Fundamentals of IP Networking

- Explain the purpose of subnet addressing
- Define subnet mask
- Identify the address class and subnet mask of an IP network
- State the primary purpose of routing in an IP network
- Describe routing tables, what they contain, and how they are used
- Understand the meaning of the fields in a routing table
- Understand how a routing table is created
- Distinguish between direct routing and indirect routing
- Use routing table information to identify how the packet is routed
- Identify network and host portions of an IP address, as well as associated hardware addresses given a network diagram
- Provide packet IP and hardware addresses as the packet travels across networks
- Describe any changes that occur to either hardware or software addresses as messages are routed across IP networks

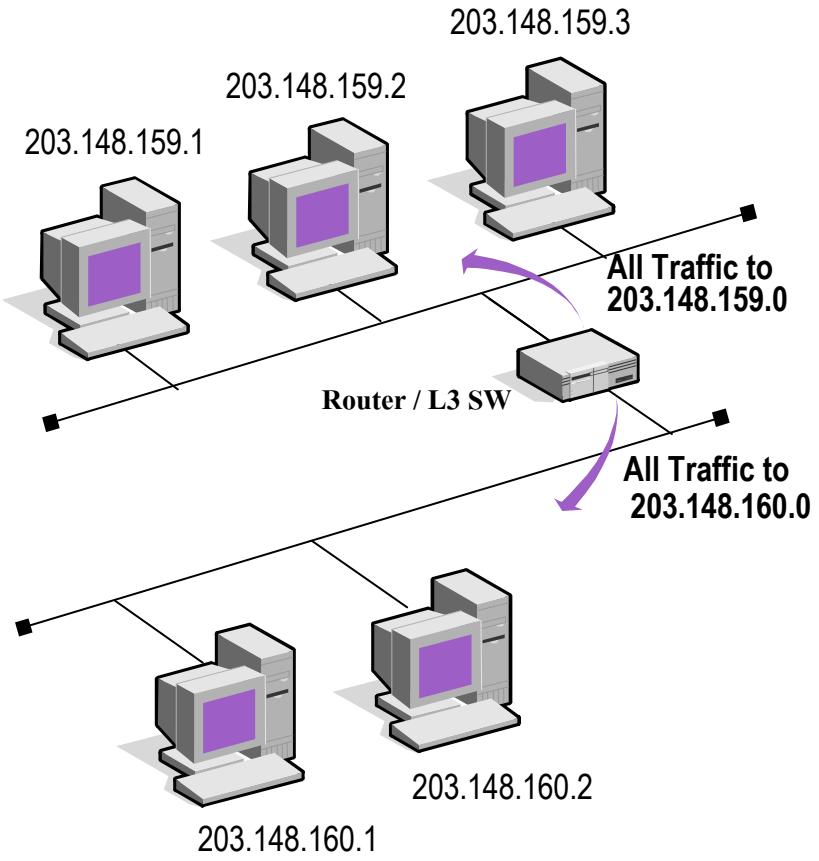
Faculty of Information Science

Pongsuree Limmaneewichid

Copyright 2002

Subnet Addressing

- Subnets are logical subdivisions of a single Internet network number.
- A Subnet mask is used to separate a single Internet network number to subnets.
- Purpose
  - For technical or administrative reasons, it is desirable in many organizations to divide a network into several different networks.
  - Subnetting allows an organization to use one Internet Address for multiple networks
  - These independent networks are then connected by routers.

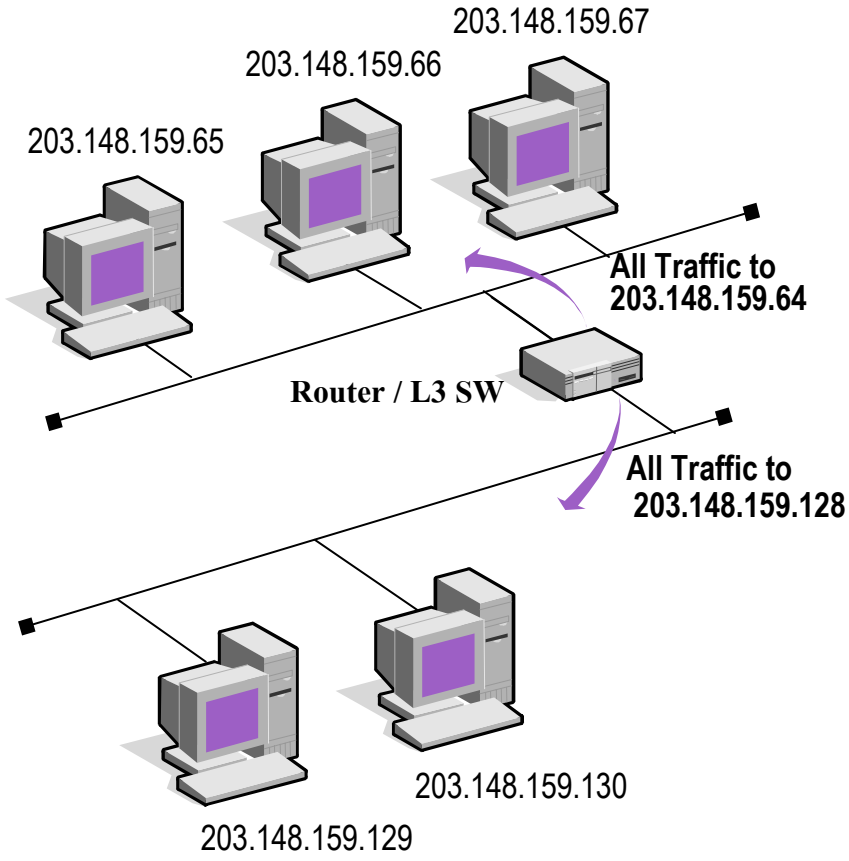


Give you a network diagram

- There are 2 physical networks.
- Networks are separated by a router.
- Router receives all traffic for a Network and selects correct interface based on network number

Without subnetting

- **Two Class C Address are defined for each nework.**
  - **203.148.159.0**
  - **203.148.160.0**
- **Router receives all traffic and selects correct interface based on number**



Subnet Addressing

- A Nets with Class C Address
- with subneting
  - 203.148.159.64
  - 203.148.159.128
- Router receives all traffic for Sub-Network and selects correct interface based on subnet number

Subnet mask

- How to define a subnet mask ?
  - With subnetting the host part of the address is divided into two parts

    Left is Subnet ID

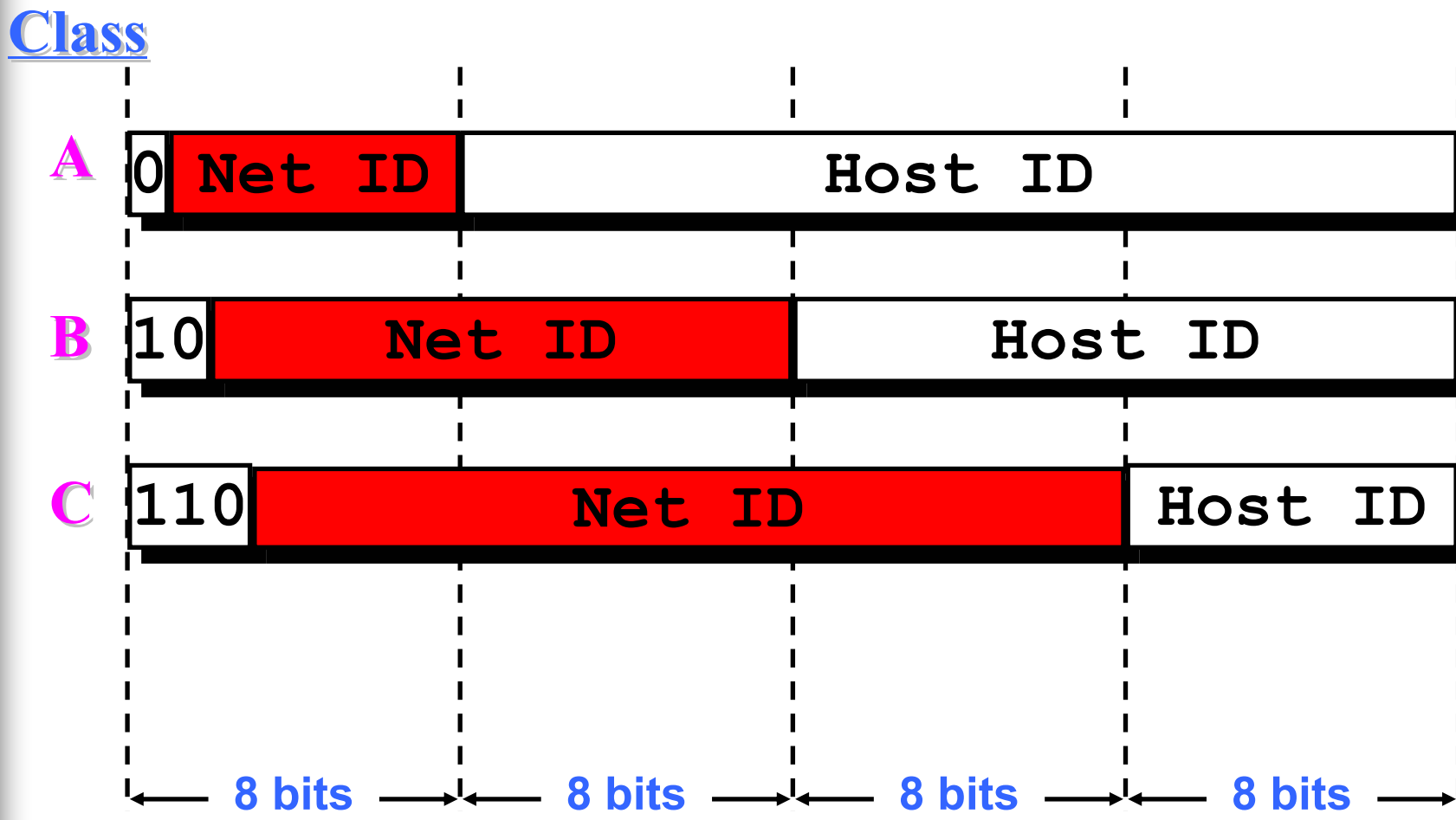
    Right is Host ID on that Subnet
  - Class is determined first
  - Subnet Mask is determined next
  - Bits in Mask indicate network and subnet ID, those that are set to 1.
  - The subnet ID is generally used to group hosts based on the physical network topology.

Regular IP Address

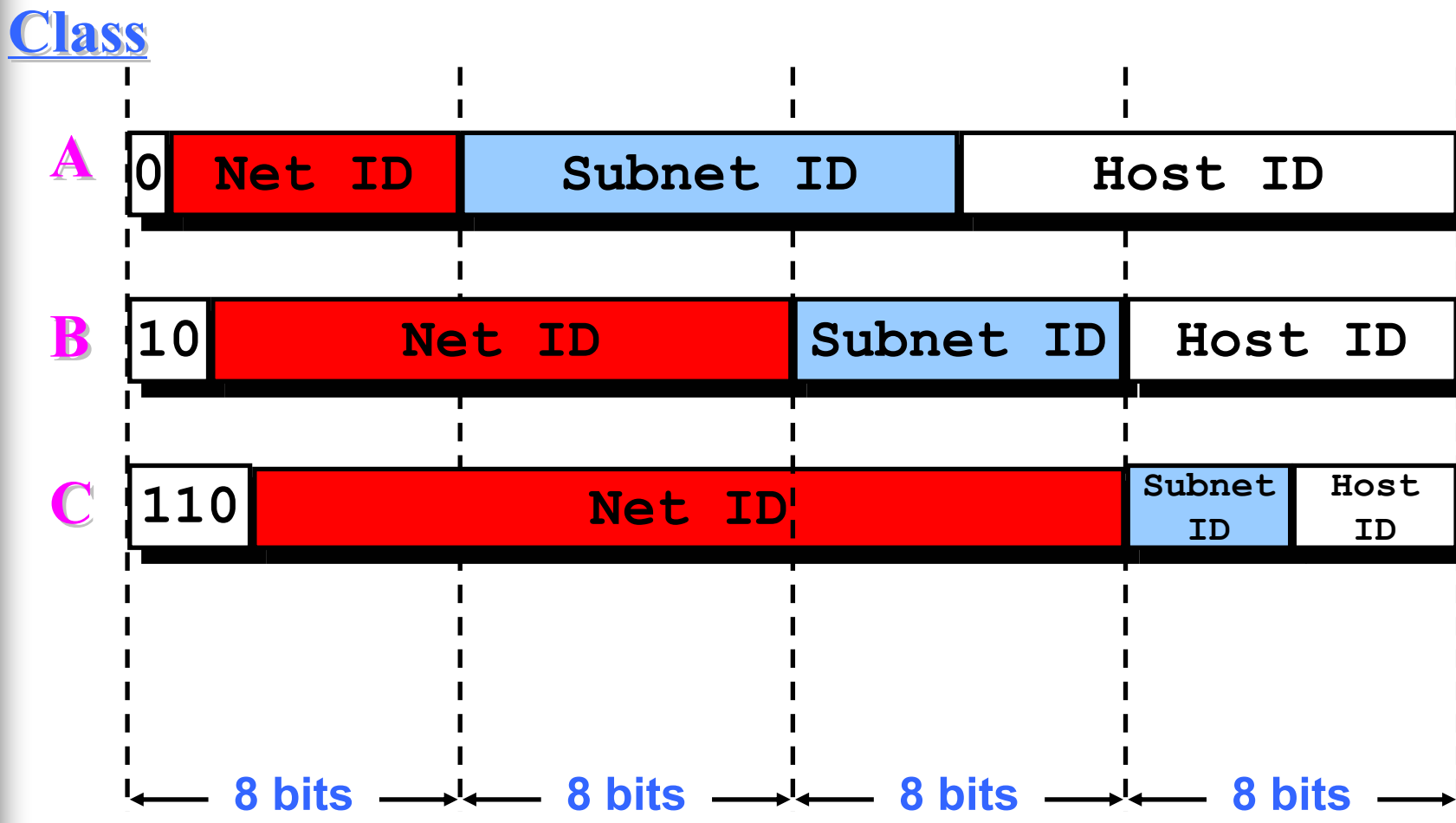
Subnet Address

Subnet Mask

Regular IP Address



IP Address Classes with Subnetting



Example Problem 1

- A regular Class B IP address of 128.1.0.0
- You need 254 subnets
- Each subnet needs to support 254 hosts

Problem 1 Solution

- 128.1.0.0 = 10000000.00000001.00000000.00000000
- Because of it's a Class B IP Address so the last 16 significant bits are Host ID which will be choosed to be a Subnet ID bits.
- Eight binary digits are required to define 254 subnets. The subnets should be numbered 1 through 254.
- Values of all 0s and 1s in the Subnet ID field should not be assigned to the actual (physical) subnets.

Subnet Numbering In Decimal and Binary

Binary	Decimal
00000001	1
00000010	2
.	.
.	.
.	.
11111110	254

- Select the 8 most significant bits of the host portion of the Internet address to define the subnets.
- These bits are displayed in bold underline text below:

128.1.0.0 = 10000000.00000001.**00000000**.*00000000*

Host bits partition of Class B

The remained host bits are host bits. (Italic text above)

- Network Number: *(can be 00000000 - 11111111)*

10000000.00000001.**00000000**.*00000000* = 128.1.0.0

- Define a subnet mask such that all bits of the network and future subnet fields are set to 1, and all bits of the future host field are set to 0.
- Subnet Mask:

11111111.11111111.11111111.00000000 = 255.255.255.0

- This subnet mask must be configured on each host and each router.
- Use the same mask for an entire set of physical networks that share the same IP address.
- The 254 subnets will have the following addresses:

Subnet #1 10000000.00000001.00000001.*00000000* = 128.1.1.0

Subnet #2 10000000.00000001.00000010.*00000000* = 128.1.2.0

.

.

.

Subnet #254 10000000.00000001.11111110.*00000000* = 128.1.254.0

What is the range of addresses you may assign for Subnet # 1?

Subnet #1 10000000.00000001.00000001.00000000 = 128.1.1.0

Low Address: 10000000.00000001.00000001.*00000001* = 128.1.1.1

High Address: 10000000.00000001.00000001.*11111110* = 128.1.1.254

NOTE: Recall that the host portion of an IP address cannot contain all 1s or all 0s.

- If the host portion contain all 0s. We call "Network Address" or "Subnet Number". (It is used to create a routing table)
- If the host portion contain all 1s. We call "Broadcast Address".

(Network use Broadcast Address to send a message to all host on the subnet)

For Subnet #1 : Network Address is 128.1.1.0

Broadcast Address is 128.1.1.255

What is the range of addresses you may assign for Subnet # 35?

Subnet #35 10000000.00000001.00100011.00000000 = 128.1.35.0

Low Address: 10000000.00000001.00100011.*00000001* = 128.1.35.1

High Address: 10000000.00000001.00100011.*11111110* = 128.1.35.254

NOTE: Recall that the host portion of an IP address cannot contain all 1s or all 0s.

For Subnet #35 : Network Address is 128.1.35.0

Broadcast Address is 128.1.35.255

Understanding Binary number system is importance !!!

- For Example Problem 1, Why did we choose 8 bits to define 254 subnets ?

- How many significant bit do we choose ?
  - If we have 1 significant bit, like having a block to fill one binary digit.

    So we can represent something like these :

Binary	Decimal
0	0
1	1

•If we have 2 significant bits, so we will represent 4 symbols.

Binary	Decimal
00	0
01	1
10	2
11	3

•If we have 3 significant bits, so we will represent 8 symbols.

Binary	Decimal
000	0
001	1
010	2
011	3

Binary	Decimal
100	4
101	5
110	6
111	7

For examples ,

if we choose 1 significant bit, we can represent 2 symbols.

if we choose 2 significant bits, we can represent 4 symbols.

if we choose 3 significant bits, we can represent 8 symbols.

We can observe that

1 significant bit , represent 2^1 = 2 symbols

2 significant bits , represent 2^2 = 4 symbols

3 significant bits , represent 2^3 = 5 symbols

So for : 8 significant bits , represent 2^8 = 256 symbols

if we choose 7 significant bits. It's not enough !!

Because 2^7 = 128 symbols

Example Problem 2

- A regular Class C IP address of 203.148.159.0
- You need 6 subnets.

Problem 2 Solution

- 203.148.159.0 = 11001011.10010100.10011111.00000000
- Because of it's a Class C IP Address so the last 8 significant bits are Host ID and they will be choosed to be a Subnet ID bits.
- Three binary digits are required to define 6 subnets. The subnets should be numbered 1 through 6. ($2^3 = 8$)
- Values of all 0s and 1s in the subnet field should not be assigned to the actual (physical) subnets.

Subnet Numbering In Decimal and Binary

Binary	Decimal
001	1
010	2
011	3
100	4
101	5
110	6

- **The 6 subnets will have the following addresses:**

Subnet #1

11001011.10010100.10011111.001*00000* = 203.148.159.32

Subnet #2

11001011.10010100.10011111.010*00000* = 203.148.159.64

Subnet #3

11001011.10010100.10011111.011*00000* = 203.148.159.96

Subnet #4

11001011.10010100.10011111.100*00000* = 203.148.159.128

Subnet #5

11001011.10010100.10011111.101*00000* = 203.148.159.160

Subnet #6

11001011.10010100.10011111.110*00000* = 203.148.159.192

The addresses you may assign to a client or a router for Subnet # 1

11001011.10010100.10011111.001*00001* = 203.148.159.33

11001011.10010100.10011111.001*00010* = 203.148.159.34

11001011.10010100.10011111.001*00011* = 203.148.159.35

11001011.10010100.10011111.001*00100* = 203.148.159.36

11001011.10010100.10011111.001*00101* = 203.148.159.37

….

….

11001011.10010100.10011111.001*11101* = 203.148.159.61

11001011.10010100.10011111.001*11110* = 203.148.159.62

Network Address : 203.148.159.32

Broadcast Address : 203.148.159.63

The addresses you may assign to a client or a router for Subnet # 2

11001011.10010100.10011111.010*00001* = 203.148.159.65

11001011.10010100.10011111.010*00010* = 203.148.159.67

11001011.10010100.10011111.010*00011* = 203.148.159.68

11001011.10010100.10011111.010*00100* = 203.148.159.69

11001011.10010100.10011111.010*00101* = 203.148.159.70

....

....

11001011.10010100.10011111.010*11101* = 203.148.159.93

11001011.10010100.10011111.010*11110* = 203.148.159.94

Network Address : 203.148.159.64

Broadcast Address : 203.148.159.95

The addresses you may assign to a client or a router for Subnet # 3

11001011.10010100.10011111.011*00001* = 203.148.159.97

11001011.10010100.10011111.011*00010* = 203.148.159.96

11001011.10010100.10011111.011*00011* = 203.148.159.99

11001011.10010100.10011111.011*00100* = 203.148.159.100

11001011.10010100.10011111.011*00101* = 203.148.159.101

....

....

11001011.10010100.10011111.011*11101* = 203.148.159.125

11001011.10010100.10011111.011*11110* = 203.148.159.126

Network Address : 203.148.159.96

Broadcast Address : 203.148.159.127

The addresses you may assign to a client or a router for Subnet # 4

11001011.10010100.10011111.100*00001* = 203.148.159.129

11001011.10010100.10011111.100*00010* = 203.148.159.130

11001011.10010100.10011111.100*00011* = 203.148.159.131

11001011.10010100.10011111.100*00100* = 203.148.159.132

11001011.10010100.10011111.100*00101* = 203.148.159.133

….

….

11001011.10010100.10011111.100*11101* = 203.148.159.157

11001011.10010100.10011111.100*11110* = 203.148.159.158

Network Address : 203.148.159.128

Broadcast Address : 203.148.159.159

The addresses you may assign to a client or a router for Subnet # 5

11001011.10010100.10011111.101*00001* = 203.148.159.161

11001011.10010100.10011111.101*00010* = 203.148.159.162

11001011.10010100.10011111.101*00011* = 203.148.159.163

11001011.10010100.10011111.101*00100* = 203.148.159.164

11001011.10010100.10011111.101*00101* = 203.148.159.165

….

….

11001011.10010100.10011111.101*11101* = 203.148.159.189

11001011.10010100.10011111.101*11110* = 203.148.159.190

Network Address : 203.148.159.160

Broadcast Address : 203.148.159.191

The addresses you may assign to a client or a router for Subnet # 6

11001011.10010100.10011111.110*00001* = 203.148.159.193

11001011.10010100.10011111.110*00010* = 203.148.159.194

11001011.10010100.10011111.110*00011* = 203.148.159.195

11001011.10010100.10011111.110*00100* = 203.148.159.196

11001011.10010100.10011111.110*00101* = 203.148.159.197

....

....

11001011.10010100.10011111.110*11101* = 203.148.159.221

11001011.10010100.10011111.110*11110* = 203.148.159.222

Network Address : 203.148.159.192

Broadcast Address : 203.148.159.223

If my university has 4 departments.

Building A : Computer and Telecommunication

Building B : Civil

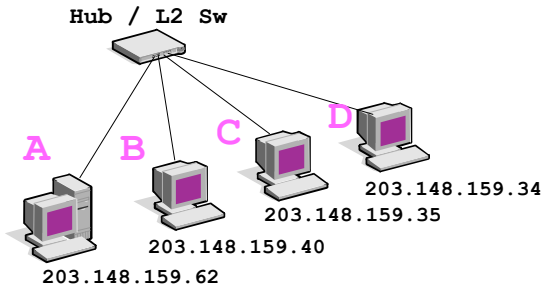
Building C : Electronics

- Each department has own network.
- The difference subnet number will be assigned for each department.

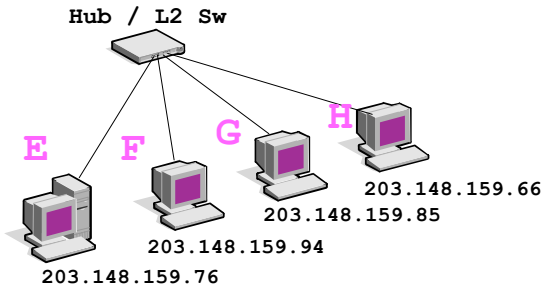
Example :

Computer :	203.148.159.32
Telecommunication :	203.148.159.64
Civil :	203.148.159.96
Electronics :	203.148.159.128

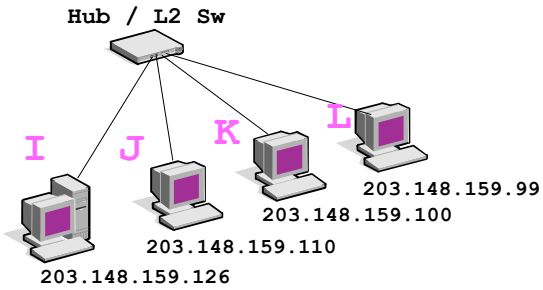
Example of network configuration.



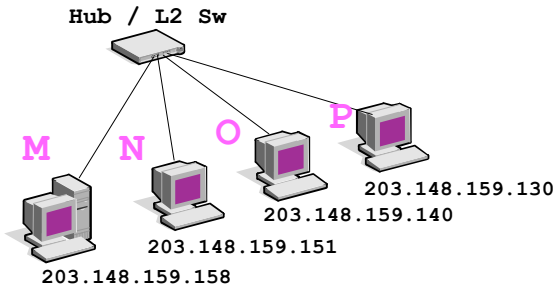
Department of Computer



Department of Telecommunication



Department of Civil



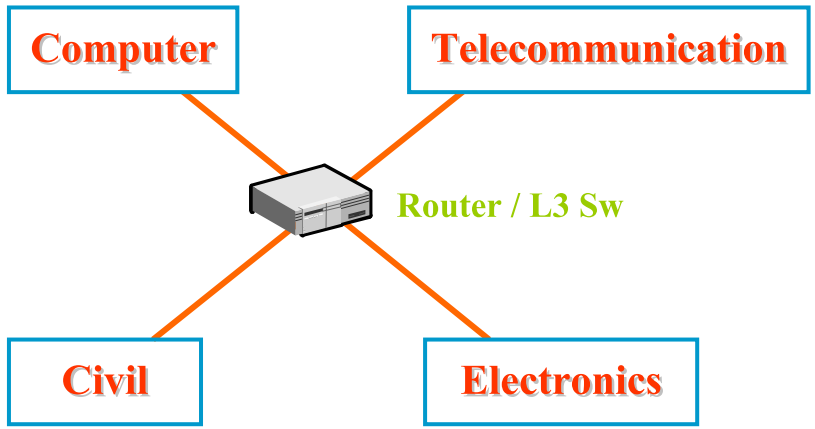
Department of Electronics

Now, we assigned a subnet number for all departments but all departments can not exchange data because all networks are not connected together.

We need a router or a layer3 switch to join all networks. Number of routers or L3 Switches up to the designing.

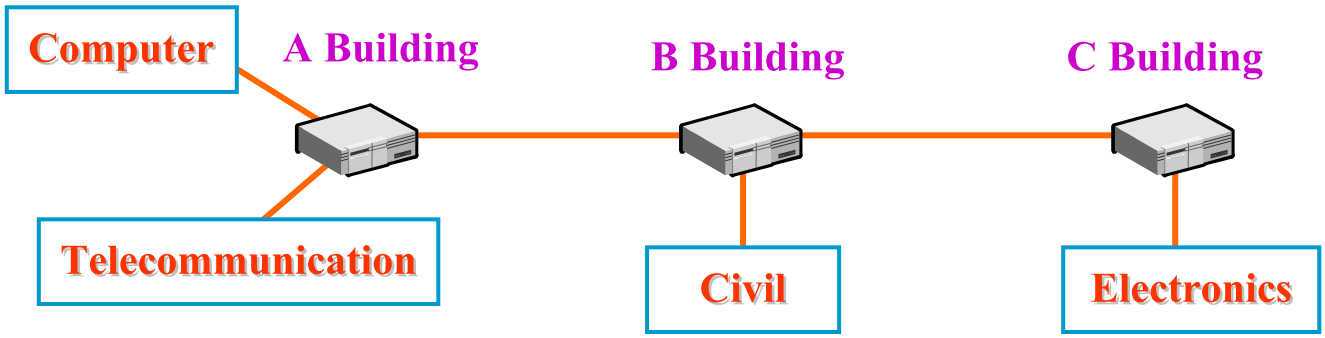
- There are 2 case studies for learning.

  The first network diagram



The second network diagram

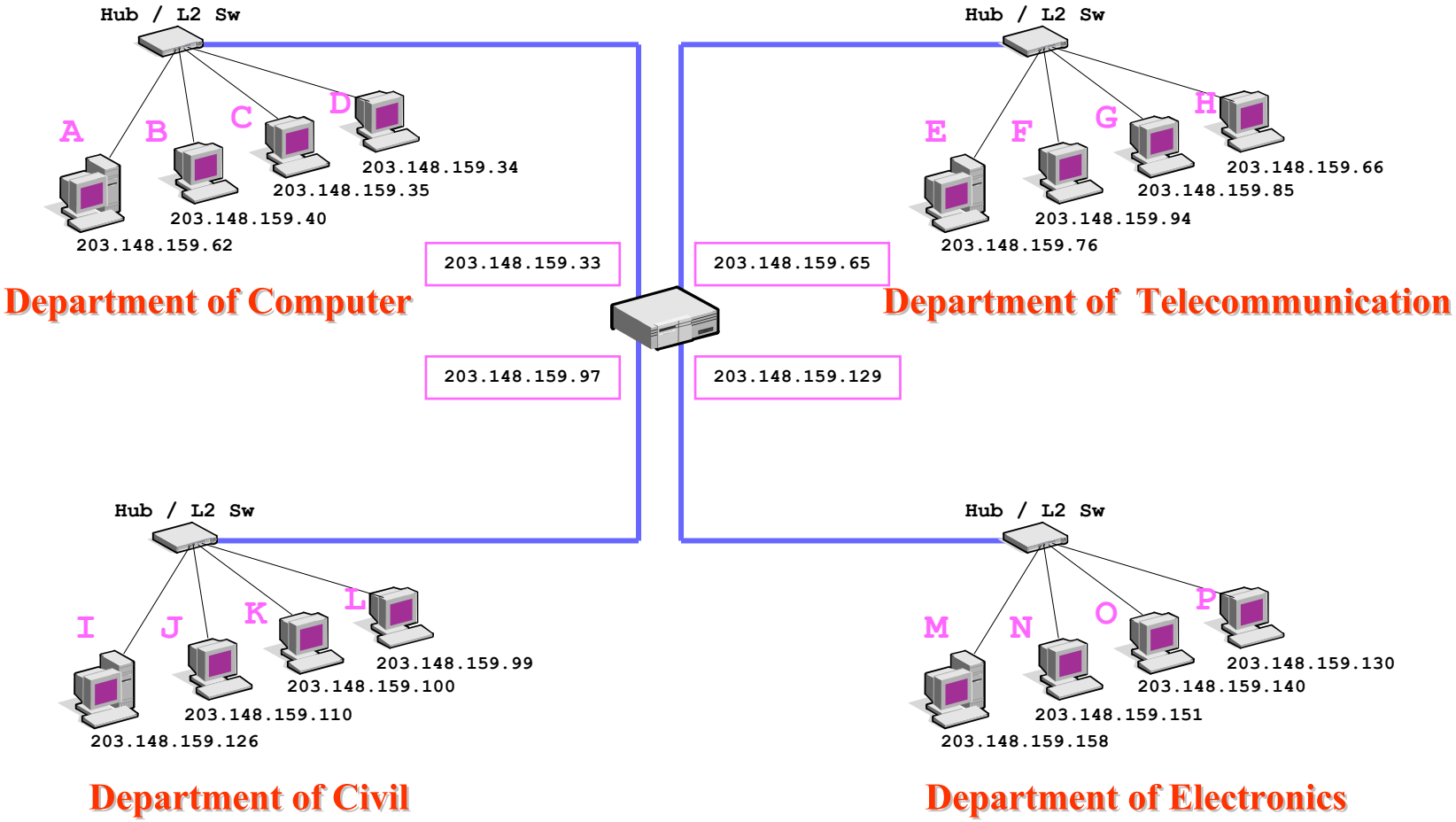
Each building has a router



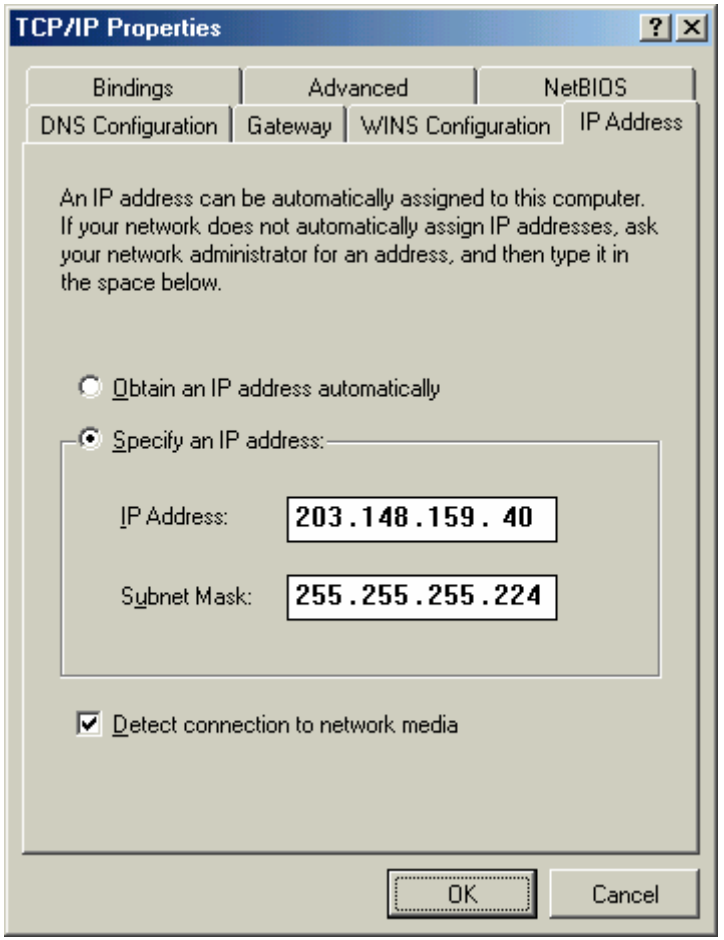
NOTE :

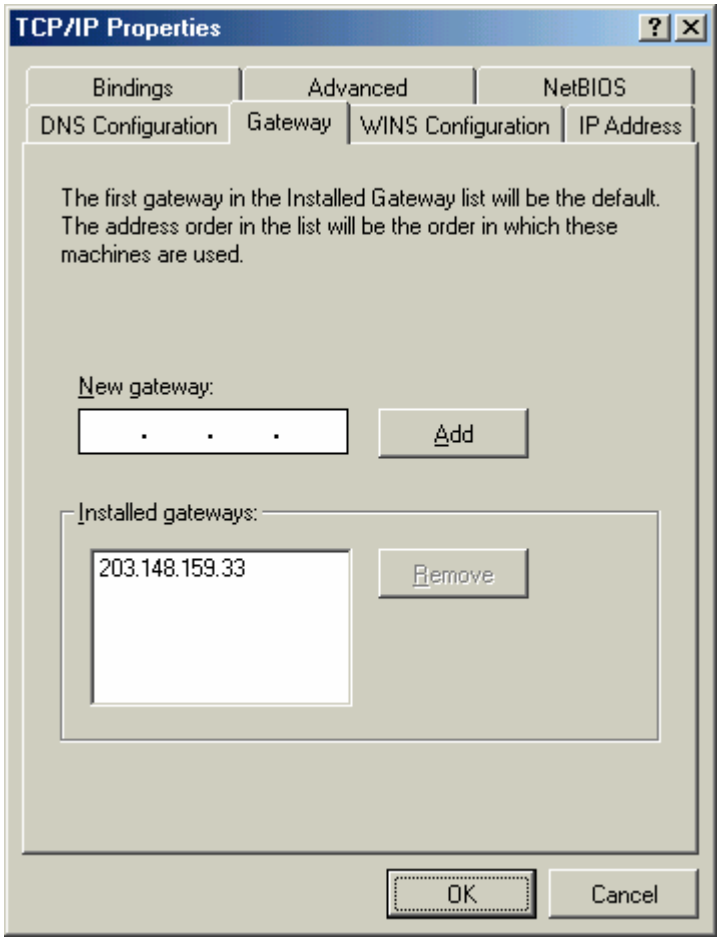
- Each router interface must connect to Hub/L3 Sw of a department's network.
- We must assign a IP Address that is in the range of that network or subnet. This IP address will be a gateway address for a host on the network.
- The connection between routers or L3 Sw is a network. We must assign a network address for it.
- After all connections (physical) are connected. We must create a routing table on each router.

The first network diagram

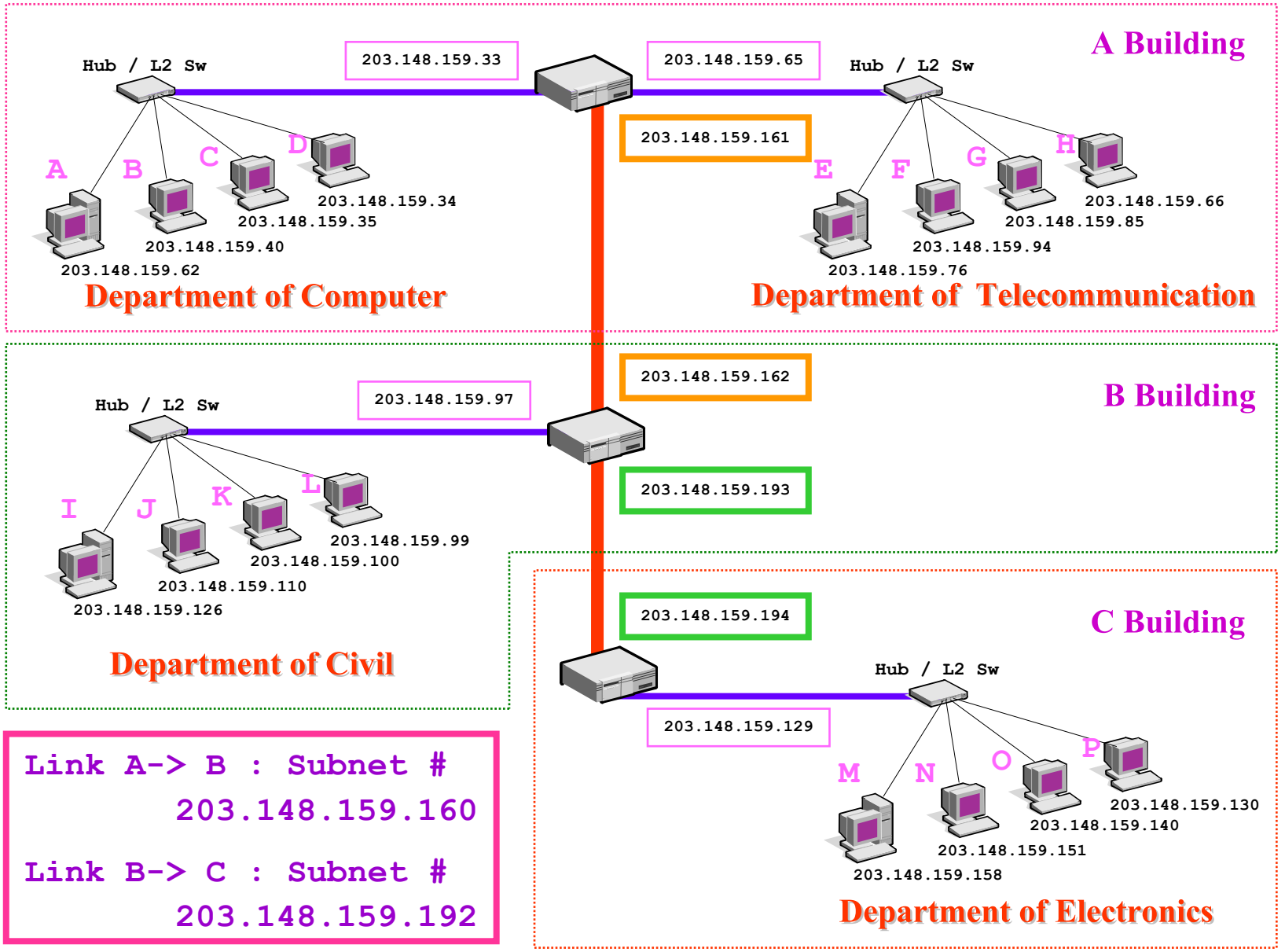


Example for host B configuration





The second network diagram



Link A-> B : Subnet #
203.148.159.160

Link B-> C : Subnet #
203.148.159.192

NOTE : The connection between routers is a network.

Routing in an IP network

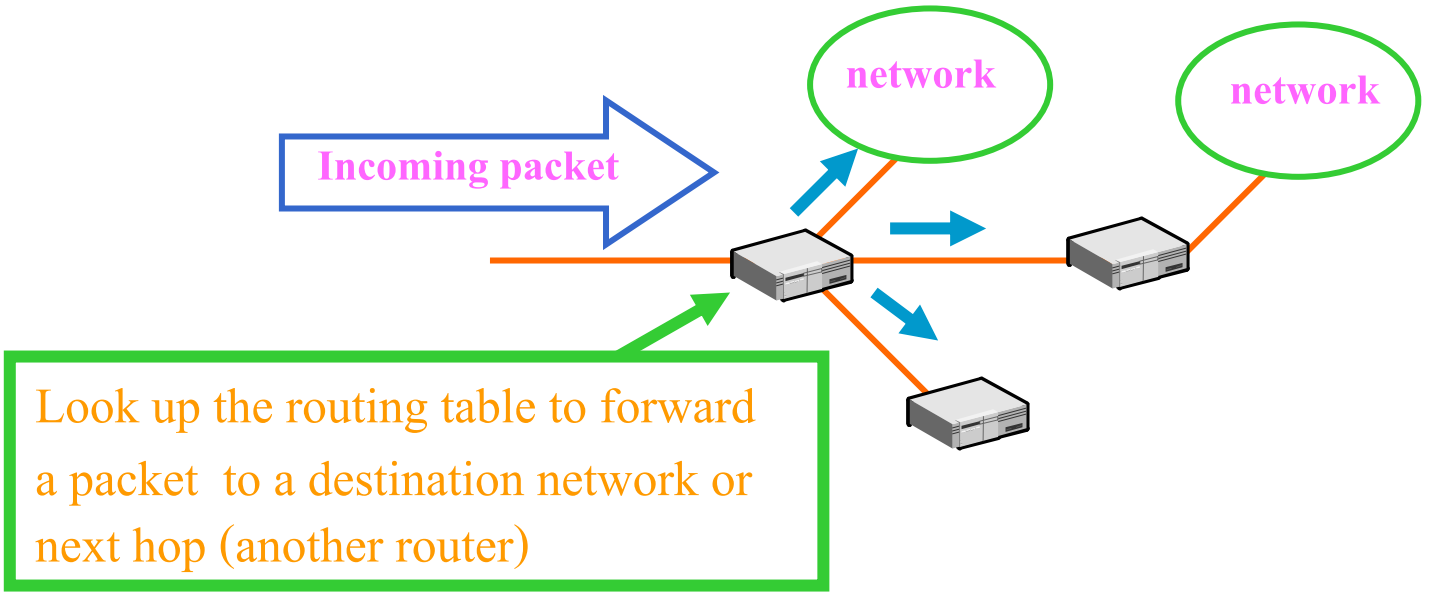
- **Purpose**
  - Routing is the act of sending data through a network from one place to another.
  - A router examines its routing table to determine how to forward a packet.
  - IP network has many routing protocols such as RIP, OSPF ,….
  - Each host has a routing table:
    - routes to specific hosts
    - routes to specific networks
    - default route

Routing Table

- What does a routing table contain ?
  - On most network, a routing table contain these field :
    - Destination
    - Netmask
    - Gateway or Next hop
- The meaning of the field in the routing table
  - Destination : IP address of a destination network or a destination host.
  - Netmask : the mask bits that will be applied to the destination.
  - Gateway : IP address of a remote router to which the local router must send the packet before the packet can be routed to the destination.

Using a routing table

- A packet in IP network contains a destination address field.
- When a packet comes in to a router and a destination address matches an entry in the routing table (match with a *Destination* field AND a *Netmask* field), the *Gateway* field tells the system how to reach the specified destination.



How to create Routing Table

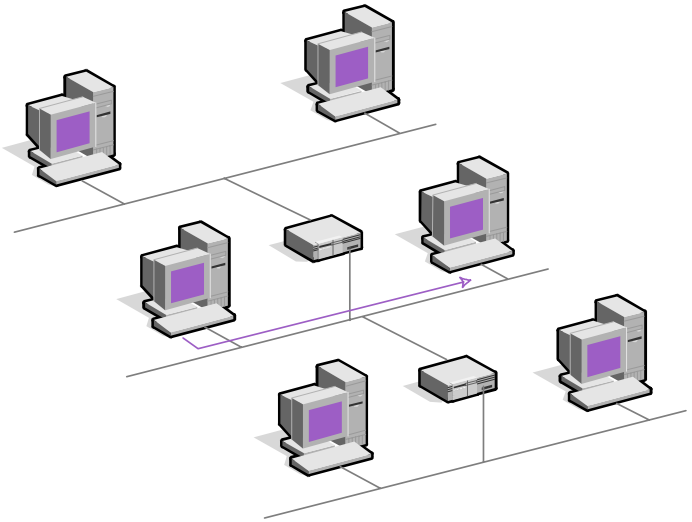
- Static route
  - by hand
  - Routers are established a routing table by the administrator and do not change until the administrator changes them.
- Dynamic routes
  - via routing protocol
  - Example RIP, OSPF, IGRP , BGP ….
  - Dynamic routing calls for routes to be calculated automatically at regular intervals by software in routing devices.
- via ICMP
  - ICMP redirect
  - ICMP router advertisement

Direct routing and Indirect routing

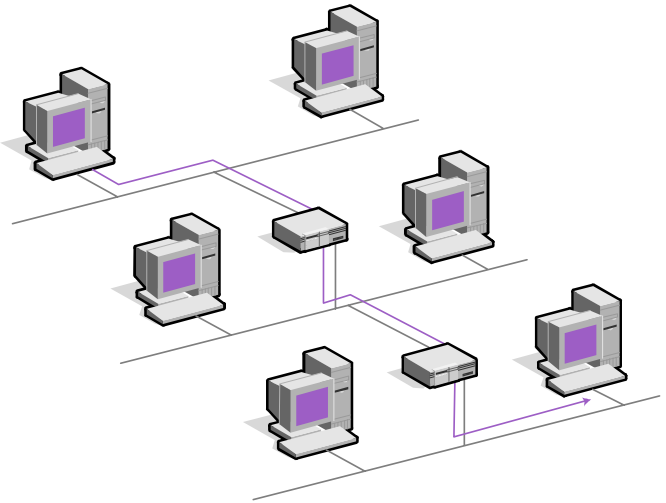
- **Direct routing**
  - Direct routing is used when the source and destination addresses have the same network number.
  - The packet must not be forwarded. Nodes communicate inside the network himself.

- **Indirect routing**
  - Indirect routing is used when the network numbers of the source and destination have the difference network number.
  - This is the case where the packet must be forwarded by a router that knows how to reach the destination.

Direct routing



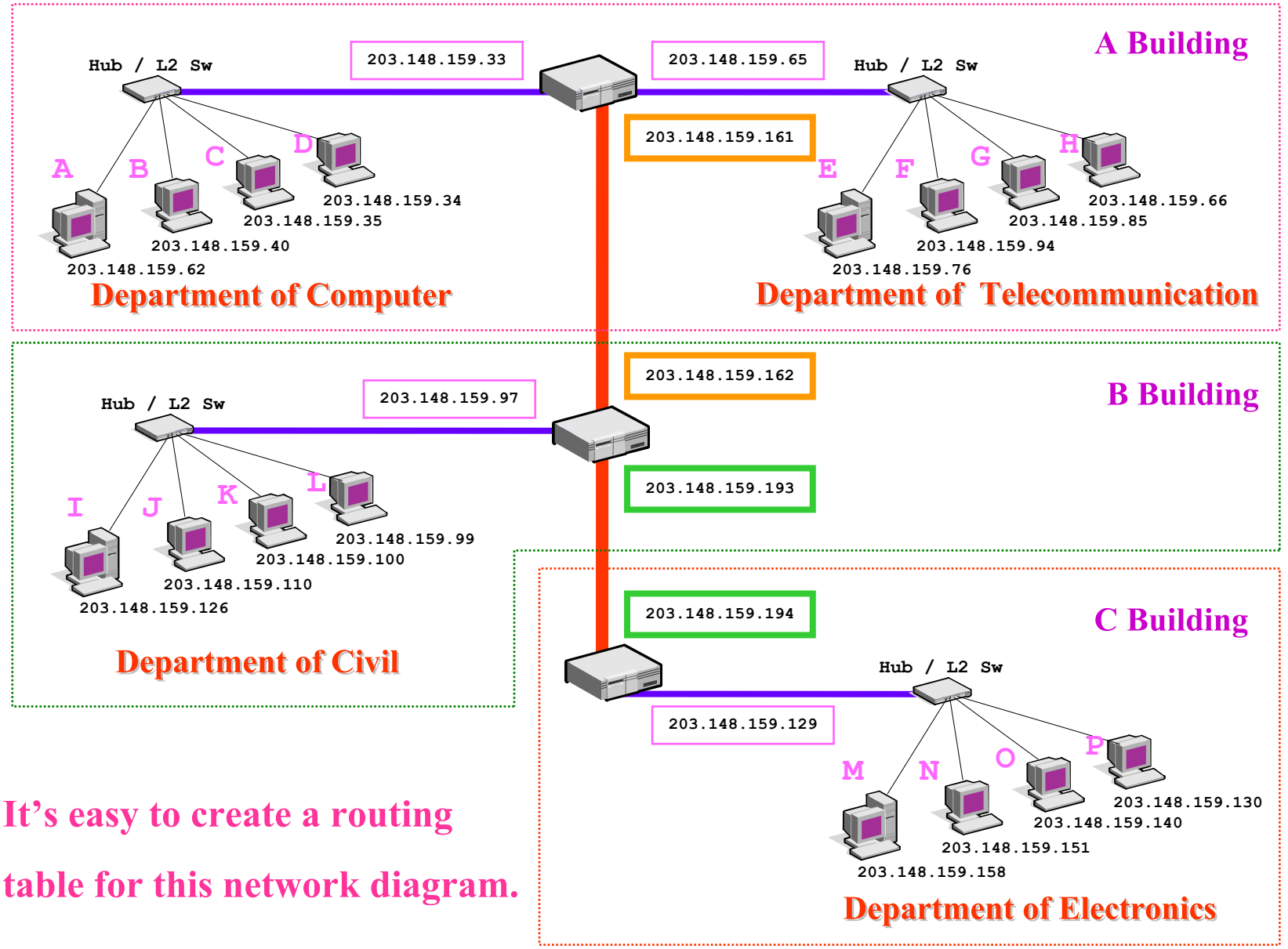
Indirect routing



Use routing table information to identify how the packet is routed

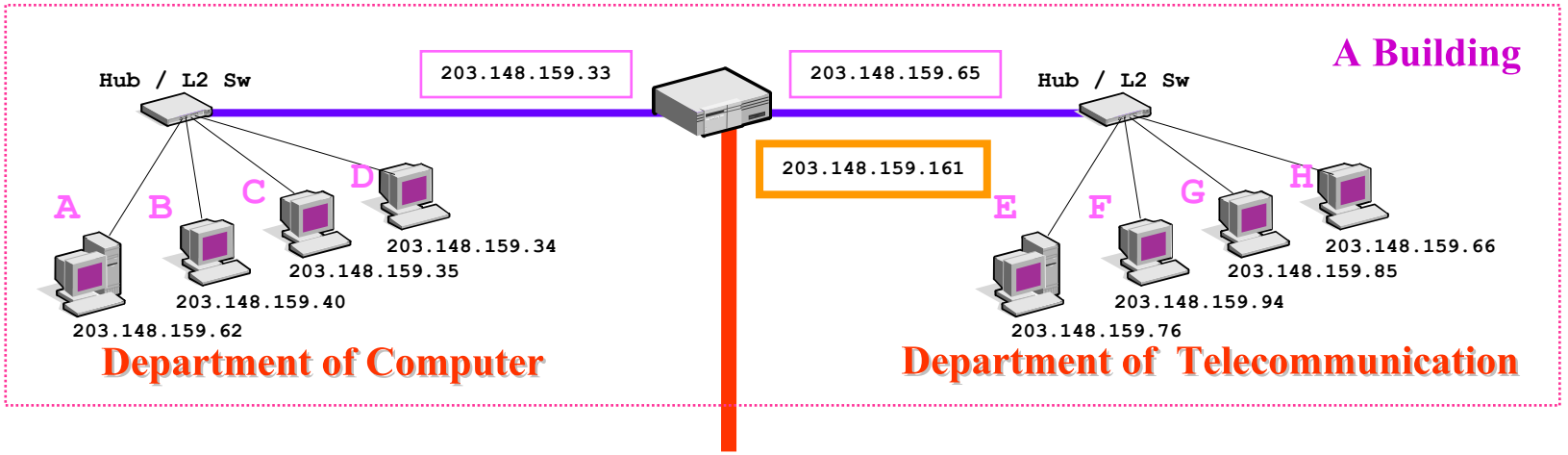
- Strategy
  - every packet (IP Datagram) contains destination's address
  - if directly connected to destination network, then forward to host. (direct routing)
  - if not directly connected to destination network, then forward to some router. (indirect routing)
  - forwarding table maps network number into next hop
  - each host has a default router.
  - each router maintains a routing table.

Example of Static route



It's easy to create a routing table for this network diagram.

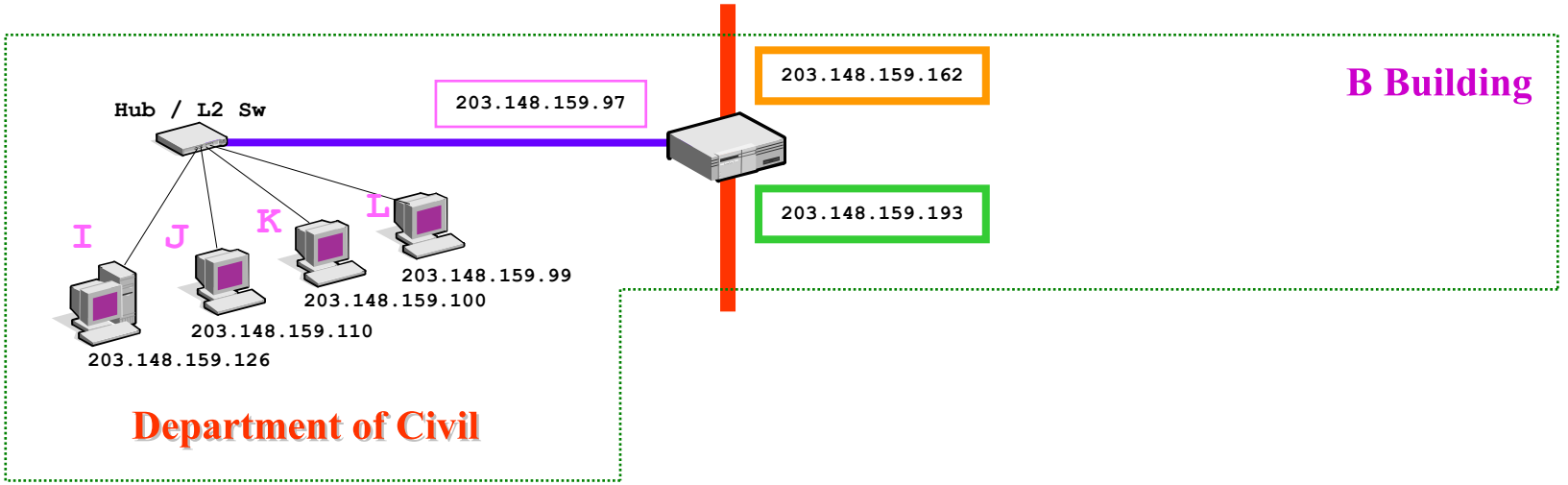
Example of Static route (cont.)



Routing Table for a router at A Building

Destination	Netmask	Gateway	
203.148.159.32	255.255.255.224	203.148.159.33	direct
203.148.159.64	255.255.255.224	203.148.159.65	direct
203.148.159.160	255.255.255.224	203.148.159.161	direct
203.148.159.96	255.255.255.224	203.148.159.162	indirect
203.148.159.128	255.255.255.224	203.148.159.162	indirect
203.148.159.192	255.255.255.224	203.148.159.162	indirect

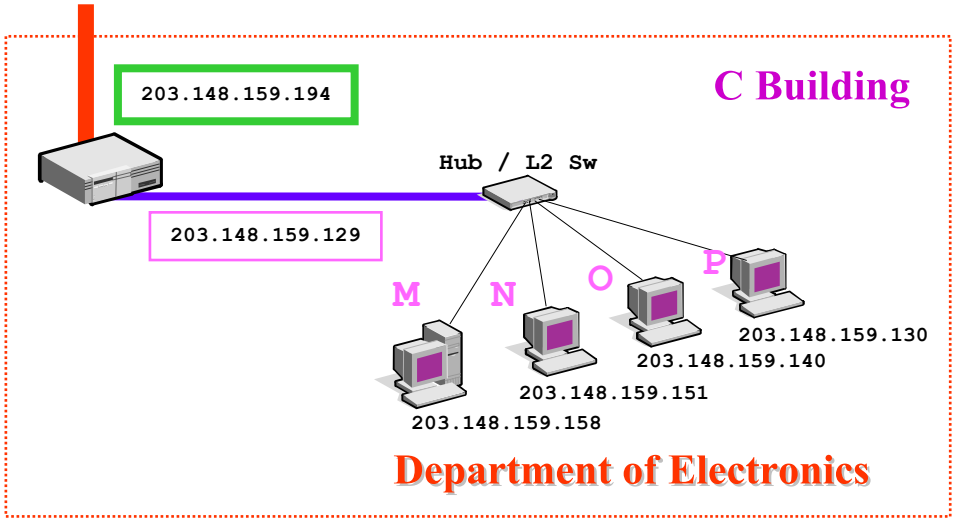
Example of Static route (cont.)



Routing Table for a router at B Building

Destination	Netmask	Gateway	
203.148.159.96	255.255.255.224	203.148.159.97	direct
203.148.159.160	255.255.255.224	203.148.159.162	direct
203.148.159.192	255.255.255.224	203.148.159.193	direct
203.148.159.32	255.255.255.224	203.148.159.161	indirect
203.148.159.64	255.255.255.224	203.148.159.161	indirect
203.148.159.128	255.255.255.224	203.148.159.194	indirect

Example of Static route (cont.)

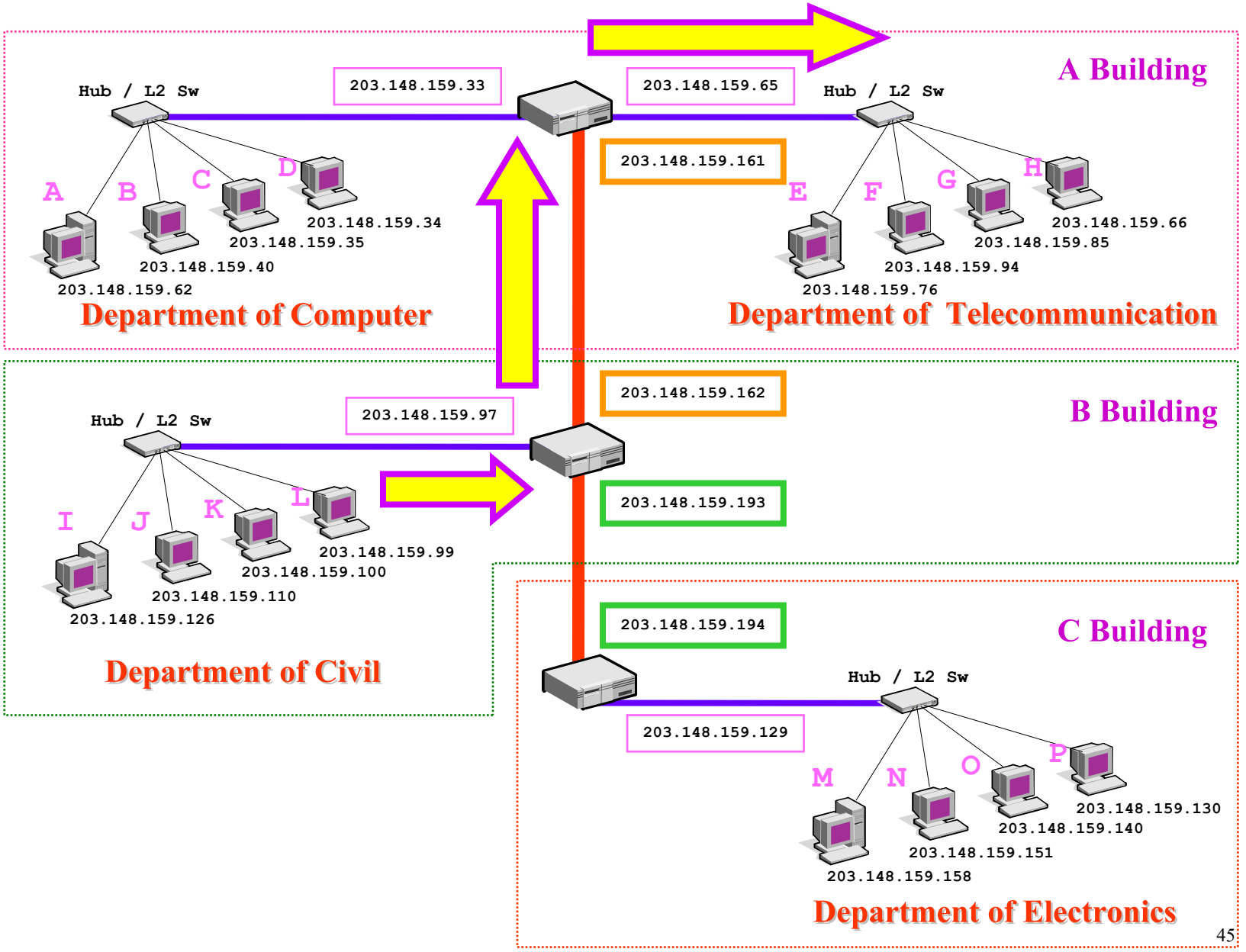


Routing Table for a router at C Building

Destination	Netmask	Gateway	
203.148.159.128	255.255.255.224	203.148.159.129	direct
203.148.159.192	255.255.255.224	203.148.159.194	direct
203.148.159.32	255.255.255.224	203.148.159.193	indirect
203.148.159.64	255.255.255.224	203.148.159.193	indirect
203.148.159.96	255.255.255.224	203.148.159.193	indirect
203.148.159.160	255.255.255.224	203.148.159.193	indirect

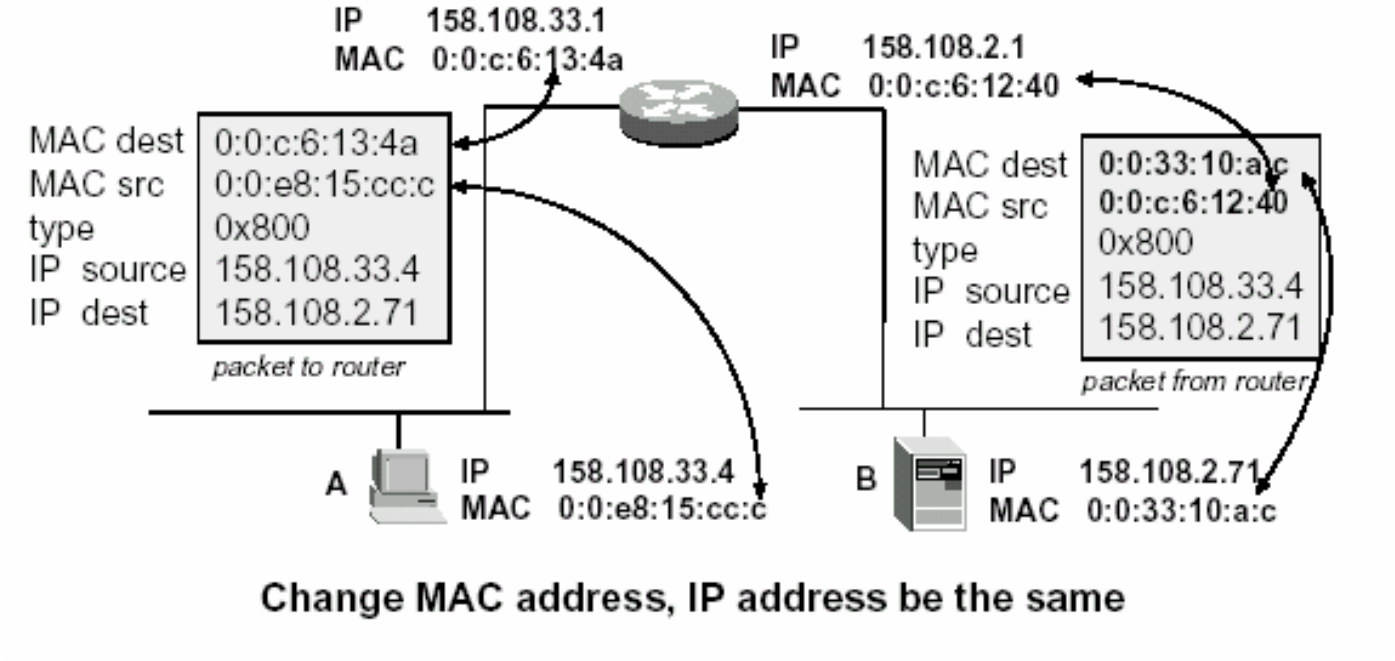
Example of Static route (cont.)

Host L wants to send data to Host G



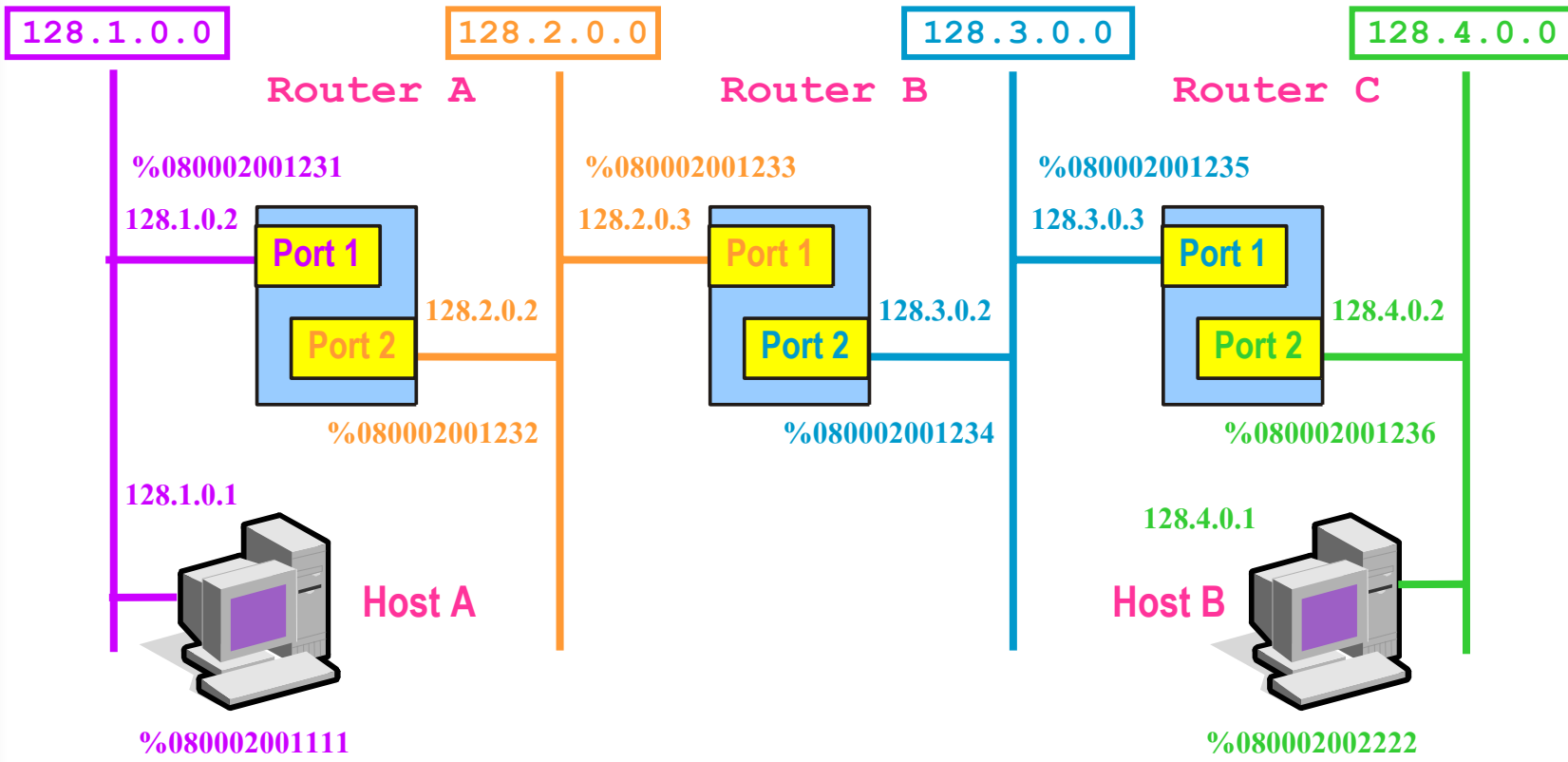
Provide packet IP and hardware addresses as the packet travels across networks

- Use Routing Table to find a destination
- Use ARP to find MAC of the next node that a packet will be forwarded.

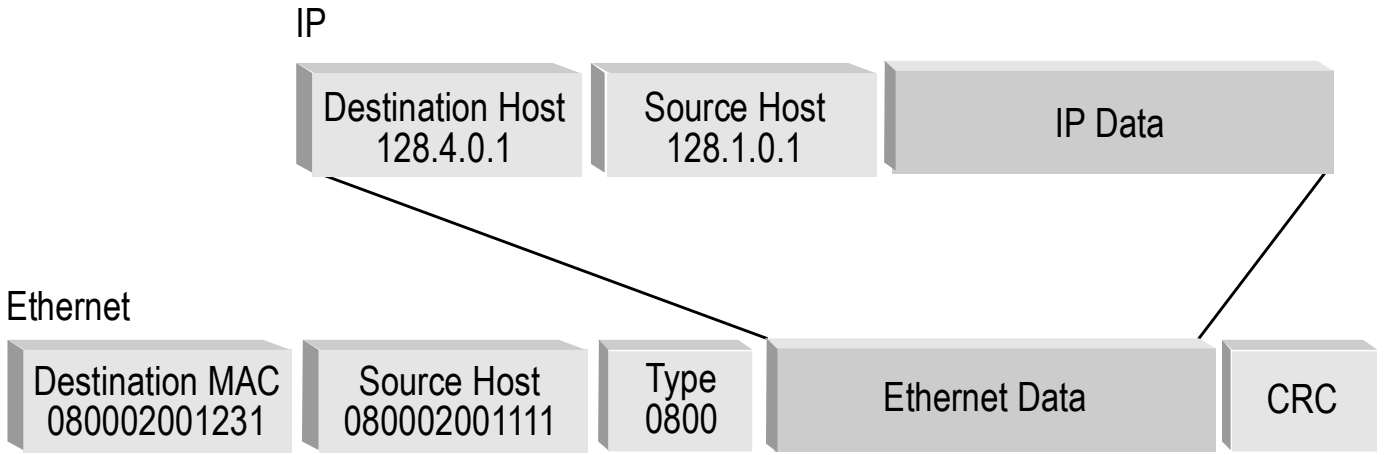


Sample Topology of Transmission Over an Internet

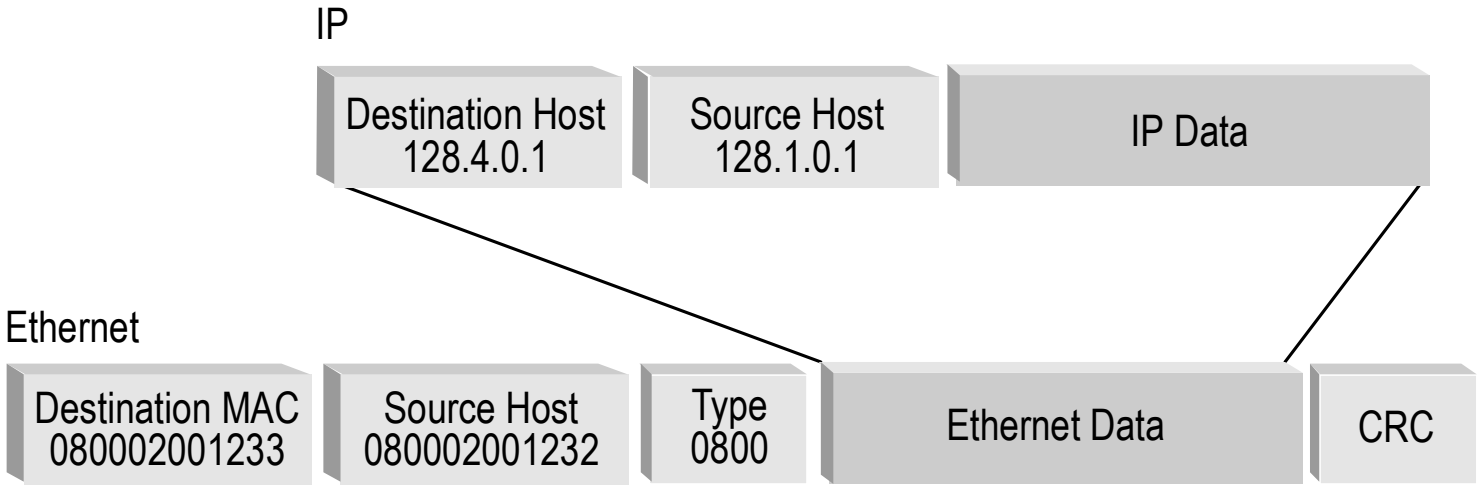
- Routing Tables are examined as a packet
- Host A wants to connect with Host B using Telnet.
- Note that Source and destination Ethernet Addresses do change.



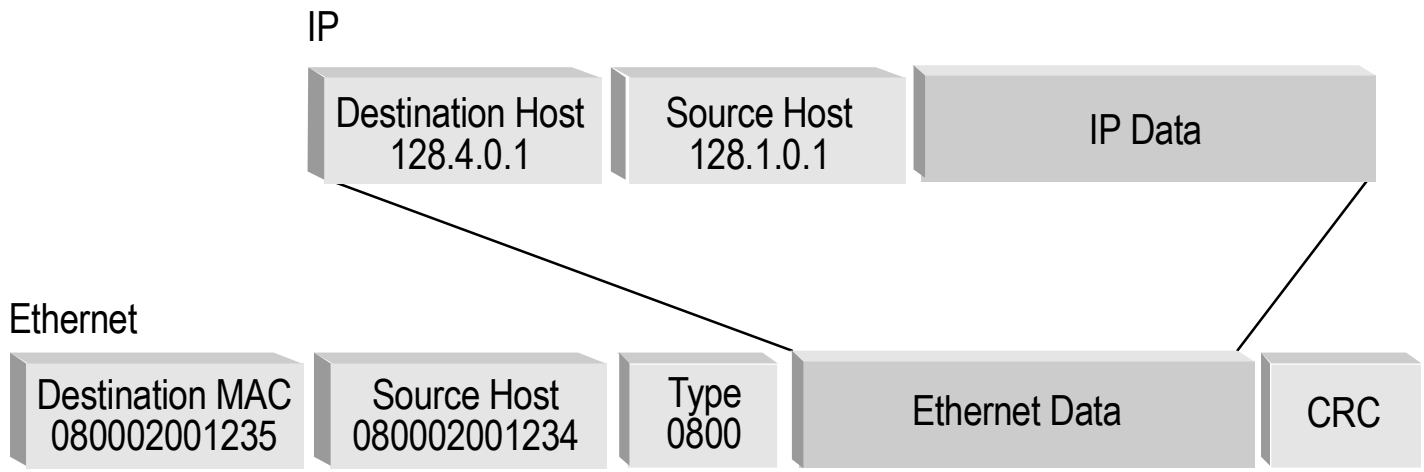
Packet on Network 128.1.0.0



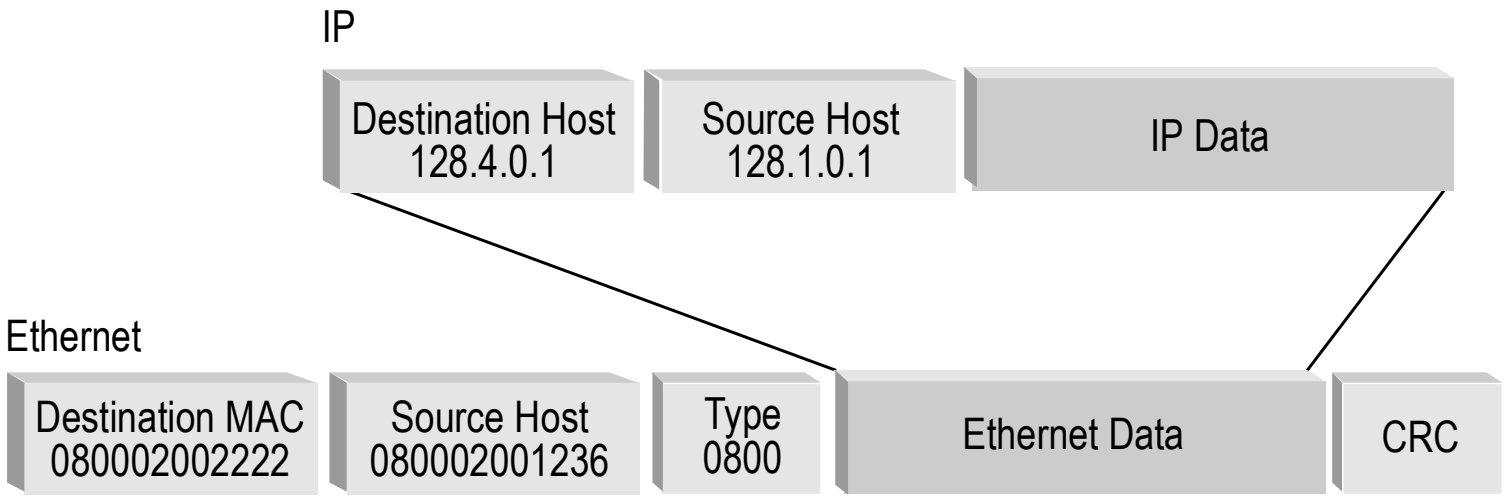
Packet on Network 128.2.0.0



Packet on Network 128.3.0.0



Packet on Network 128.4.0.0



End of day…