Network Layer (2): Addressing & Subnetting

Required reading:
Kurose 4.3.3

EECS 3214, Winter 2020
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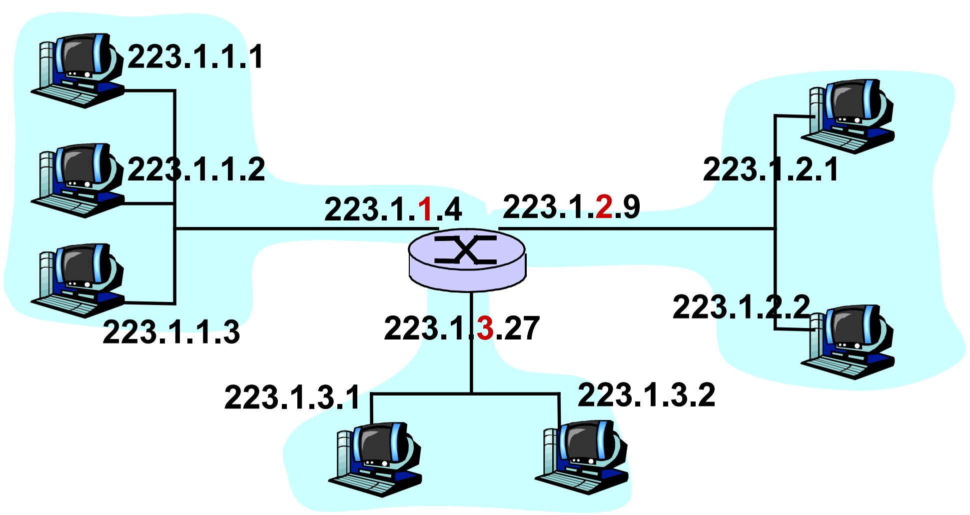
1. Introduction
2. Network Layer Protocols in the Internet
   2.1 IPv4
   2.2 IP Addressing and Subnetting
   2.3 IPv6
   2.4 ARP
   2.5 ICMP
3. Routing Algorithms
4. Routing in the Internet

IP Addressing

Internetwork Address (Network-level Addresses) – **<u>uniquely</u> and <u>universally</u> identifies each device connected to the (inter)network**

- **IP Address: 32-bit (4-byte) binary address that identifies a host / router interface to the Internet**
- **two devices on the Internet can <u>never</u> have the same address at the same time; BUT, a single device can have two IP addresses if it is connected to the Internet via two networks**
- **routers typically have multiple interfaces, i.e. multiple IP addresses**



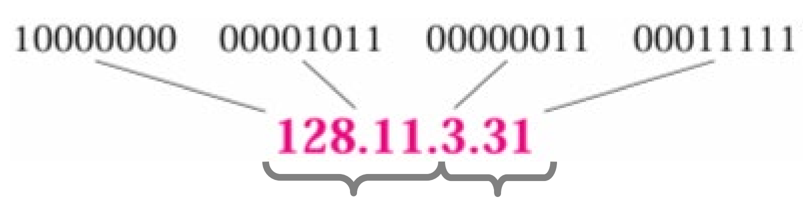
IP Addressing (cont.)

IP Address: Binary Notation – **32-bit / 4-byte representation with a space inserted between each octet (byte)**

IP Address: Decimal Notation – **4-number decimal representation with a decimal dot separating the numbers**

- **each decimal number corresponds to a byte**

  ⇒ each decimal number ∈ [0, 255]



IP address = network part + host part

assigned by global authority (ICANN) to organization — assigned by local authority to particular machine

Example [IP Address Conversion]

Change the following IP addresses from binary to dotted decimal notation.

(a) 10000001 00001011 00001011 11101111 ⇒ 129.11.11.239
(b) 11111001 10011011 11111011 00001111 ⇒ 249.155.251.15

IP Addressing (cont.)

Example **[ranges of IP addresses]**

146 . 102 . 29 . 0

Assume the first 3 bytes form NetID. How many IP addresses can be generated if we allow the last decimal number to change from 0 – 255.

146 . 102 . 29 . **0**

NetID

[0 – 255]

Assume the first 2 bytes form NetID. How many IP addresses can be generated if we allow the last decimal number to change from 0 – 255.

146 . 102 . **29 . 0**

NetID

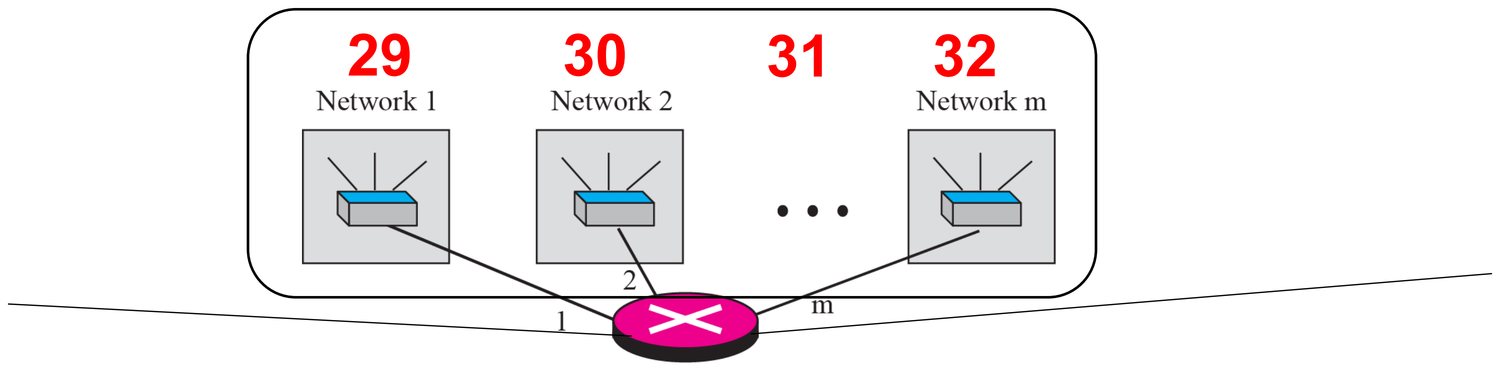
[0 – 255] **[0 – 255]**

IP Addressing (cont.)

Example **[range of addresses]**

Find the number of addresses in a sub-network if the first and last assigned addresses are

146. 102. 29. 0 and 146. 102. 32. 255.



Solution:

Subtract the first from the last address in base 256.

$$(146.102.32.255)_{256} - (146.102.29.0)_{256} = 0.0.3.255$$

Or, simply realize that there are only 4 possible values in the 3rd byte, and for each of those there are 256 possible values in the 4th byte. Hence …

# of addresses = 4*(256) = 1024

Classful and Classless IP Addressing

Originally, IP addressing used the concept of classes. This architecture is called **classful addressing**.

In the mid 1990s, a new architecture – **classless addressing**, was introduced.

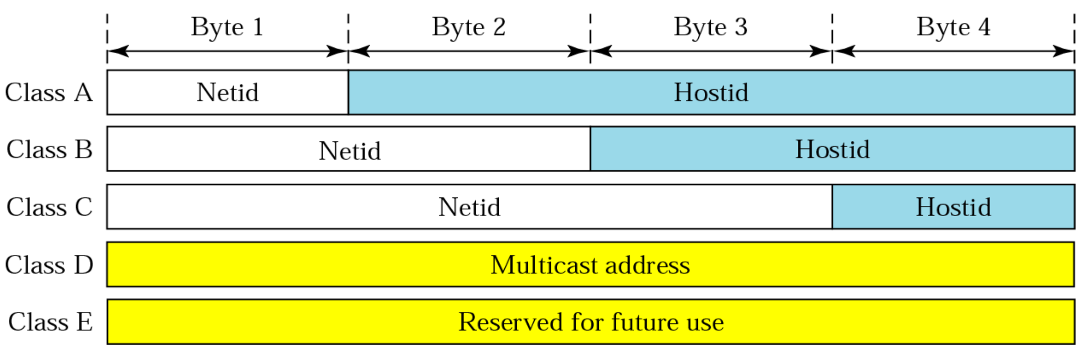
Understanding classful addressing paves the way for understanding classless addressing …

Classful IP Addressing

Classful IP Addressing – **supports addressing of different size networks by dividing address space into 5 classes: A, B, C, D, E**

Simple to deploy, but ineffective use of address space. Nowadays largely obsolete. But, very hepful in understanding classless addressing.

- **an IP address in classes A, B, and C is divided into Netid and Hostid**
- **class A addresses (1-byte Netid): get assigned to organizations with a large number of hosts or routers – there are only 126 class A networks with up to 16 million hosts in each**
- **class B addresses (2-byte Netid): allow around 16,000 networks and around 64,000 hosts per each network**
- **class C addresses (3-byte Netid): allow around 2 million networks and around 254 hosts per each network**



While many class A and B addresses are wasted, the number of addresses in class C is smaller than the needs of most organizations.

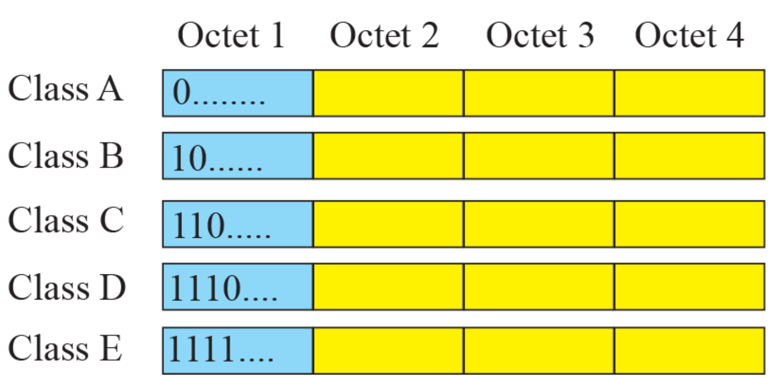
How do we know if an IP address is a class-A / B or C!?

Classful IP Addressing (cont.)

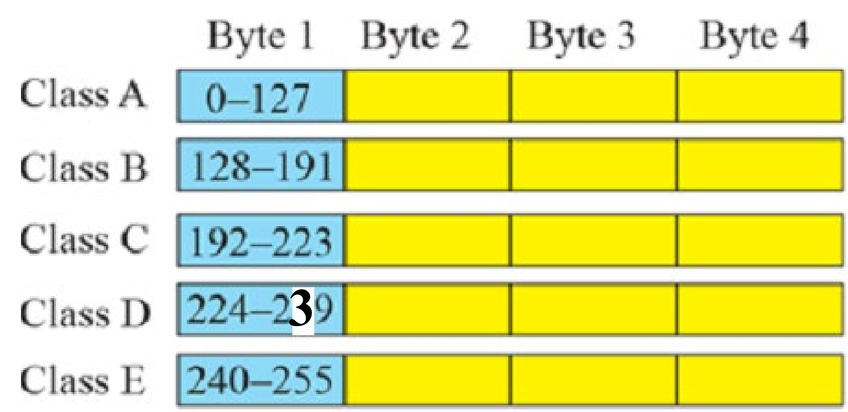
Recognizing Classes: Looking at 1st Byte

(1) Binary Notation – first few bits of an IP address in binary notation immediately identify the class of the given address

(2) Decimal Notation – each class has a specific range of numbers in decimal notation ⇒ it is enough to look at the first number to determine the class



Binary notation

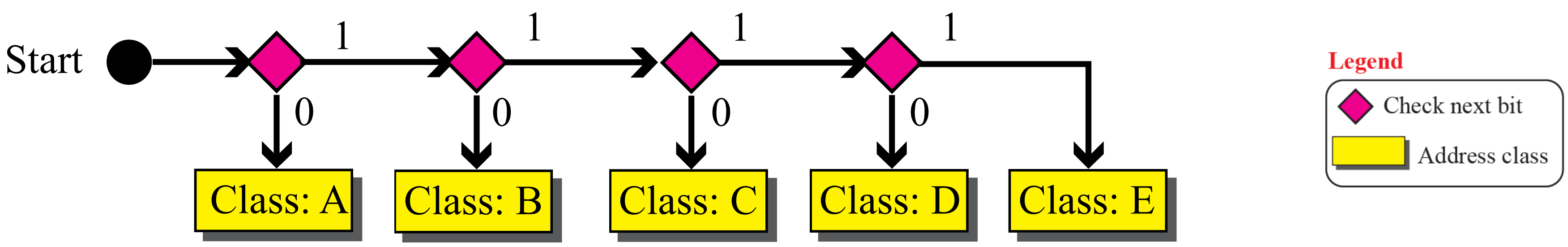


Dotted-decimal notation

From "TCP/IP Protocol Suite" by B. Forouzan, 4/e, pp. 122

Classful IP Addressing (cont.)

Finding the Address Class using Continuous Checking



From "TCP/IP Protocol Suite" by B. Forouzan, 4/e, pp. 121 and 122

Classful IP Addressing (cont.)

Example [classes of IP Address – binary notation]

Find the class of each address:

(a) 00000001 00001011 00001011 11101111
(b) 11110011 10011011 11111011 00001111

<u>Solution</u>:

(a) The first bit is 0 $\Rightarrow$ this is a class A address.
(b) The first 4 bits are 1 $\Rightarrow$ this is a class E address.

Example [classes of IP Address – binary notation]

Find the class of each address:

(a) 227.12.14.87
(b) 14.23.120.8

	Byte 1	Byte 2	Byte 3	Byte 4
Class A	0–127			
Class B	128–191			
Class C	192–223			
Class D	224–299			
Class E	240–255			

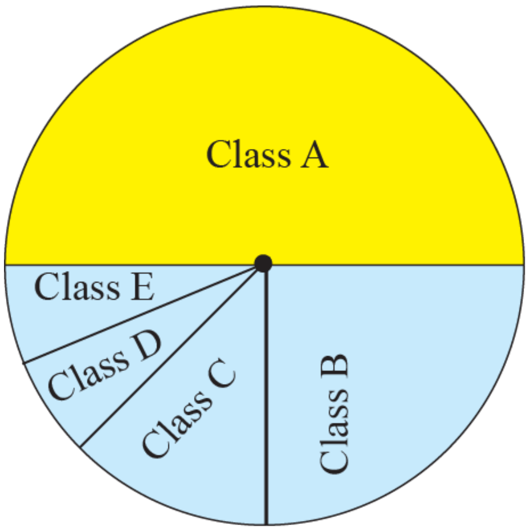
Dotted-decimal notation

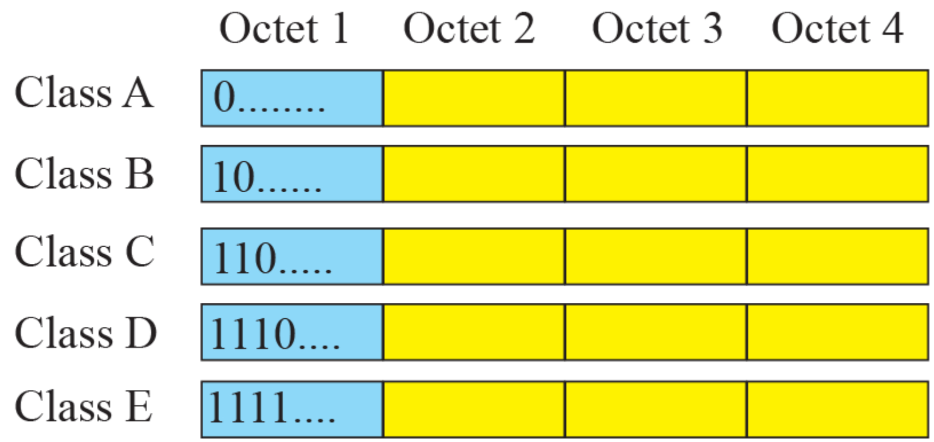
<u>Solution</u>:

(a) The first byte is 227 (between 224 and 239) $\Rightarrow$ this is a class D address.
(b) The first byte is 14 (between 0 and 127) $\Rightarrow$ this is a class A address.

Classful IP Addressing (cont.)

Occupation of Address Space by Class





Binary notation

Class A: 2^{31} = 2,147,483,648 addresses, 50%

Class B: 2^{30} = 1,073,741,824 addresses, 25%

Class C: 2^{29} = 536,870,912 addresses, 12.5%

Class D: 2^{28} = 268,435,456 addresses, 6.25%

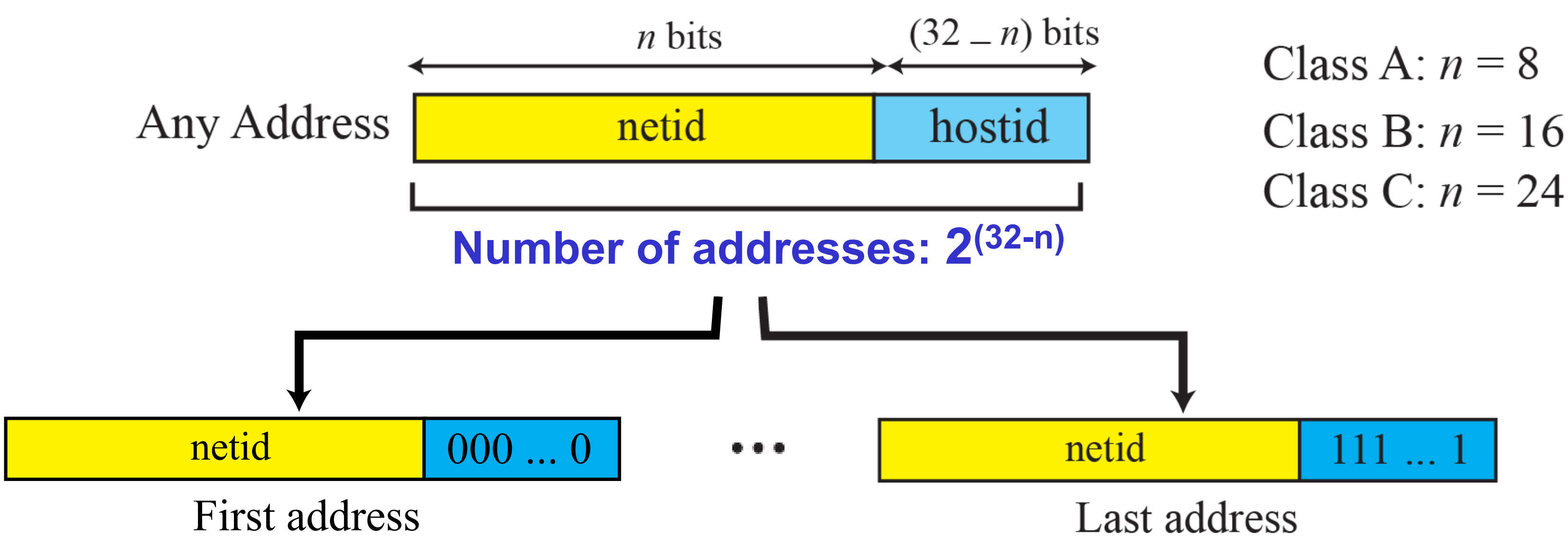
Class E: 2^{28} = 268,435,456 addresses, 6.25%

<ins>From “TCP/IP Protocol Suite” by B. Forouzan, 4/e, pp. 121 and 122</ins>

Classful IP Addressing (cont.)

Block of Addresses – group/range of addresses **with the same NetID**

- given any address in a block, we normally like to know three pieces of information about the block:
  1) the number of addresses in the given block
  2) the 1st address in the given block
  3) the last address in the given block



Network address – identifier of the network !!!

Broadcast address of the given network !!!

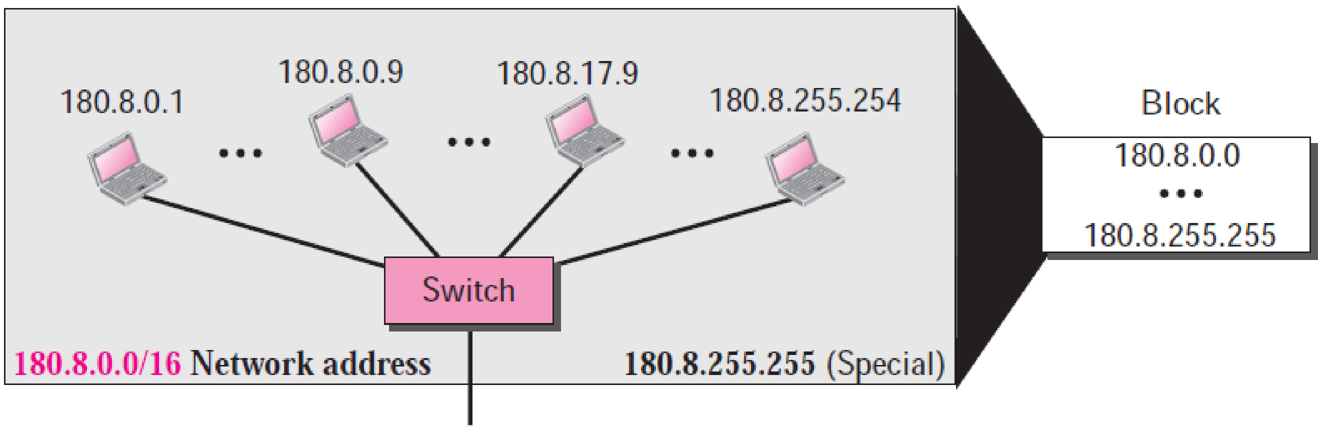
From "TCP/IP Protocol Suite" by B. Forouzan, 4/e, pp. 127

Classful IP Addressing (cont.)

Example [block of addresses]

An address in a classful block is given as 180.8.17.9. Find the number of addresses in the block, the first address, and the last address.

possible configuration of the network using the given block



Since 180 is between 128 and 191, the class of the address is B. The value of n for class B is 16. Figure 5.17 shows a possible configuration of the network that uses this block.

1. The number of addresses in this block is $N = 2^{32-n} = 2^{16} = 65{,}536$.
2. To find the first address, we keep the leftmost 16 bits and set the rightmost 16 bits all to 0s. The first address (network address) is 18.8.0.0/16, in which 16 is the value of n.
3. To find the last address, we keep the leftmost 16 bits and set the rightmost 16 bits all to 1s. The last address is 18.8.255.255.

<u>**From "TCP/IP Protocol Suite" by B. Forouzan, 4/e, pp. 128**</u>

Classful IP Addressing (cont.)

Example [network address]

Given the (<u>classful</u>) address 23.56.7.91, find the network address.

<u>Solution</u>:

The class is A $\Rightarrow$ only the first byte defines the Netid. We can find the network address by replacing the Hostid bytes with 0s. Therefore, the network address is 23.0.0.0

Example [network address]

Given the (<u>classful</u>) address 132.6.17.85, find the network address.

<u>Solution</u>:

The class is B $\Rightarrow$ the first two byte define the Netid. We can find the network address by replacing the hostid bytes with 0s. Therefore, the network address is 132.6.0.0.

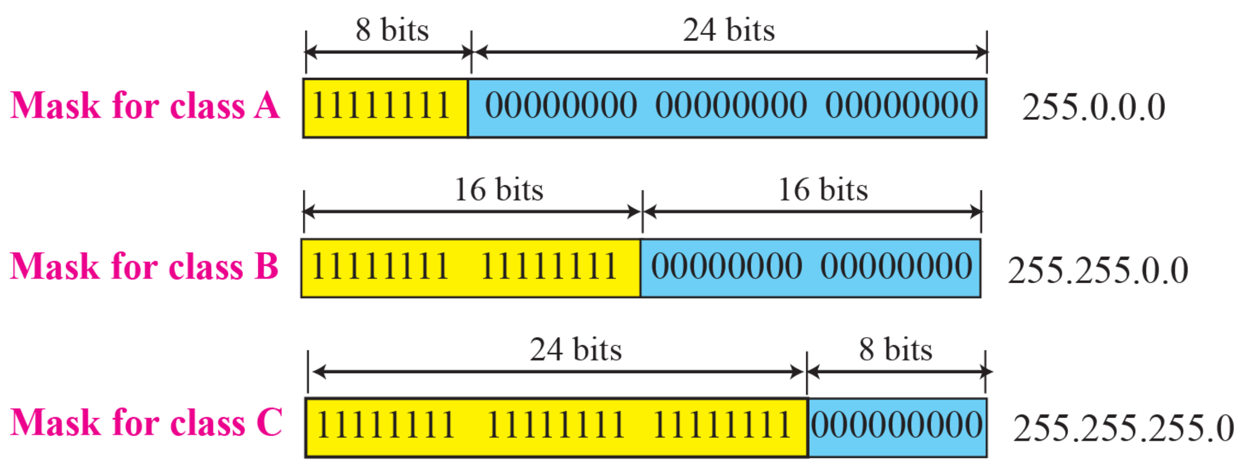
Classful IP Addressing (cont.)

Network Address – **NetID + all-0s – used for routing of packets to their destination**

- **when a packet arrives to a router, the router needs to know to which network the packet should be sent**
  ⇒ <u>destination network address need to be extracted from destination host address !!!</u>

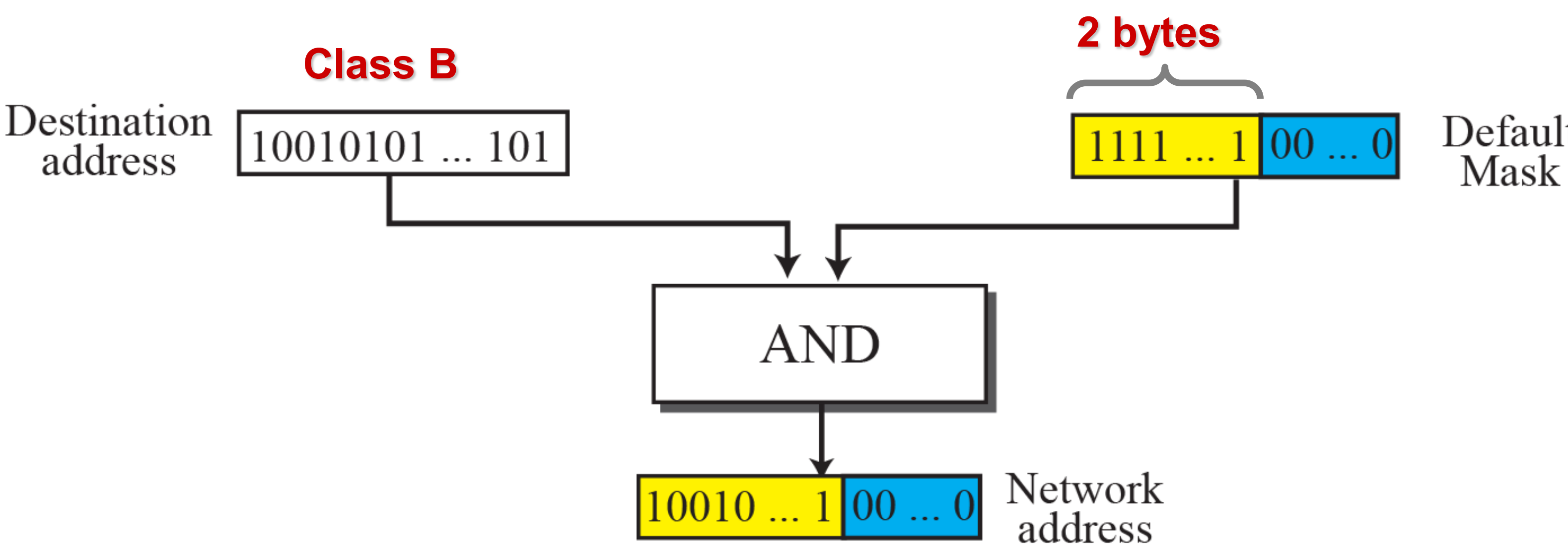
Network Mask – **32-bit number with all n leftmost bits set to 1s and (32-n) rightmost bits all set to 0s**

- **enables quick extraction of network addresses**
- **there are 3 different masks in classful addressing:**



Example **[finding a network address using network mask]**

Assume a packet with destination address 10010101 … 101 has arrived to a router. Describe the process of determining the network address of the destination network.



Classful IP Addressing (cont.)

Example **[steps performed by a router in classful address domain]**

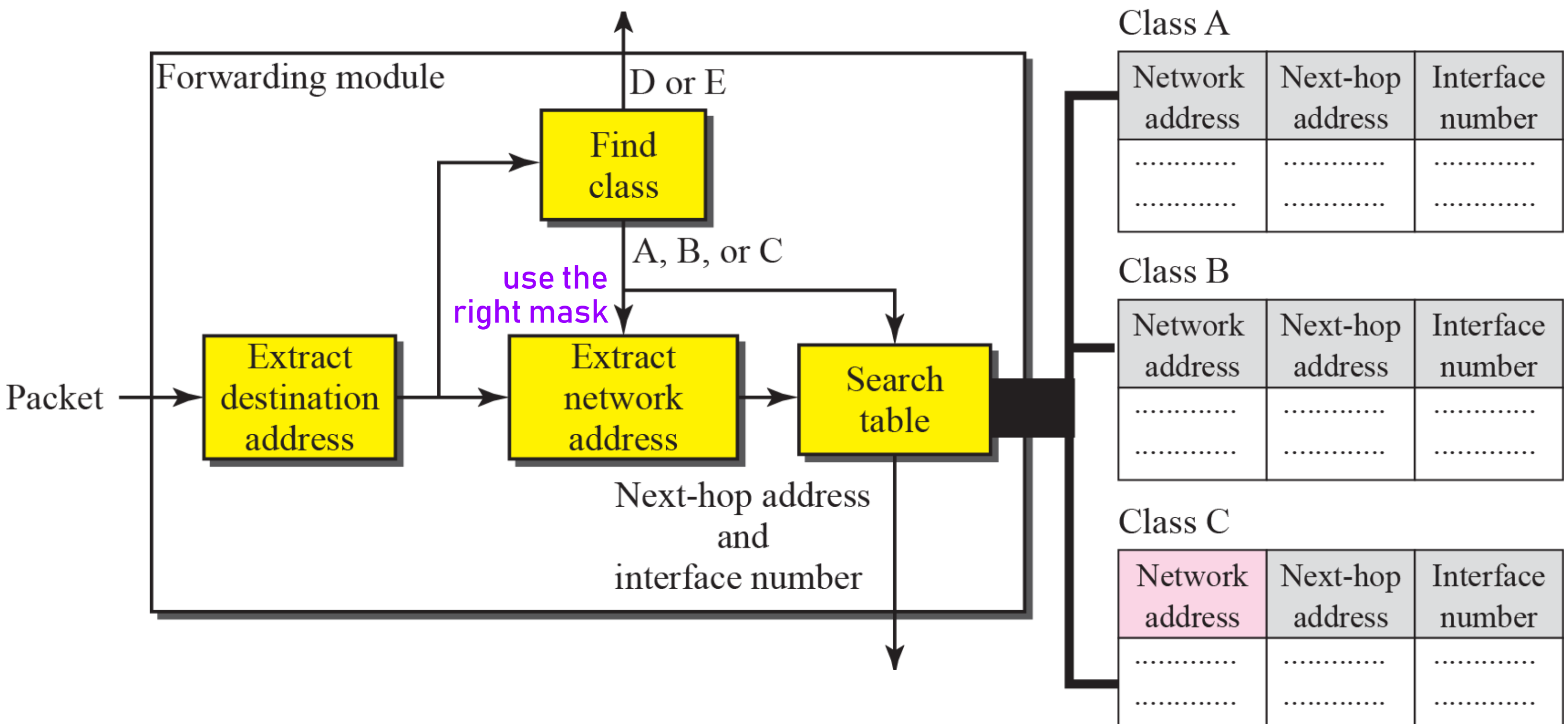
A router receives a packet with destination address 190.240.7.91. Show how it finds the network address to route the packet.

Solution:

(1) Find the class of the destination network – class B in this case.

(2) Default mask for class B is 255.255.0.0. The router ANDs this mask with the address …

(3) The router looks in its routing table to find out how to route this packet …



Classful IP Addressing (cont.)

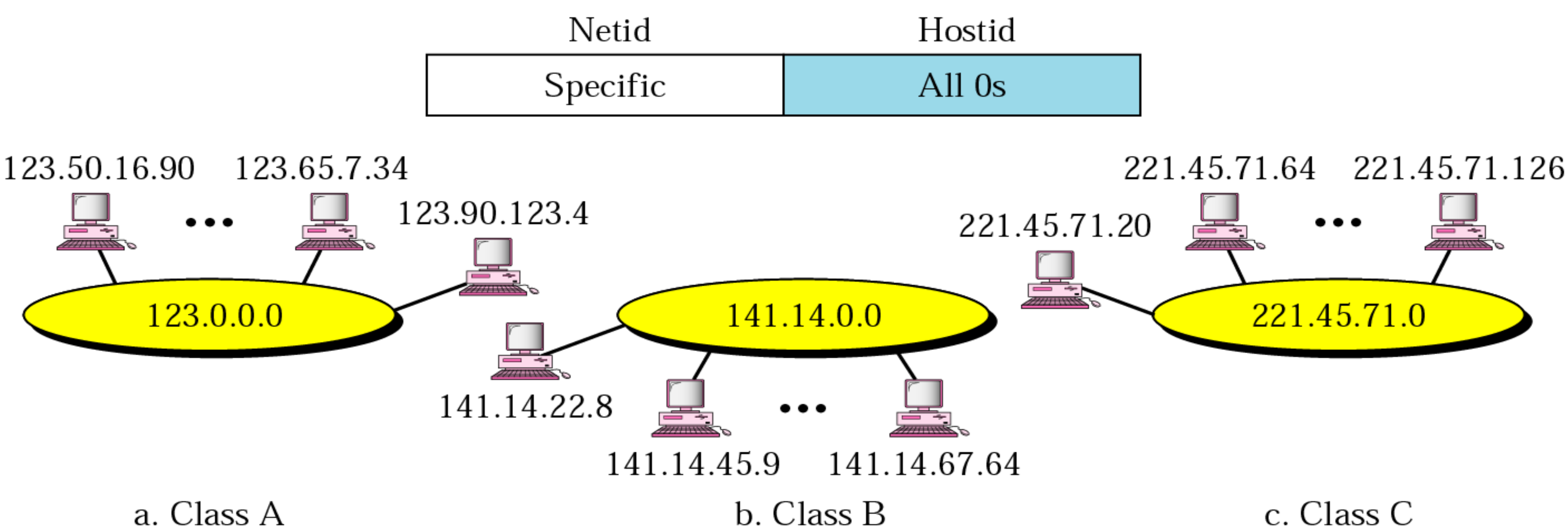
Special Addressing – some parts of address space are used for special purposes, and some of these addresses cannot be assigned to a host

Special Address	*Netid*	*Hostid*	*Source or Destination*
Network Address	Specific	All 0-s	None
Direct Broadcast Address	Specific	All 1-s	Destination
Limited Broadcast Address	All 1-s	All 1-s	Destination
This host on this network	All 0-s	All 0-s	Source
Loopback Address	127	Any	Destination
Private Addresses	*multiple*	*multiple*	Both
Local-Link Addresses	165.254	Any	Both

Classful IP Addressing (cont.)

Network Address – defines the network to the rest of the Internet – cannot be assigned to a host

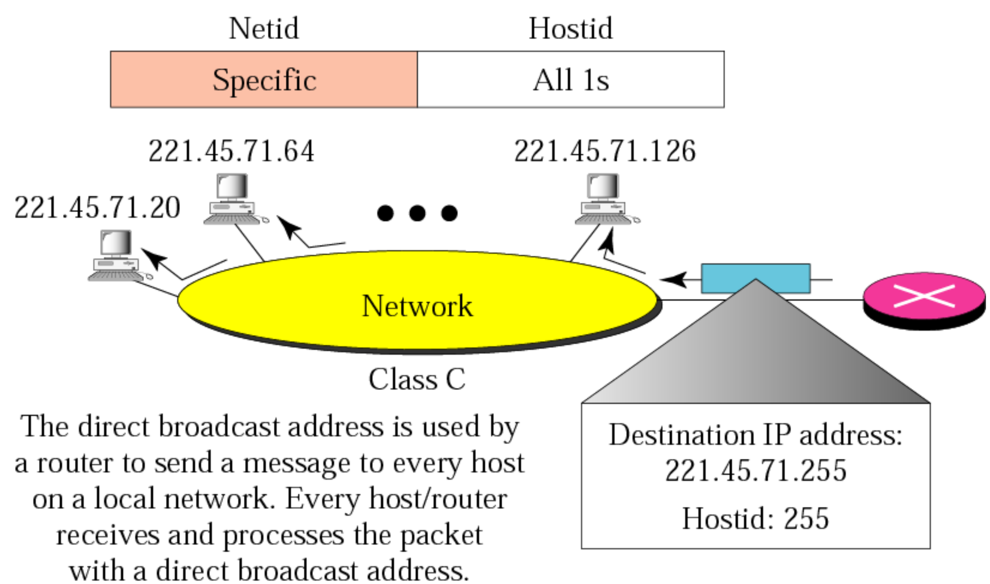
- network address ≠ Netid – network address has both Netid and Hostid, with 0s for the Hostid
- Netid alone is also known as network prefix
- reduces the number of available addresses in classes A, B and C by 1



Classful IP Addressing (cont.)

Direct Broadcast Address – **hostid = all 1s** – **last address in a block of addresses**

- **used by a router to send packets to all hosts in a specific network**
- **further reduces the number of available addresses by 1**

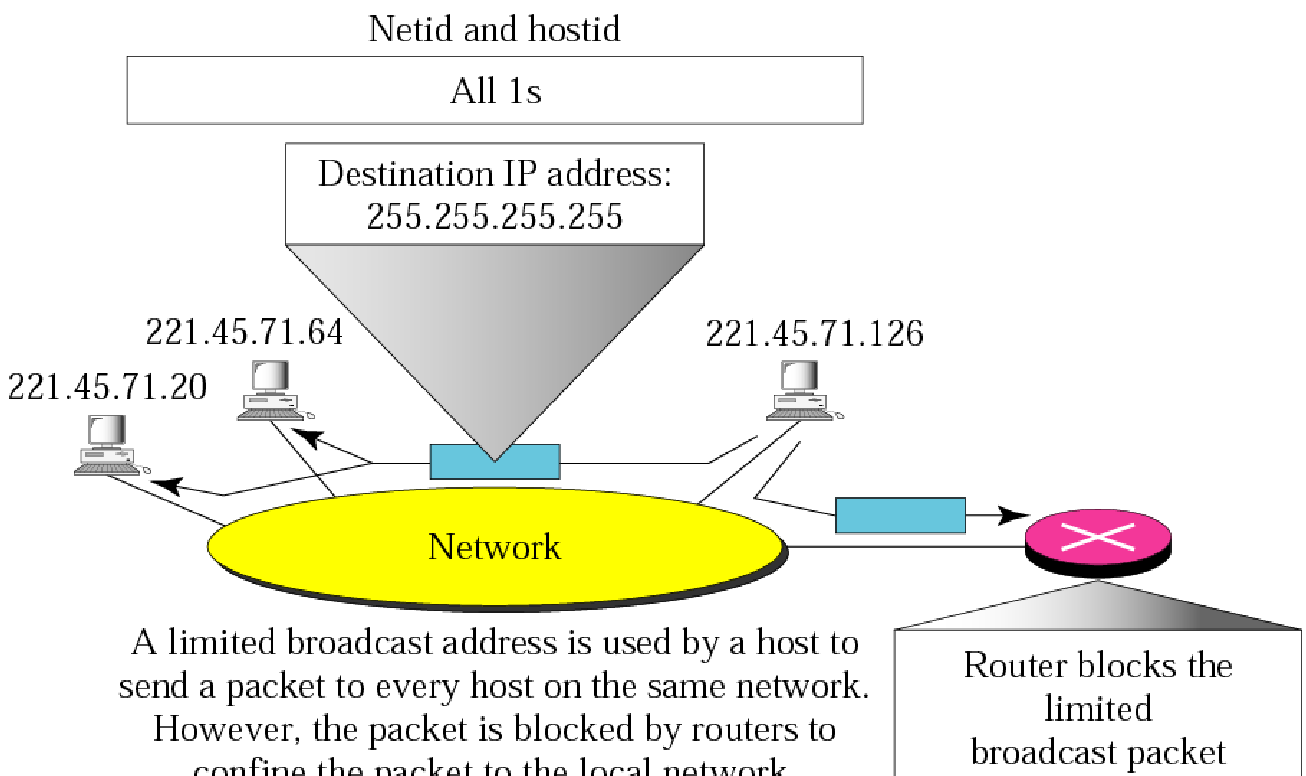


Allows a remote system to send a single packet that will be broadcast on the specified LAN.
To avoid potential problems, many sites configure routers to reject all direct broad. packets.

Classful IP Addressing (cont.)

Limited Broadcast Address – **all 1-s** ⇒ **class E address** – **used by a host to send packets to every other host in its current LAN**

- **limited broadcast packet is NOT forwarded by routers** ⇒ **packet is confined within its LAN**

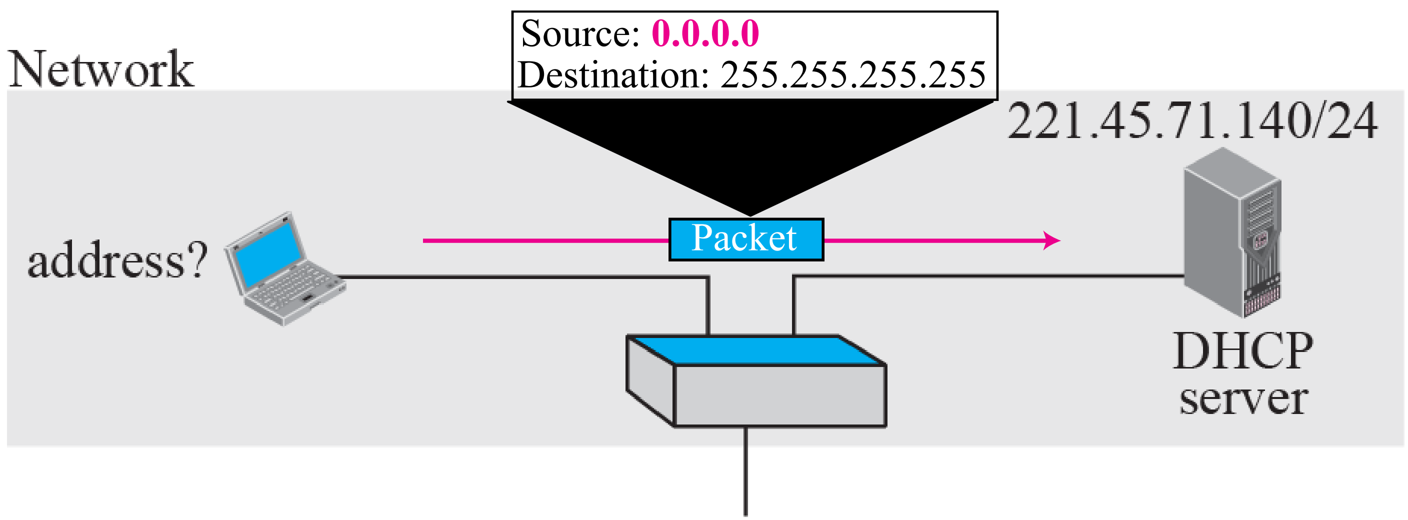


A limited broadcast address is used by a host to send a packet to every host on the same network. However, the packet is blocked by routers to confine the packet to the local network.

Classful IP Addressing (cont.)

All-Zeros Address – **reserved for communication when a host needs to send an IP packet but does not know/have its own IP address**

- **normally used by a host at bootstrap time to send a request to a DHCP server**

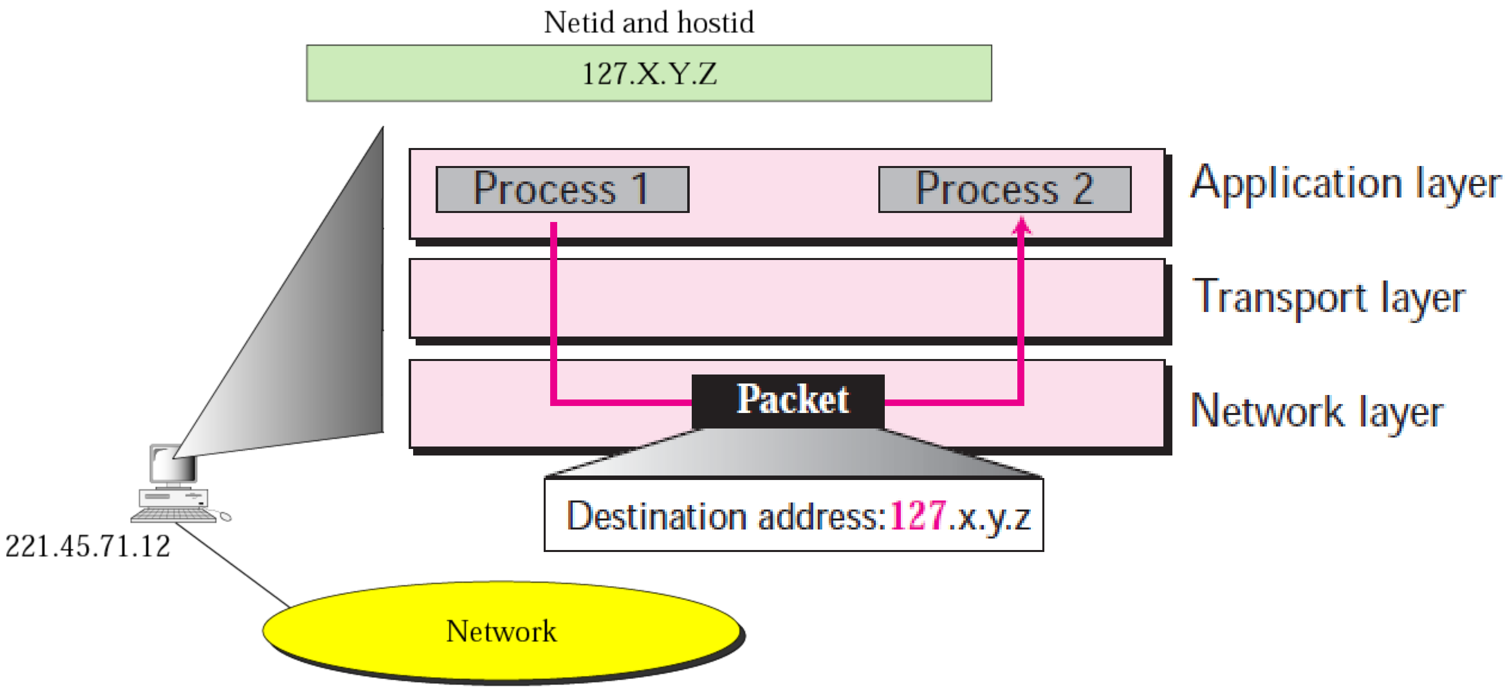


From "TCP/IP Protocol Suite" by B. Forouzan, 4/e, pp. 147

Classful IP Addressing (cont.)

Loopback Address – **first byte = 127** – **used to test software on a machine**

- **packet with loopback address as destination address never leaves machine**
- **e.g. to test if IP software works – execute "ping 127.x.y.z"**
- **e.g. can be used by a client process to send a message to a server process on the same machine**



A packet with a loopback address will not reach the network.

Classful IP Addressing (cont.)

Local-Link Addresses – a block of addresses reserved for special use in 'local-link' addressing – not unique beyond its LAN

- in absence of static or dynamic address allocation, a device can assign itself an address from this block
- routers do NOT forward packets with these source addr.

169.254.0.0/16

Address for Private Networks – blocks of addresses assigned for private use – assigned by local DHCP server

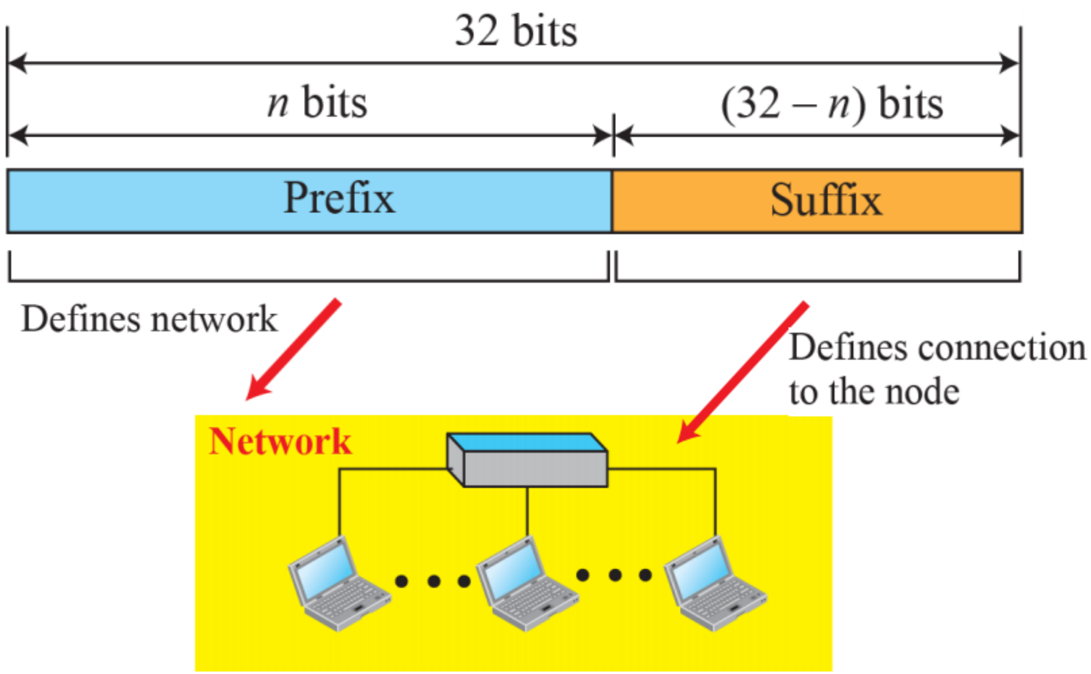
- they are not globally recognized
- they can be used in isolation or in combination with NAT

Range			*Total*	
10.0.0.0	to	10.255.255.255	2^{24}	class A
172.16.0.0	to	172.31.255.255	2^{20}	class B
192.168.0.0	to	192.168.255.255	2^{16}	class C

Classful IP Addressing (cont.)

Address Prefix – **aka Net ID – defines the network …**

Address Suffix – **aka Host ID – defines the node …**



In Classful addressing, prefix is of fixed length (1, 2, or 3 bytes)!

Classful IP Addressing (cont.)

Advantages of Classful Addressing

- given an address, prefix can be found immediately
  - no extra information is needed!!!

Disadvantages of Classful Addressing

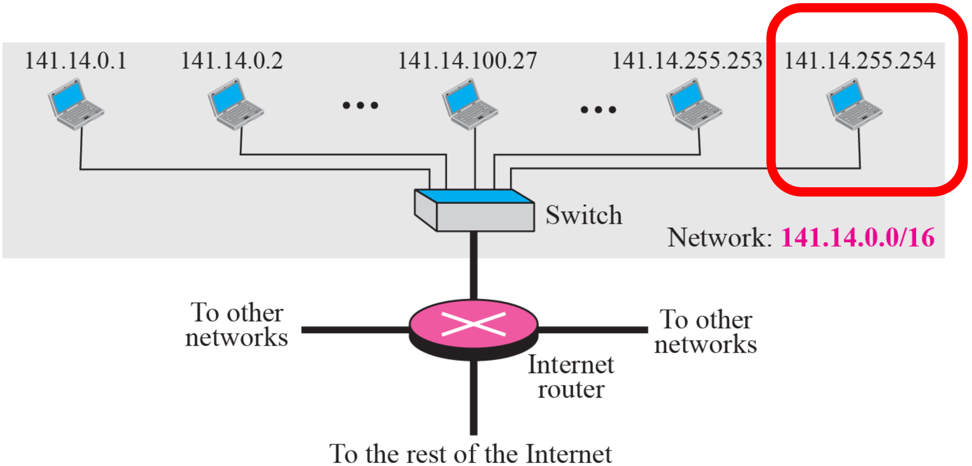
- lack of a class to support medium-sized organizations
  - class C which supports 254 hosts - too small
  - class B which supports 65534 hosts - too large
- premature depletion of class A & B addresses
  - in the early days of the Internet, IP addresses were freely assigned to those who asked for them, without concerns about eventual depletion
- two existing mechanisms for overcoming the limitations of classful addressing:

  (1) **subnetting** – if an organization gets assigned a "big" block of IP addresses how to distribute these internally, among multiple LAN

  (2) **supernetting** – how an organization can combine several class C blocks to create a larger range of addresses

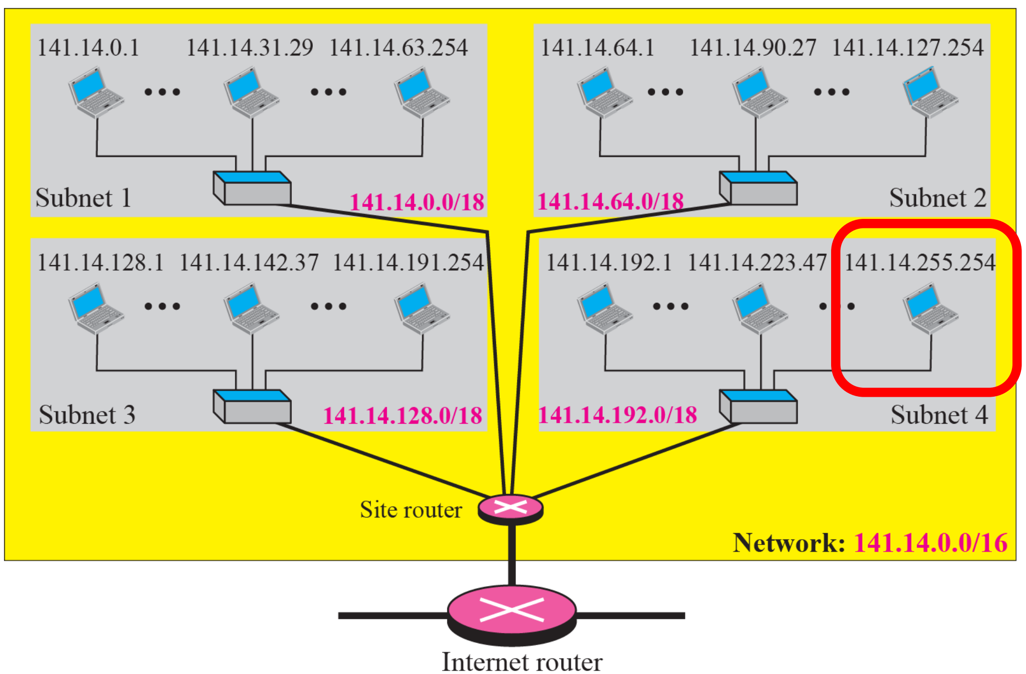
Subnetting

Example [Why is subnetting useful?!]



Class B network <u>before</u> subnetting: each packet flooded through entire network. 2-level routing hierarchy:

(1) deliver to the network
(2) deliver to the host



Class B network <u>after</u> subnetting: packets routed only to appropriate network segment. 3-level routing hierarchy:

(1) deliver to the network
(2) deliver to the subnetwork
(3) deliver to the host