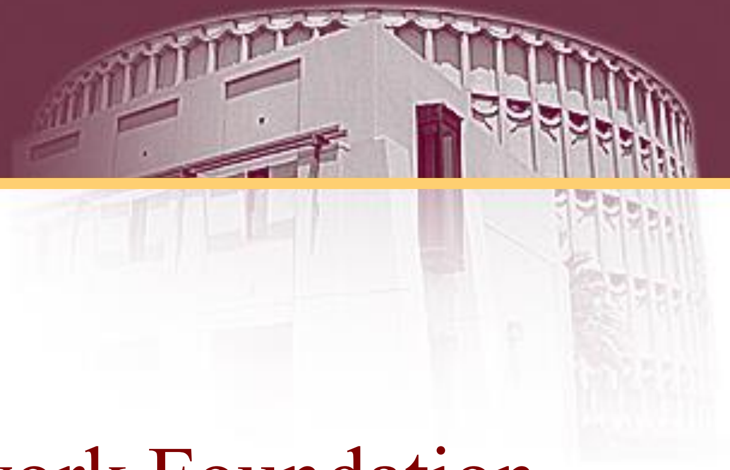

Computer Network Foundation

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Outline

- Network Addressing
- Subnetting
- Classless Inter-Domain Routing (CIDR)
- Route Aggregation

Network Addressing

- How does the network decide where to send a packet???
- All Hosts on the network have an address that can be used to route the packet.

IP Address (As Originally Specified)

Two levels IP address (32-bits)

Network Number (Net ID)	Host Number (Node ID)

Class A

0	1 7	8 31
0	Network Number	Host Number

Class B

0 1	2 15	16 31
1 0	Network Number	Host Number

Class C

0 1 2	3 23	24 31
1 1 0	Network Number (21 bits)	Host Number

Class D

0 1 2 3	4 31
1 1 1 0	Multicast group ID (28 bits)

Class E

0 1 2 3 4	5 31
1 1 1 1 0	Reserved for future use (27 bits)

IP Address Dot Notation

- Binary presentation: (N-network, n-node).

  Class A -- NNNNNNNN.nnnnnnnn.nnnnnnnn.nnnnnnnn.
  Class B -- NNNNNNNN.NNNNNNNN.nnnnnnnn.nnnnnnnn.
  Class C -- NNNNNNNN.NNNNNNNN.NNNNNNNN.nnnnnnnn.

- Decimal presentation:

  Class A (0xxx), 1 ~ 126 in decimal. 2^7 -2 nets and 2^24-2 (=16M) hosts/net

  Class B (10xx), 128 ~ 191 in decimal. 2^14 nets and 2^16-2 (=64K) hosts/net

  Class C (110x), 192 ~ 223 in decimal. 2^21 nets and 2^8-2 (=254) hosts/net

  Class D (1110), 224 ~ 239 in decimal (for multicast).

  Class E (1111), 240 ~ 254 in decimal (reserved for future use).

Private IP Address (RFC 1918)

There are three IP network addresses reserved for private networks. The addresses are

10.0.0.0/8	**One Class A address**
172.16.0.0/12	**16 Class B addresses**
192.168.0.0/16	**256 Class C addresses**

Limitations of Classful IP Addressing

- Designed almost 40 years later
- Only 3 classes of networks
- Address space used *inefficiently*
- For example,
  - if a network needs to support 260 hosts, which class of address it requires? How many addresses waste?

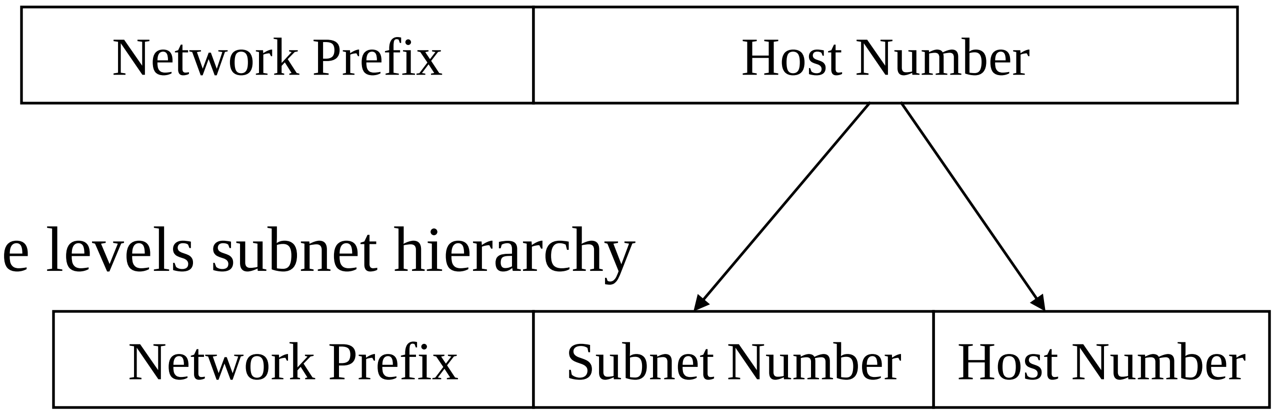
Subnetting

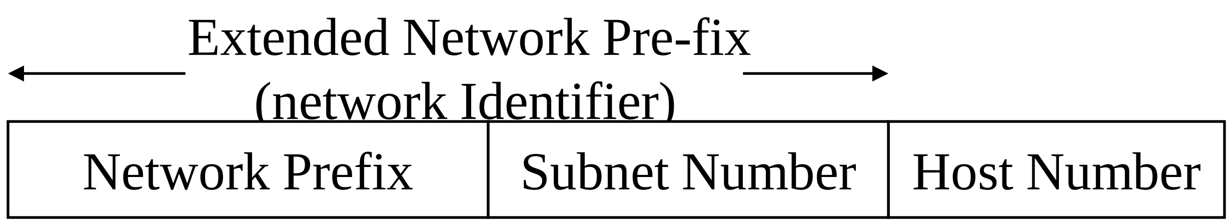
IETF RFC 950:

Create multiple logical networks that exist within a single class.

Two levels classful hierarchy

Three levels subnet hierarchy





Subnet Masking

Applying a subnet mask to an IP address allows you to identify the network and node parts of the address. The **network bits** are represented by the **1s** in the mask, and the **node bits** are represented by the **0s**. Performing a bitwise logical AND operation between the IP address and the subnet mask results in the *Network Address* or Identifier.

Example:

```
    10001100.10110011.11110000.11001000    140.179.240.200 Class B IP Address
& ) 11111111.11111111.00000000.00000000    255.255.000.000 Default Class B Subnet Mask
    -----------------------------------
    10001100.10110011.00000000.00000000    140.179.000.000 Network Address
```

Subnetting Presentation:

- Binary Presentation:
  - **Class A** - 11111111.00000000.00000000.00000000
  - **Class B** - 11111111.11111111.00000000.00000000
  - **Class C** - 11111111.11111111.11111111.00000000

- Decimal Presentation:
  - **Class A** - 255.0.0.0
  - **Class B** - 255.255.0.0
  - **Class C** - 255.255.255.0

- "/" or Length presentation (CIDR notation)
  - **Class A** - /8
  - **Class B** - /16
  - **Class C** - /24

Extended Network Prefix – Subnet Masks

A subnet address cannot be all "0"s or all "1"s.
This also implies that a 1 bit subnet mask is not allowed

Example:

← Extended Network Prefix →

← Network Prefix → ⟷

10001100.10110011.11011100.11001000	140.179.220.200 IP Address
11111111.11111111.**111**00000.00000000	255.255.**224**.000 Subnet Mask
-- ------	
10001100.10110011.11000000.00000000	140.179.192.000 Subnet Address
10001100.10110011.11011111.11111111	140.179.223.255 Broadcast Address

140.179.220.200/19

How many **subnets** do we have from above example?

An Example: 200.133.175.x/28

Class C examples

Subnet bits	Network Number	Node Addresses	Broadcast Address
0000	200.133.175.0	Reserved	None
0001	200.133.175.16	.17 thru .30	200.133.175.31
0010	200.133.175.32	.33 thru .46	200.133.175.47
0011	200.133.175.48	.49 thru .62	200.133.175.63
0100	200.133.175.64	.65 thru .78	200.133.175.79
0101	200.133.175.80	.81 thru .94	200.133.175.95
0110	200.133.175.96	.97 thru .110	200.133.175.111
0111	200.133.175.112	.113 thru .126	200.133.175.127
1000	200.133.175.128	.129 thru .142	200.133.175.143
1001	200.133.175.144	.145 thru .158	200.133.175.159
1010	200.133.175.160	.161 thru .174	200.133.175.175
1011	200.133.175.176	.177 thru .190	200.133.175.191
1100	200.133.175.192	.193 thru .206	200.133.175.207
1101	200.133.175.208	.209 thru .222	200.133.175.223
1110	200.133.175.224	.225 thru .238	200.133.175.239
1111	200.133.175.240	Reserved	None

Subnet Design Considerations

1) How many *total subnets* does the organization need today?

2) How many total subnets will the organization need in the future?

3) How many *hosts* are there on the organization's largest subnet today?

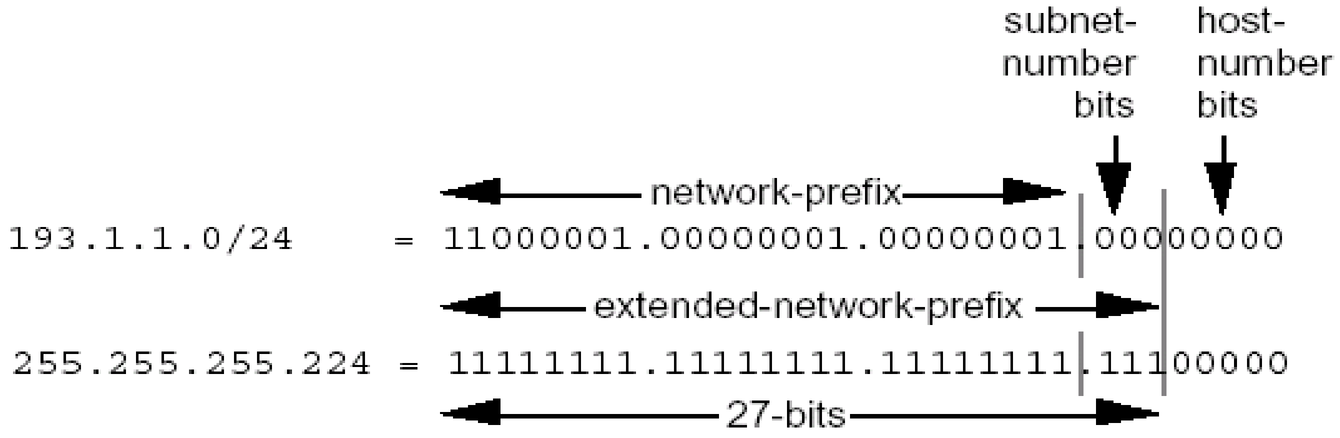
4) How many hosts will there be on the organization's largest subnet in the future?

Design Examples

Subnet Example #1

Given

An organization has been assigned the network number 193.1.1.0/24 and it needs to define 6 subnets. The largest subnet is required to support 25 hosts.



Design Examples - Continued

Base Net: 11000001.00000001.00000001.00000000 = 193.1.1.0/24

Subnet #0: 11000001.00000001.00000001.00000000 = 193.1.1.0/27
Subnet #1: 11000001.00000001.00000001.00100000 = 193.1.1.32/27
Subnet #2: 11000001.00000001.00000001.01000000 = 193.1.1.64/27
Subnet #3: 11000001.00000001.00000001.01100000 = 193.1.1.96/27
Subnet #4: 11000001.00000001.00000001.10000000 = 193.1.1.128/27
Subnet #5: 11000001.00000001.00000001.10100000 = 193.1.1.160/27
Subnet #6: 11000001.00000001.00000001.11000000 = 193.1.1.192/27
Subnet #7: 11000001.00000001.00000001.11100000 = 193.1.1.224/27

Defining Host Address for Each Subnet

- The all-1s host-number and all 0s host-number are both reserved.
- In our current example, there are 5 bits in the host-number field of each subnet address. This means that each subnet represents a block of 30 host addresses. The hosts on each subnet are numbered 1 through 30.

Defining Host Address for Each Subnet

Subnet #2: 11000001.00000001.00000001.**010 00000** = 193.1.1.64/27
Host #1: 11000001.00000001.00000001.**010 00001** = 193.1.1.65/27
Host #2: 11000001.00000001.00000001.**010 00010** = 193.1.1.66/27
Host #3: 11000001.00000001.00000001.**010 00011** = 193.1.1.67/27
Host #4: 11000001.00000001.00000001.**010 00100** = 193.1.1.68/27
Host #5: 11000001.00000001.00000001.**010 00101** = 193.1.1.69/27

.

.

Host #15: 11000001.00000001.00000001.**010 01111** = 193.1.1.79/27
Host #16: 11000001.00000001.00000001.**010 10000** = 193.1.1.80/27

.

.

Host #27: 11000001.00000001.00000001.**010 11011** = 193.1.1.91/27
Host #28: 11000001.00000001.00000001.**010 11100** = 193.1.1.92/27
Host #29: 11000001.00000001.00000001.**010 11101** = 193.1.1.93/27
Host #30: 11000001.00000001.00000001.**010 11110** = 193.1.1.94/27

Defining the Broadcast Address for Subnet #2
The broadcast address for Subnet #2 is the all 1's host address or:
11000001.00000001.00000001.010 **11111** = 193.1.1.95

Design Examples

Subnet Example #2

Given

An organization has been assigned the network number 140.25.0.0/16 and it needs to create a set of subnets that supports up to 60 hosts on each subnet.

140.25.0.0/16

10001100.00011001.00000000.00000000/16

How many subnets can be created?

Design Examples - Continued

Subnet Example #2

Given

An organization has been assigned the network number 140.25.0.0/16 and it needs to create a set of subnets that supports up to 60 hosts on each subnet.

140.25.0.0/26

10001100.00011001.00000000.00000000/26

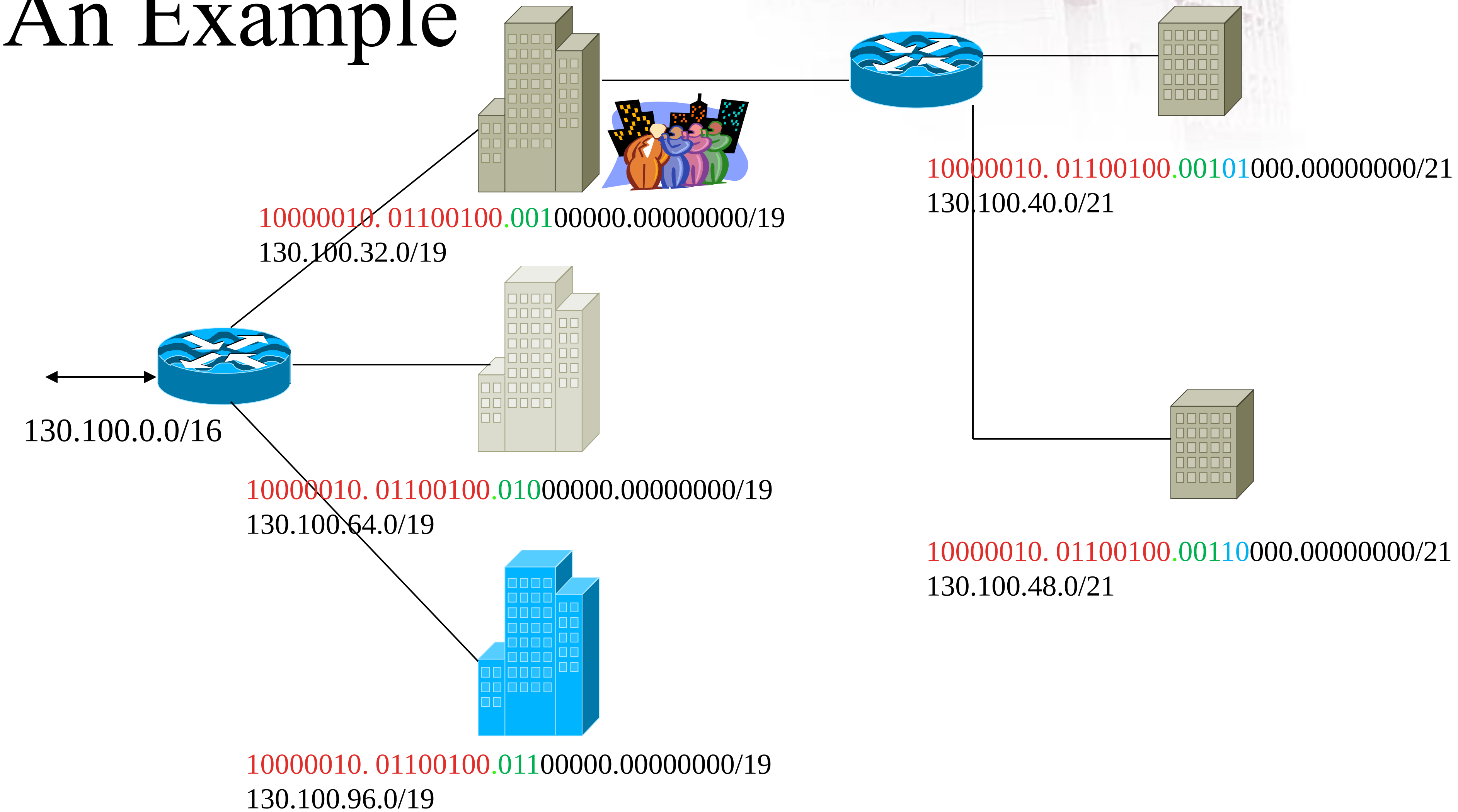
subnet #1, host 1

10001100.00011001.00000000.01000001/26

etc.

How many hosts for each subnet?

An Example

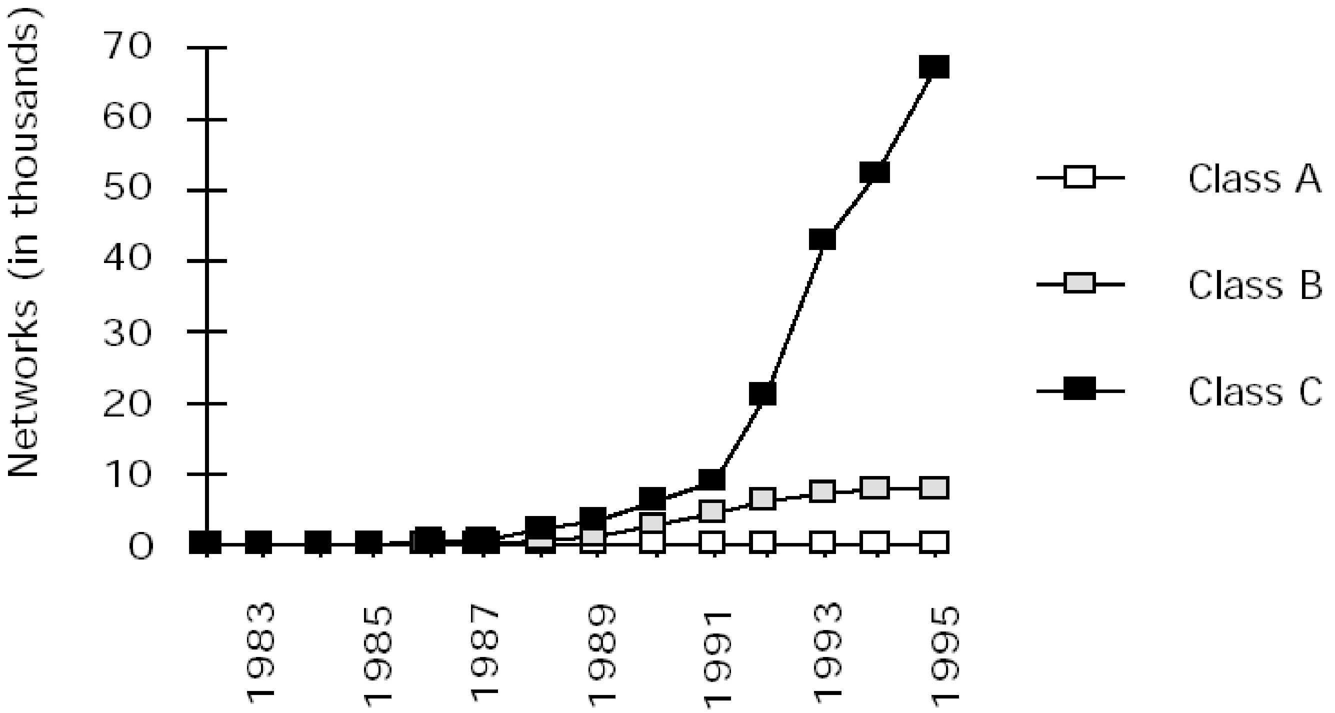

10000010. 01100100.00100000.00000000/19
130.100.32.0/19
10000010. 01100100.00101000.00000000/21
130.100.40.0/21
130.100.0.0/16
10000010. 01100100.01000000.00000000/19
130.100.64.0/19
10000010. 01100100.00110000.00000000/21
130.100.48.0/21
10000010. 01100100.01100000.00000000/19
130.100.96.0/19

Pros and Cons of Subnetting

- Advantages
  - Assign IP address more efficiently
  - Speeds up the network (reduce the size of broadcast domain)
  - Easy to organize the network resources
  - Improve security
- Disadvantages
  - Added layer of complexity (more routers)
  - Difficult to change once hierarchy is established.

Internet Scaling Problem 1

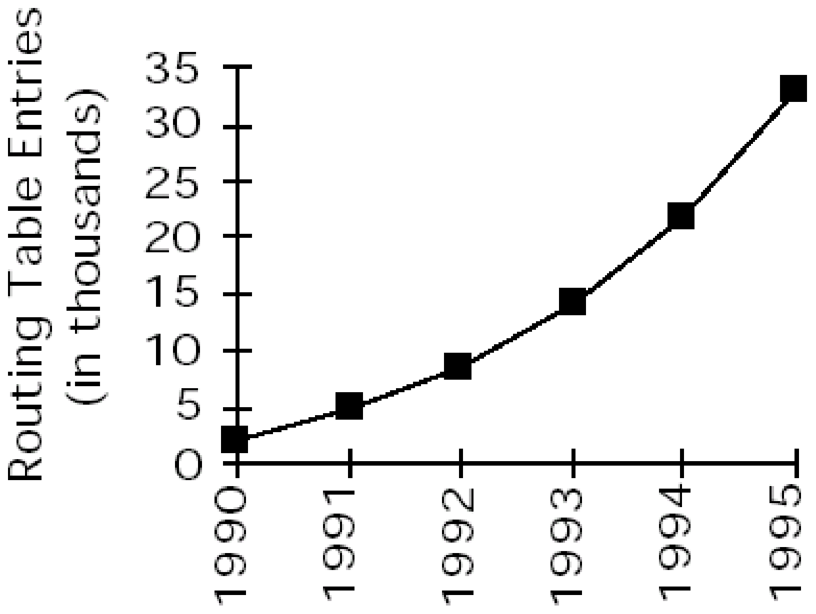
The eventual depletion of the IP address space.



Internet Scaling Problem 2

The rapid growth in the size of the Internet routing

This makes the routers both **slower** (in terms of identifying routes) and **more expensive** (because of the increased routing table capacity)



CIDR -- Classless InterDomain Routing

CIDR was officially documented in September 1993 in RFC 1517, 1518, 1519, and 1520.

CIDR :

- Breaks the rigid boundaries between class A, B, C
  - Allocate IPv4 address more efficiently
- Supports Route Aggregation
  - Single routing entry in the routing table to specify how to route traffic to many individual network addresses.

CIDR -- Classless InterDomain Routing

Superneting Example:

192.60.128.0/24	(11000000.00111100.10000000.00000000)	Class C address
192.60.129.0/24	(11000000.00111100.10000001.00000000)	Class C address
192.60.130.0/24	(11000000.00111100.10000010.00000000)	Class C address
192.60.131.0/24	(11000000.00111100.10000011.00000000)	Class C address
192.60.128.0/22	(11000000.00111100.10000000.00000000)	Supernet
255.255.252.0	(11111111.11111111.11111100.00000000)	Supernet Mask
192.60.131.255	(11000000.00111100.10000011.11111111)	Broadcast address

So classful addresses can easily be written in CIDR notation (Class A = /8, Class B = /16, and Class C = /24)

CIDR Address Blocks Example

CIDR	Dotted-Decimal mask	# of addresses	# of Classful Networks
/13	255.248.0.0	512K	8 Bs or 2048 Cs
/14	255.252.0.0	256K	4 Bs or 1024 Cs
/15	255.254.0.0	128K	2 Bs or 512 Cs
/16	255.255.0.0	64K	1 B or 256 Cs
/17	255.255.128.0.0	32K	128 Cs
/18	255.255.192.0.0	16K	64 Cs
/19	255.255.224.0	8K	32 Cs
/20	255.255.240.0	4K	16 Cs
…			
/24	255.255.255.0	256	1 C
/25	255.255.255.128	128	½ C

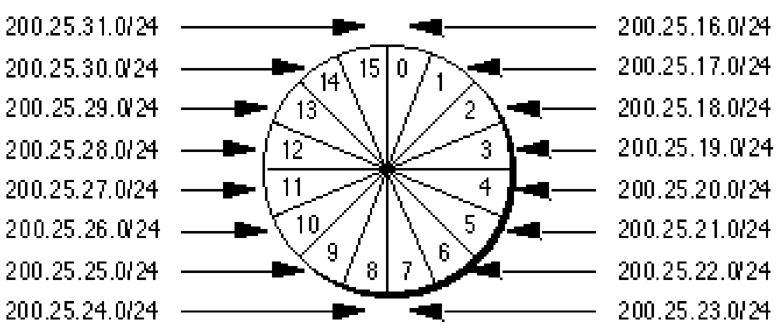
CIDR Address Allocation Example

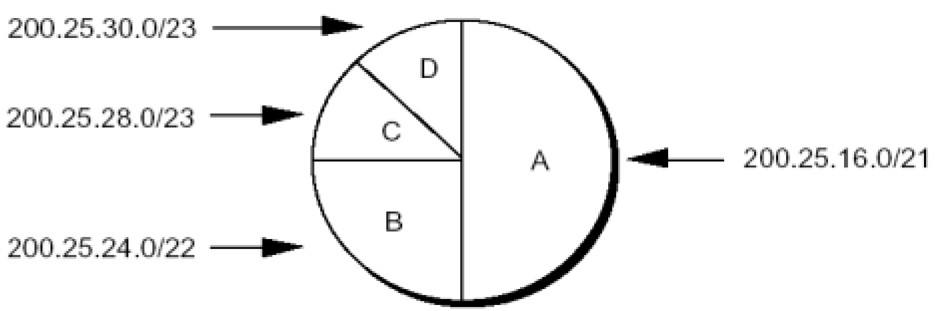
Assume that an ISP owns the address block 200.25.0.0/16.

- This block represents 65, 536 (2^16) IP addresses (or 256 /24s).

If the ISP wants to allocate the 200.25.16.0/20 address block.

- In a classful environment, this smaller block represents 4,096 (2^12) IP addresses (or 16 /24s).
- In a classless environment, the ISP is free to cut up the pie any way it wants.
    - One-half of the address space for Organization A
    - One-fourth of the address space for Organization B
    - One-eight of the address space for Organization C and Organization D





CIDR Example - Continued

Step #1: Divide the address block 200.25.16.0/20 into two equal size slices.
Each block represents one-half of the address space or 2,048 (2^11) IP addresses.

ISP's Block 11001000.00011001.00010000.00000000 200.25.16.0/20
Org A: 11001000.00011001.00010000.00000000 200.25.16.0/21
Reserved: 11001000.00011001.00011000.00000000 200.25.24.0/21

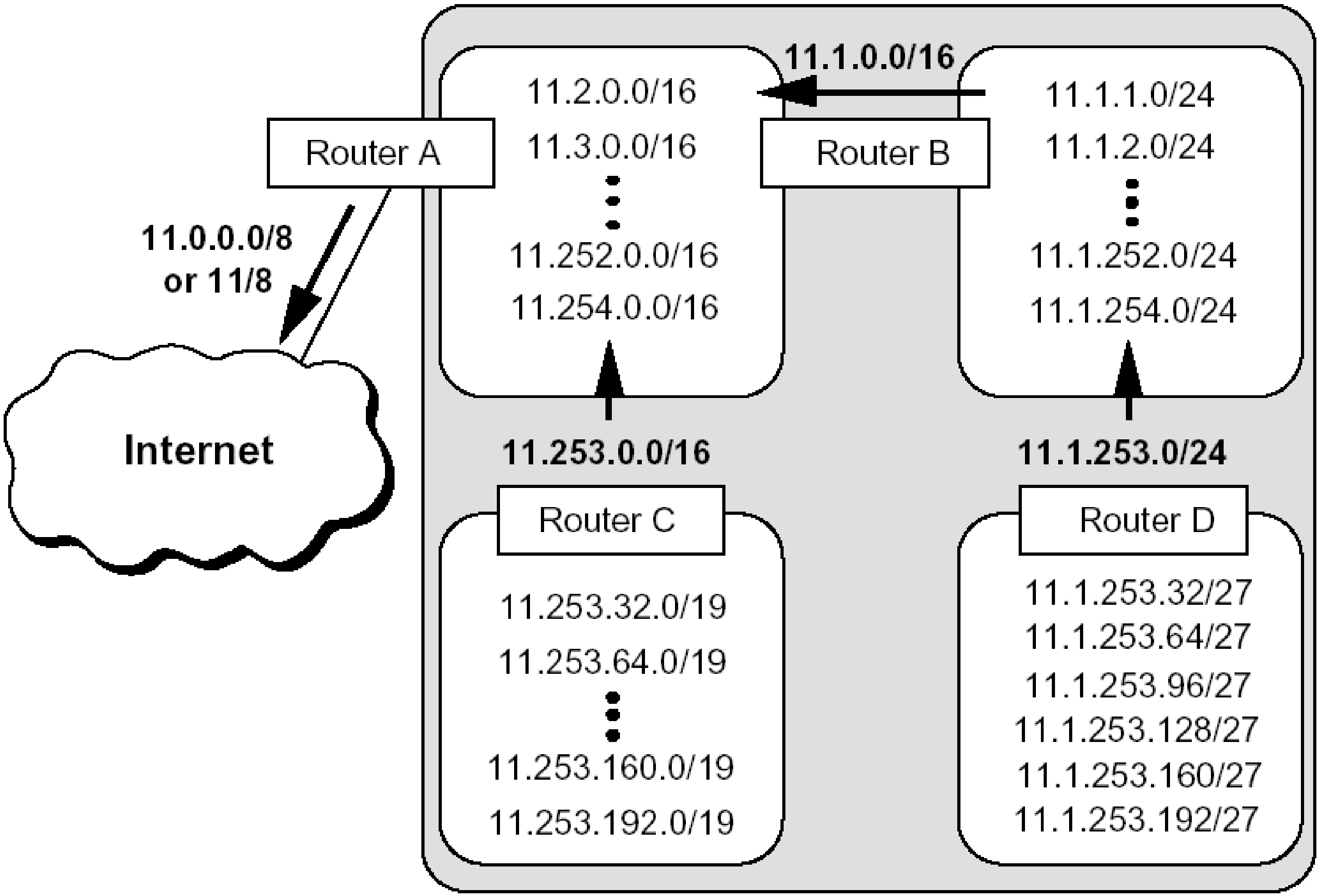
Step #2: Divide the reserved block (200.25.24.0/21) into two equal size slices.
Each block represents one-fourth of the address space or 1,024 (2^10) IP addresses.

Reserved 11001000.00011001.00011000.00000000 200.25.24.0/21
Org B: 11001000.00011001.00011000.00000000 200.25.24.0/22
Reserved 11001000.00011001.00011100.00000000 200.25.28.0/22

Step #3: Divide the reserved address block (200.25.28.0/22) into two equal size blocks.
Each block represents one-eight of the address space or 512 (2^9) IP addresses.

Reserved 11001000.00011001.00011100.00000000 200.25.28.0/22
Org C: 11001000.00011001.00011100.00000000 200.25.28.0/23
Org D: 11001000.00011001.00011110.00000000 200.25.30.0/23

Route Aggregation



Longest Prefix Match Forwarding

- Forwarding tables in IP routers
  - Maps each IP prefix to next-hop link(s)
- Destination-based forwarding
  - Packet has a destination address in the IP Header
  - Router identifies longest-matching prefix

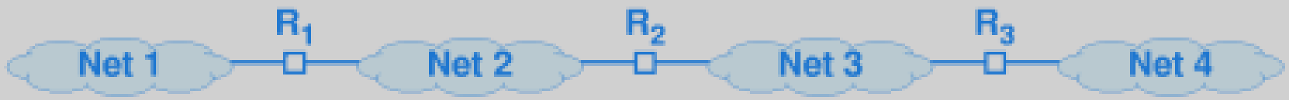
forwarding table

destination
201.10.6.17 →

4.0.0.0/8
4.83.128.0/17
201.10.0.0/21
201.10.6.0/23
126.255.103.0/24

→ outgoing link
Serial0/0.1

IP Forwarding



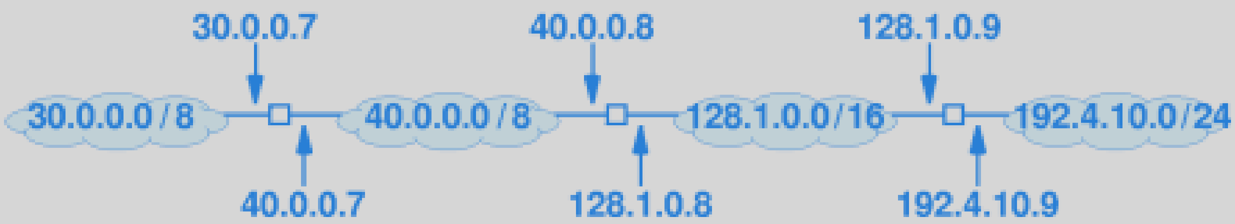
(a)

Destination	Next Hop
net 1	R_1
net 2	deliver direct
net 3	deliver direct
net 4	R_3

(b)

Routing table of R2

IP Forwarding - Continued



(a)

Destination	Mask	Next Hop
30.0.0.0	255.0.0.0	40.0.0.7
40.0.0.0	255.0.0.0	deliver direct
128.1.0.0	255.255.0.0	deliver direct
192.4.10.0	255.255.255.0	128.1.0.9

(b)

Routing table of the center router

Summary

- Protocol Stacks and Layering
- Network Addressing
- Subnetting
- CIDR
- Route Aggregation
- IPv6 is the future?