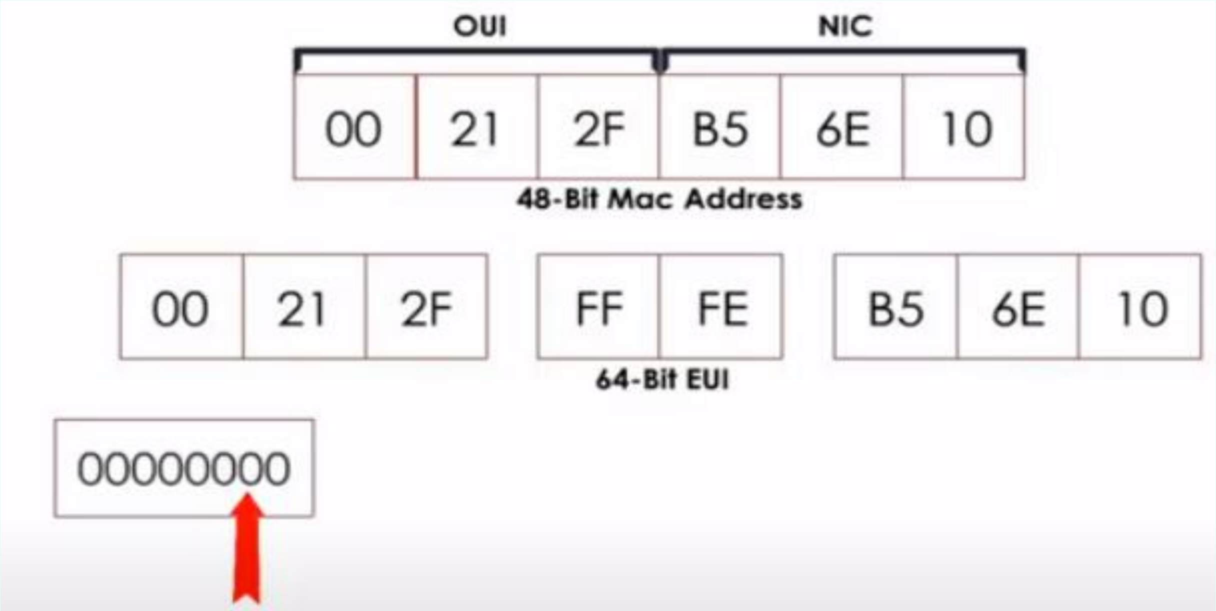
How does a device self generate a 64-bit long interface ID with 48-bit long MAC address?

Internet Protocol Suite

Type of IPv6 address: Global unicast addresses

How does devices get global unicast address?

EUI- Extended Unique Identifier

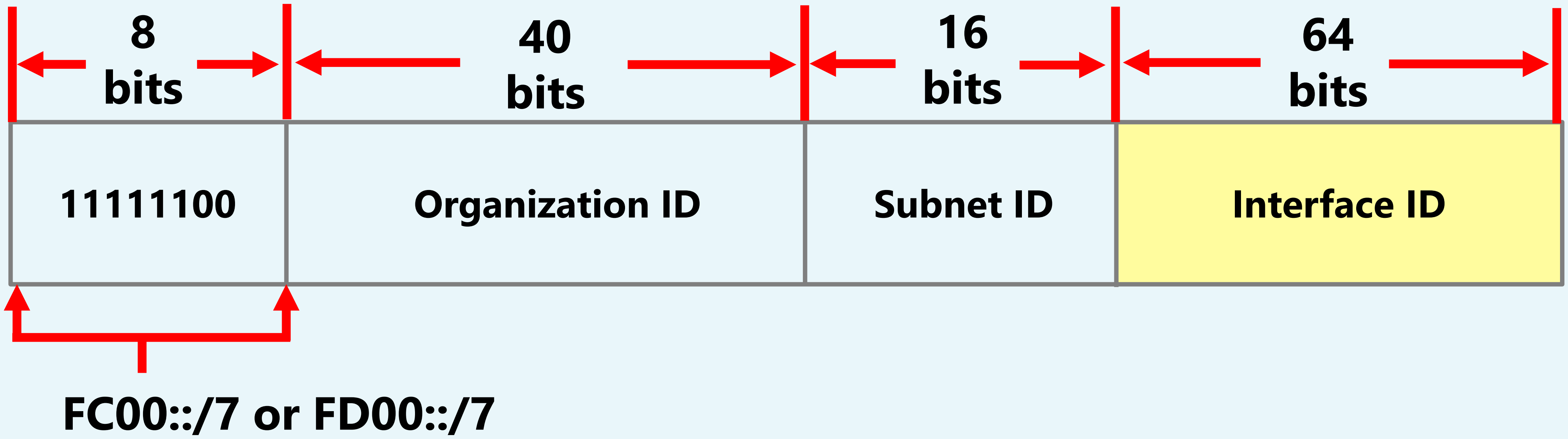


Flip the 7th bit from the left

Internet Protocol Suite

Type of IPv6 address: Global unicast addresses

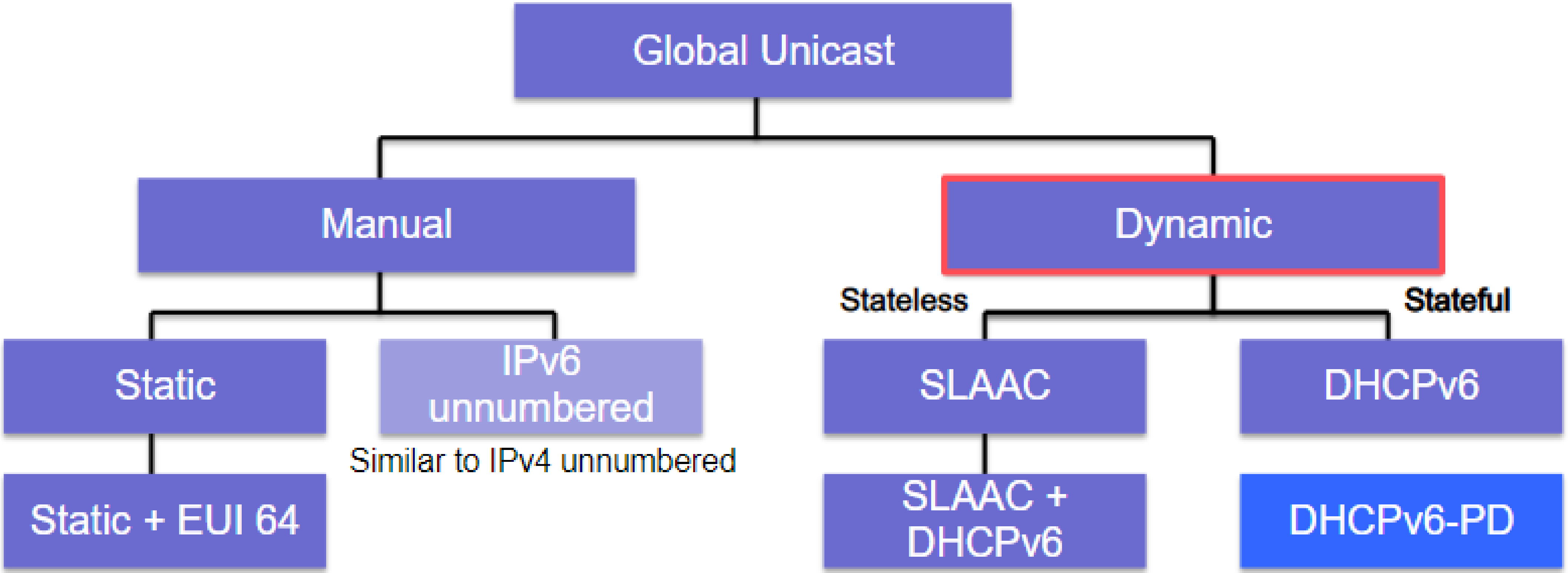
- Are equivalent to IPv4 private addresses
- Require the organization ID to be randomly generated
- Allocate 16 bits for internal subnetting



Internet Protocol Suite

Autoconfiguration options for IPv6

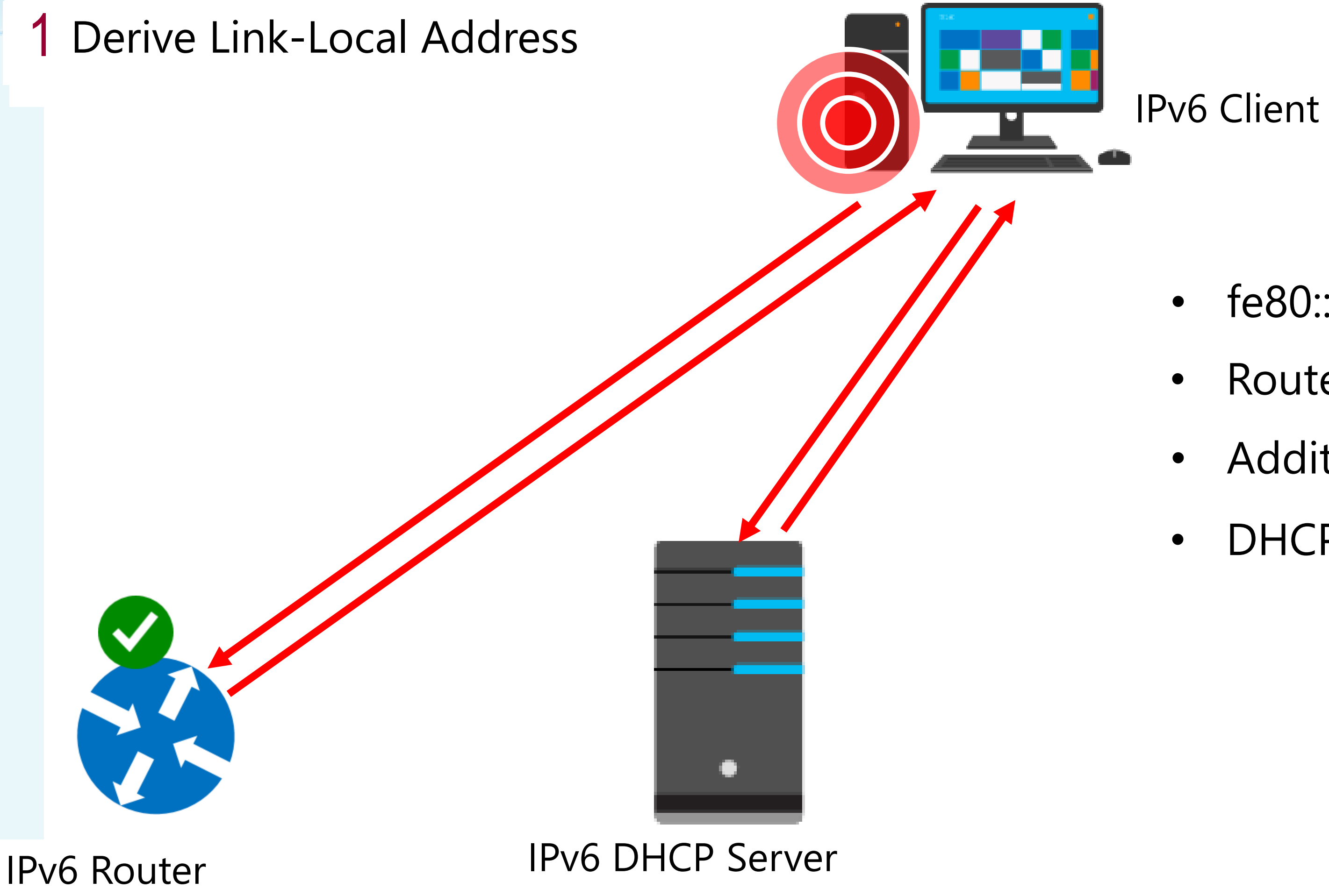
SLAAC with DHCPv6



Internet Protocol Suite

Autoconfiguration options for IPv6

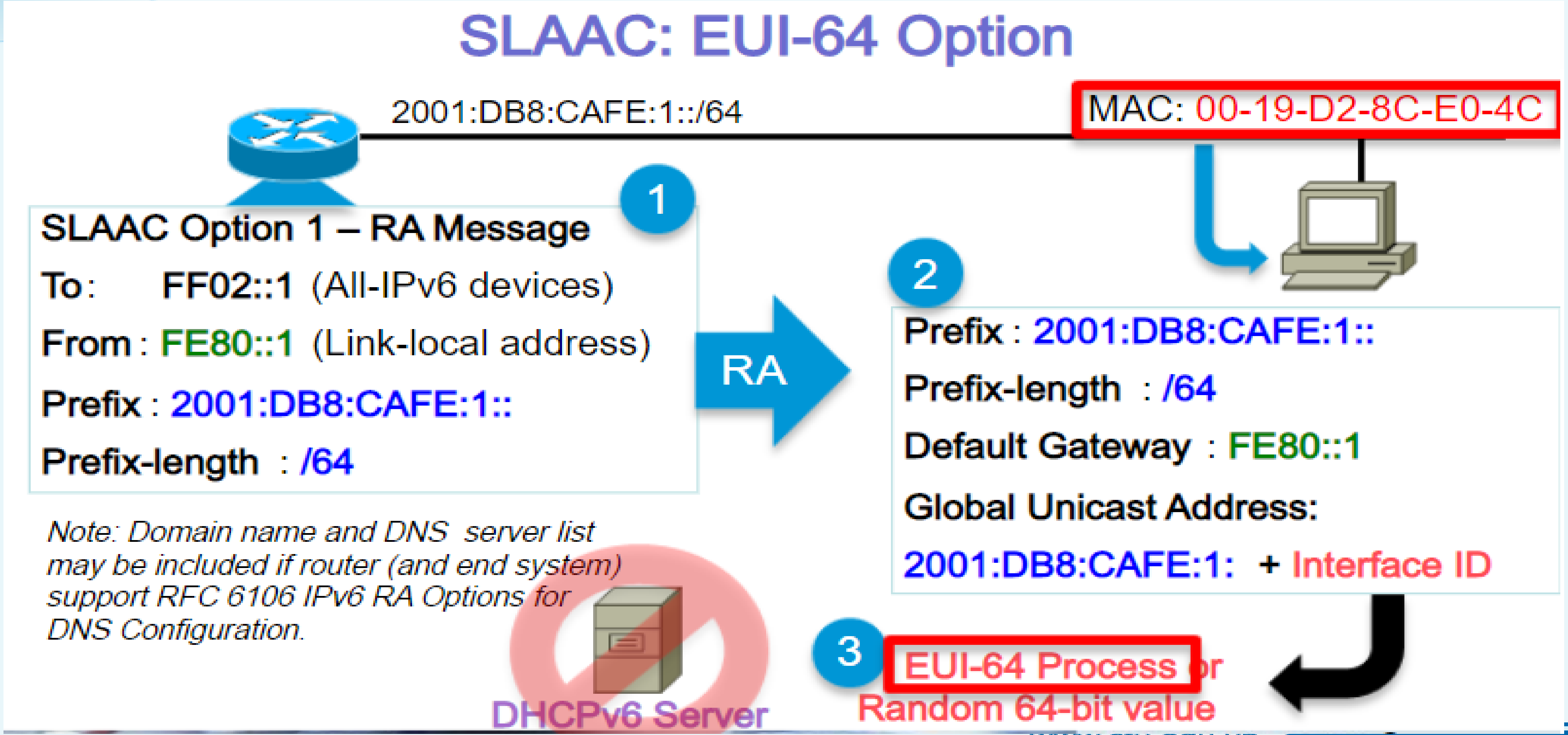
1 Derive Link-Local Address



- fe80::d593:e1e:e612:53e4%10
- Router configuration information
- Additional router prefixes
- DHCPv6 information received

Internet Protocol Suite

Autoconfiguration options for IPv6



Internet Protocol Suite
IPV6 packet format