
University of Colorado Boulder

Fundamentals of Data Communications CSCI 5010

IPv4 Addressing

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Review

IPv4 Addressing

- **IP address**
  - Public & Private

- **Networks and Subnets**
  - Network Number & Broadcast

- **Subnet Masks**
  - Slash notation
    - ***Number of hosts (-2)***

Why IP Addresses?

- They uniquely identify each device on an IP network.
  - ***IP address is to Layer 3, what MAC is to Layer 2***

- Every host (computer, networking device, printer, scanner, peripheral, etc.) must have a unique address.

- IP addresses are assigned by the organization/administer (typically)

IP Address

- IP network addresses consist of two parts:
  - ***network ID***
  - ***host ID***
- Similar to the address of a house:
  - ***The network portion is like the city, state, zip code***
  - ***The host portion is like the house and street number***

- IPv4 addresses have 32 binary bits
  - ***Binary = 0s and 1s***
    - Largest IP address = 255.255.255.255 or 11111111111111111111111111111111
    - Smallest IP address = 0.0.0.0 or 00000000000000000000000000000000

- Divided into four “sections” called octets

- Displayed in dotted decimal format
  - ***192.168.154.218***

Powers of 2

Power of 2	Calculation	Value
2^0		1
2^1	2	2
2^2	2 * 2	4
2^3	2 * 2 * 2	8
2^4	2 * 2 * 2 * 2	16
2^5	2 * 2 * 2 * 2 * 2	32
2^6	2 * 2 * 2 * 2 * 2 *2	64
2^7	2 * 2 * 2 * 2 * 2 *2 * 2	128

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Decimal vs. Binary Numbers

- Decimal numbers are represented by the numbers 0 through 9.
- Binary numbers are represented by a series of 1s and 0s.
  - ***Machines/Computers read binary***

Decimal	Binary
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001

Decimal	Binary
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111
16	10000
17	10001
18	10010
19	10011

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IP Address Format: Dotted Decimal Notation

128 64 32 16 8 4 2 1

	Example			
An IP address is a 32-bit binary number	10101100	00010000	10000000	00010001
For readability, the 32-bit binary number can be divided into four 8-bit octets	10101100	00010000	10000000	00010001
Each octet (or byte) can be converted to decimal	172	16	128	17
The address can be written in dotted decimal notation	172.	16.	128.	17

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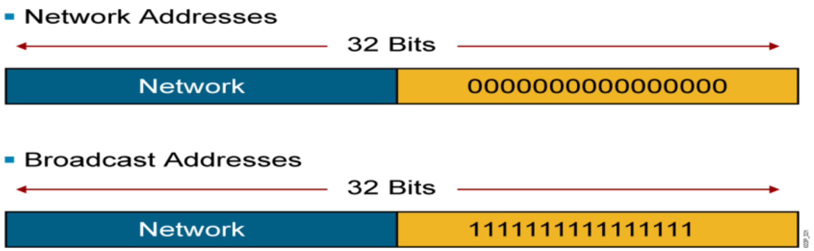
The binary-to-decimal and decimal-to-binary conversion will be detailed later

IP Address

- Certain IP addresses (network and broadcast) are reserved and cannot be assigned to individual network devices.

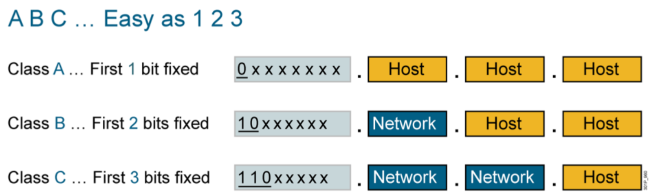


- IP addresses are broken down into ranges called classes

IP Address Classes: The First Octet

A B C … Easy as 1 2 3

Class A … First 1 bit fixed	0 x x x x x x x	. Host	. Host	. Host
Class B … First 2 bits fixed	1 0 x x x x x x	. Network	. Host	. Host
Class C … First 3 bits fixed	1 1 0 x x x x x	. Network	. Network	. Host



IP Address Ranges

IP Address Class	First Octet Binary Value	First Octet Decimal Value	Possible Number of Hosts
Class A	1-126	00000001 to 01111110*	16,777,214
Class B	128-191	10000000 to 10111111	65,534
Class C	192-223	11000000 to 11011111	254

*127 (01111111) is a Class A address reserved for loopback testing and cannot be assigned to a network.

IP Addresses: Public vs. Private

– Internet hosts require a globally unique, public IP address

– Private hosts can have any valid private address that is unique within the private network

Private IP Addresses (RFC 1918)

Class	Private Address Range
A	10.0.0.0 to 10.255.255.255
B	172.16.0.0 to 172.31.255.255
C	192.168.0.0 to 192.168.255.255

Public IP Addresses

Class	Public IP Ranges
A	1.0.0.0 to 9.255.255.255 11.0.0.0 to 126.255.255.255
B	128.0.0.0 to 172.15.255.255 172.32.0.0 to 191.255.255.255
C	192.0.0.0 to 192.167.255.255 192.169.0.0 to 223.255.255.255

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Exercise

Decimal-to-Binary Conversion

$\text{Base}^{\text{Exponent}}$	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Place Value	128	64	32	16	8	4	2	1
Example: Convert decimal 35 to binary	0	0	1	0	0	0	1	1

$35 = 2^5 + 2^1 + 2^0$

$35 = (32 * 1) + (2 * 1) + (1 * 1)$

$35 = 0 + 0 + 1 + 0 + 0 + 0 + 1 + 1$

35 = 00100011

Decimal-to-Binary Conversion

- **128 64 32 16 8 4 2 1**

Binary-to-Decimal Conversion

Base^{Exponent}	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Place Value	128	64	32	16	8	4	2	1
Example: Binary Number	1	0	1	1	1	0	0	1
Decimal Number Total: 185	128	0	32	16	8	0	0	1

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1 0 1 1 1 0 0 1 = (128 * 1) + (64 * 0) + (32 * 1) + (16 * 1) + (8 * 1) + (4 * 0) + (2 * 0) + (1 * 1)
1 0 1 1 1 0 0 1 = 128 + 0 + 32 + 16 + 8 + 0 + 0 + 1
1 0 1 1 1 0 0 1 = 185

Binary-to-Decimal Conversion

- **128 64 32 16 8 4 2 1**

Subnetting and Subnet Masks

- Networks are often divided into smaller subnetworks (subnets)
  - ***Subnets can improve network performance, management, and security***
    - Broadcast domain

- A subnet address extends the network portion
  - ***Borrows bits from the original host portion and designates them as the subnet field***

- Determining the optimal number of subnets and hosts depends on the type of network and the number of host addresses required.

IP Address Class	First Octet Binary Value	First Octet Decimal Value	Possible Number of Hosts
Class A	1-126	00000001 to 01111110*	16,777,214
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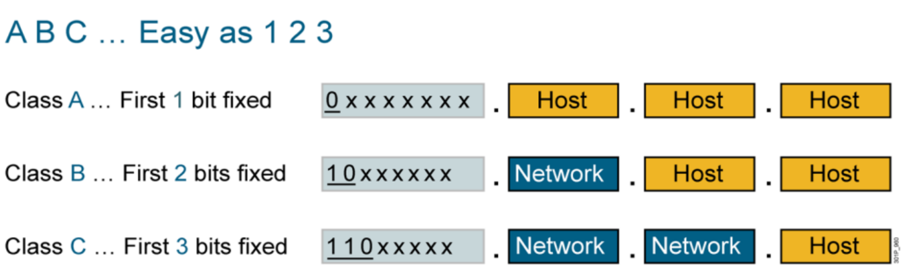
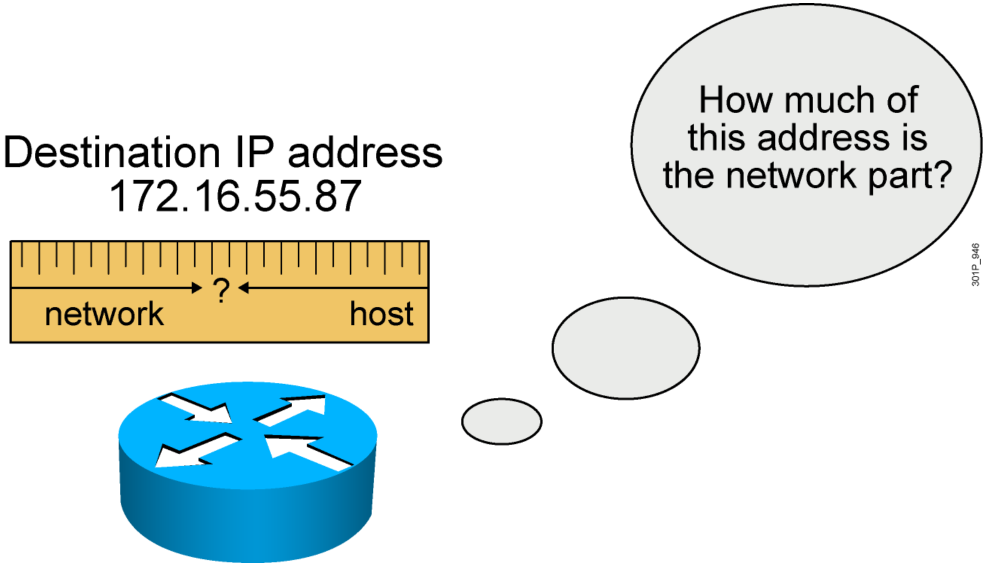


Subnetting and Subnet Masks

- Subnet mask
  - ***The "tool" that the router uses to determine which bits are routing (network and subnet) bits and which bits are host bits.***
- End systems use subnet masks to compare the network portion of the local network addresses with the destination addresses of the packets to be sent.
- Routers use subnet masks to determine if the network portion of an IP address is on the corresponding routing table or if the packet needs to be sent to the next router.

What does a Subnet Mask do?

- Tells the router the number of bits to look at when routing
- Defines the number of bits that are significant
- Used as a measuring tool, not to hide anything



Octet Values of a Subnet Mask

128	64	32	16	8	4	2	1		
1	0	0	0	0	0	0	0	=	128
1	1	0	0	0	0	0	0	=	192
1	1	1	0	0	0	0	0	=	224
1	1	1	1	0	0	0	0	=	240
1	1	1	1	1	0	0	0	=	248
1	1	1	1	1	1	0	0	=	252
1	1	1	1	1	1	1	0	=	254
1	1	1	1	1	1	1	1	=	255

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Subnet masks, like IP addresses, are represented in the dotted decimal format like 255.255.255.0

Slash Notation or (CIDR)

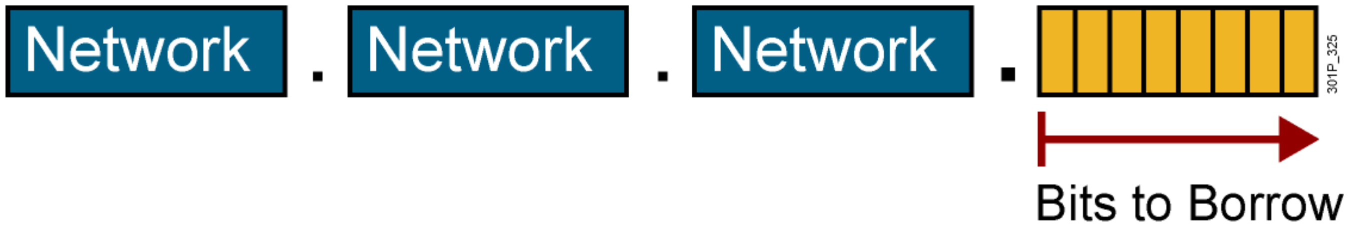
Bits used for mask	Default netmask	Subnet binary
/8	255.0.0.0	11111111.00000000.00000000.00000000
/16	255.255.0.0	11111111.11111111.00000000.00000000
/24	255.255.255.0	11111111.11111111.11111111.00000000

128 64 32 16 8 4 2 1

Network: 172.16.56.0
Computer 1: 172.16.56.40
Computer 2: 172.16.56.55
Printer 1: 172.16.56.100

IP address: 172.16.56.40
Mask: 255.255.255.0
Binary mask: 11111111.11111111.11111111.00000000

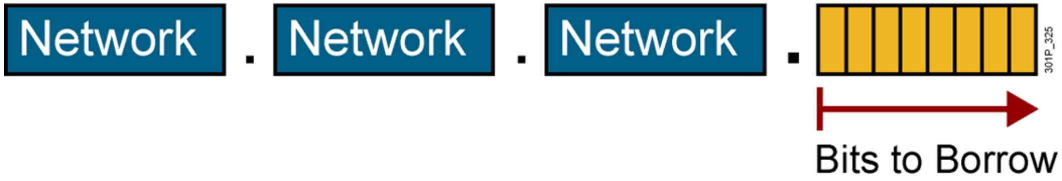
Possible Subnets and Hosts for a Class C Network



Number of Bits Borrowed (s)	Number of Subnets Possible (2^s)	Number of Bits Remaining in Host ID (8 - s = h)	Number of Hosts Possible Per Subnet (2^h - 2)
1	2	7	126
2	4	6	62
3	8	5	30
4	16	4	14
5	32	3	6
6	64	2	2
7	128	1	2

Power of 2	Calculation	Value
2^0		1
2^1	2	2
2^2	2 * 2	4
2^3	2 * 2 * 2	8
2^4	2 * 2 * 2 * 2	16
2^5	2 * 2 * 2 * 2 * 2	32
2^6	2 * 2 * 2 * 2 * 2 *2	64
2^7	2 * 2 * 2 * 2 * 2 *2 * 2	128

How many Networks or Hosts?

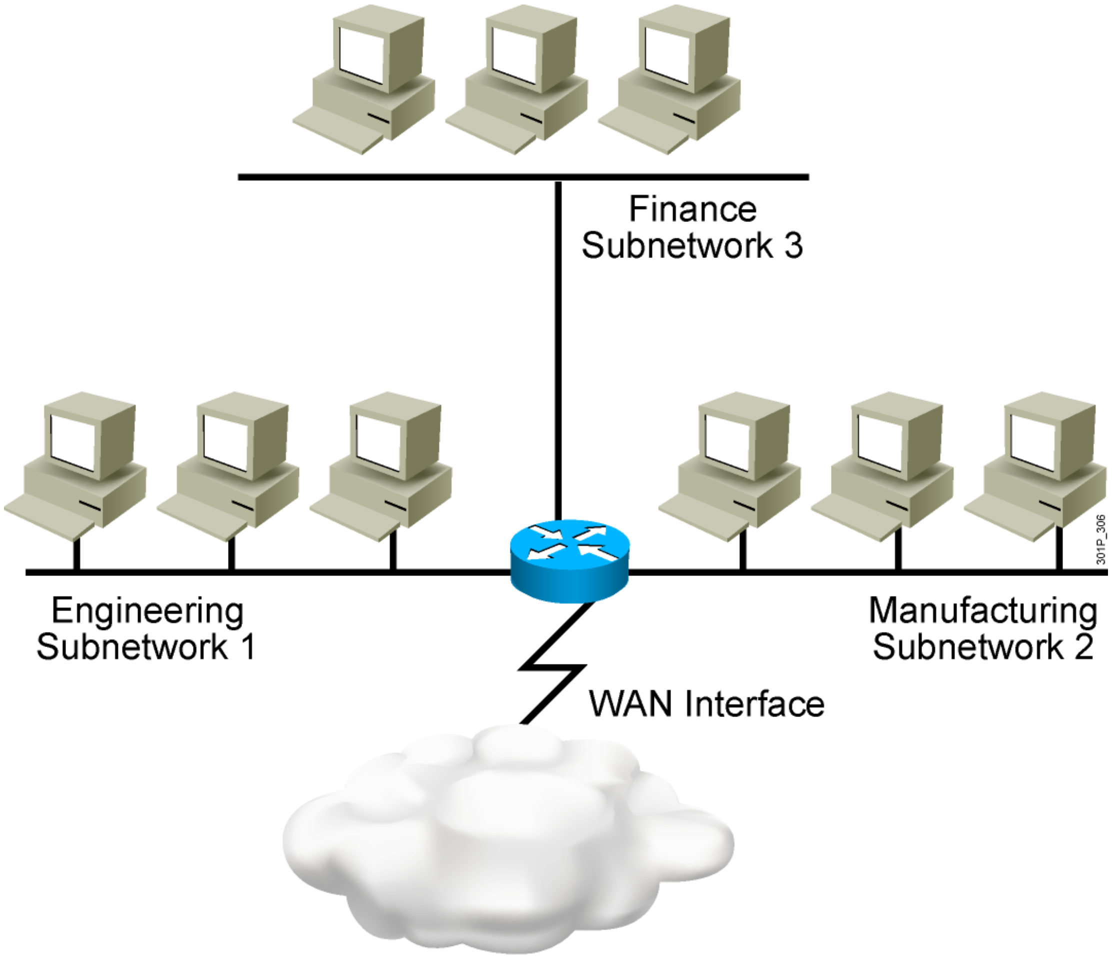


Power of 2	Calculation	Value
2^0		1
2^1	2	2
2^2	2 * 2	4
2^3	2 * 2 * 2	8
2^4	2 * 2 * 2 * 2	16
2^5	2 * 2 * 2 * 2 * 2	32
2^6	2 * 2 * 2 * 2 * 2 *2	64
2^7	2 * 2 * 2 * 2 * 2 *2 * 2	128

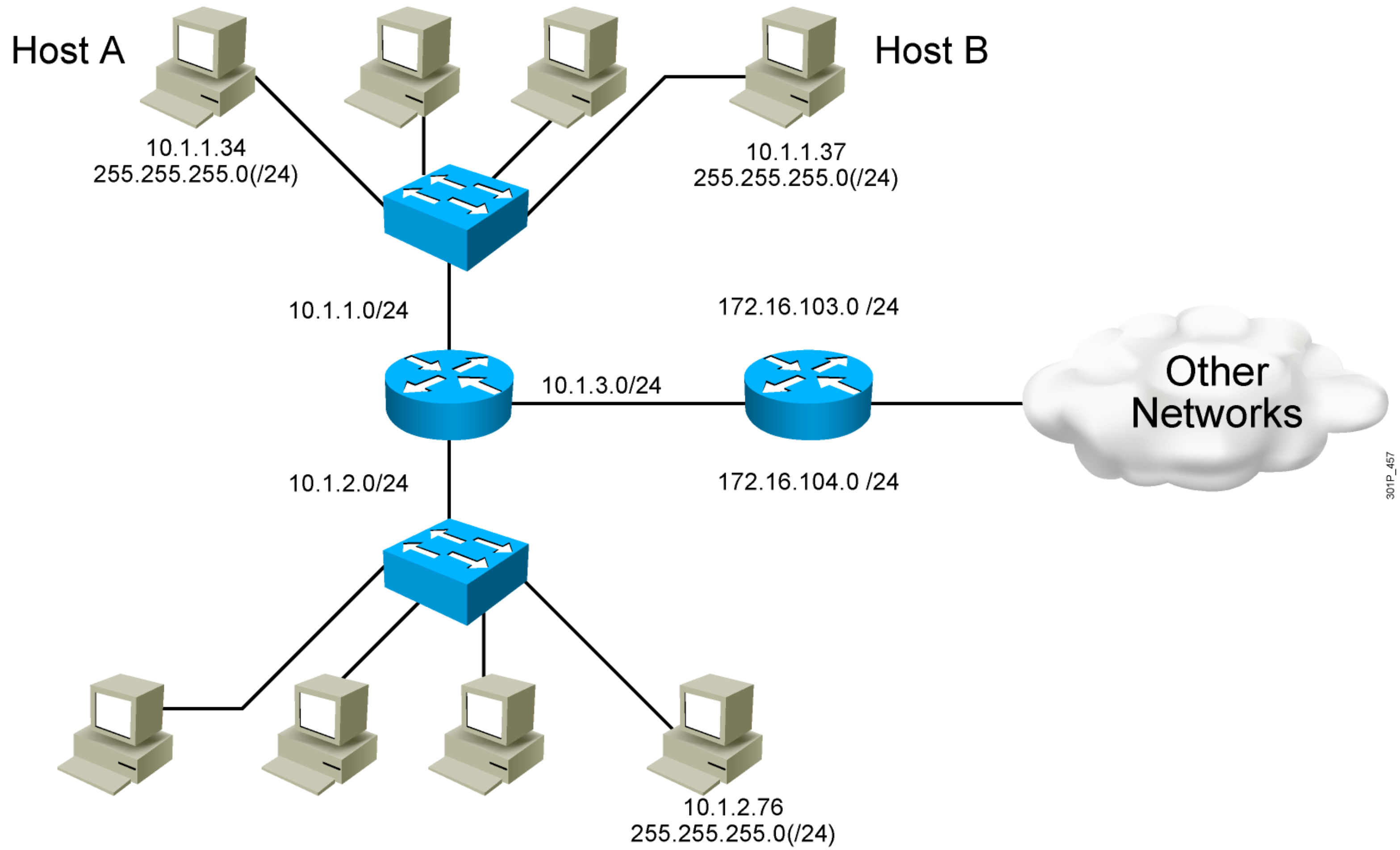
128 64 32 16 8 4 2 1

Subnetworks (Subnets)

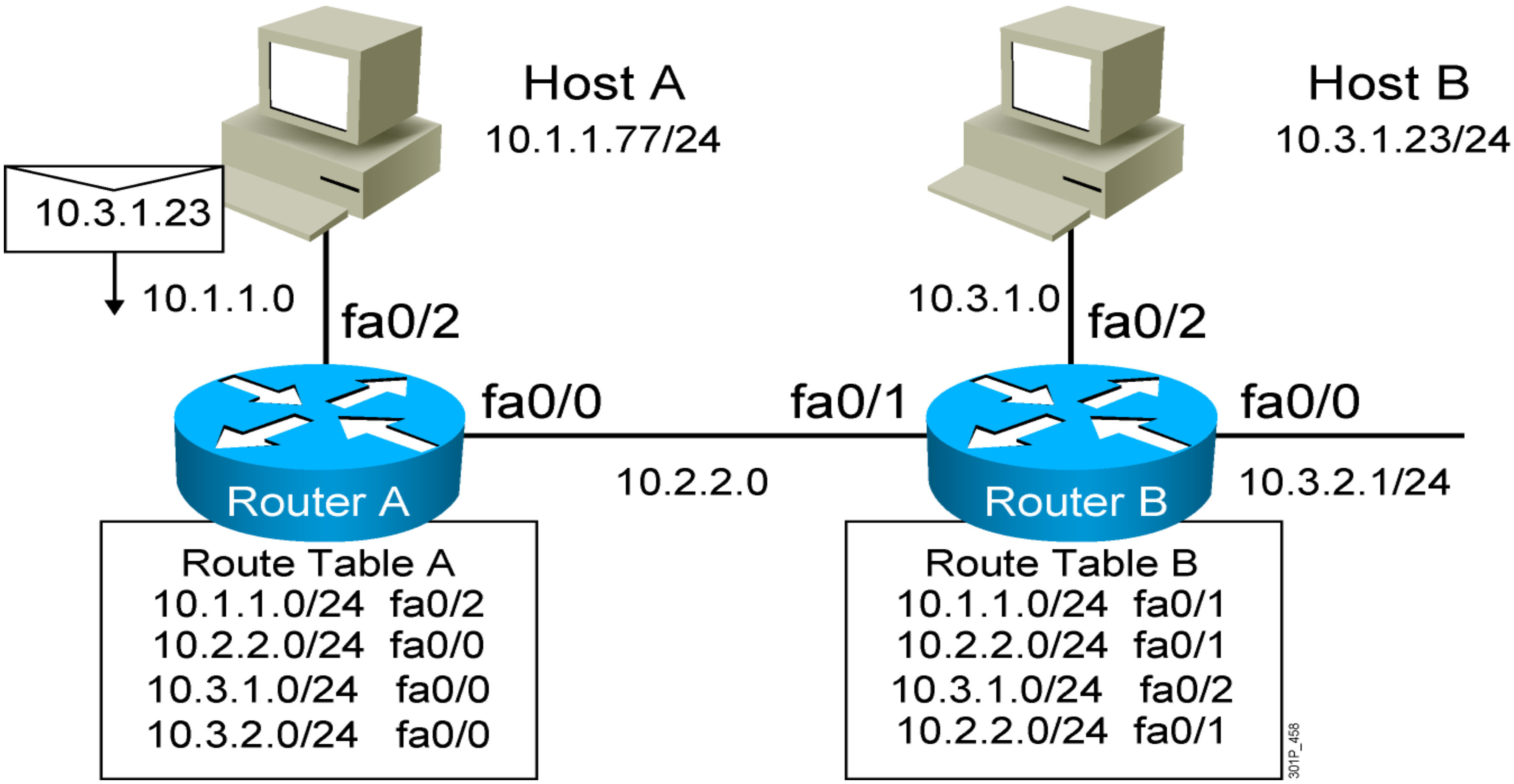
- Smaller networks are easier to manage.
- Overall traffic is reduced.
- You can more easily apply network security policies.



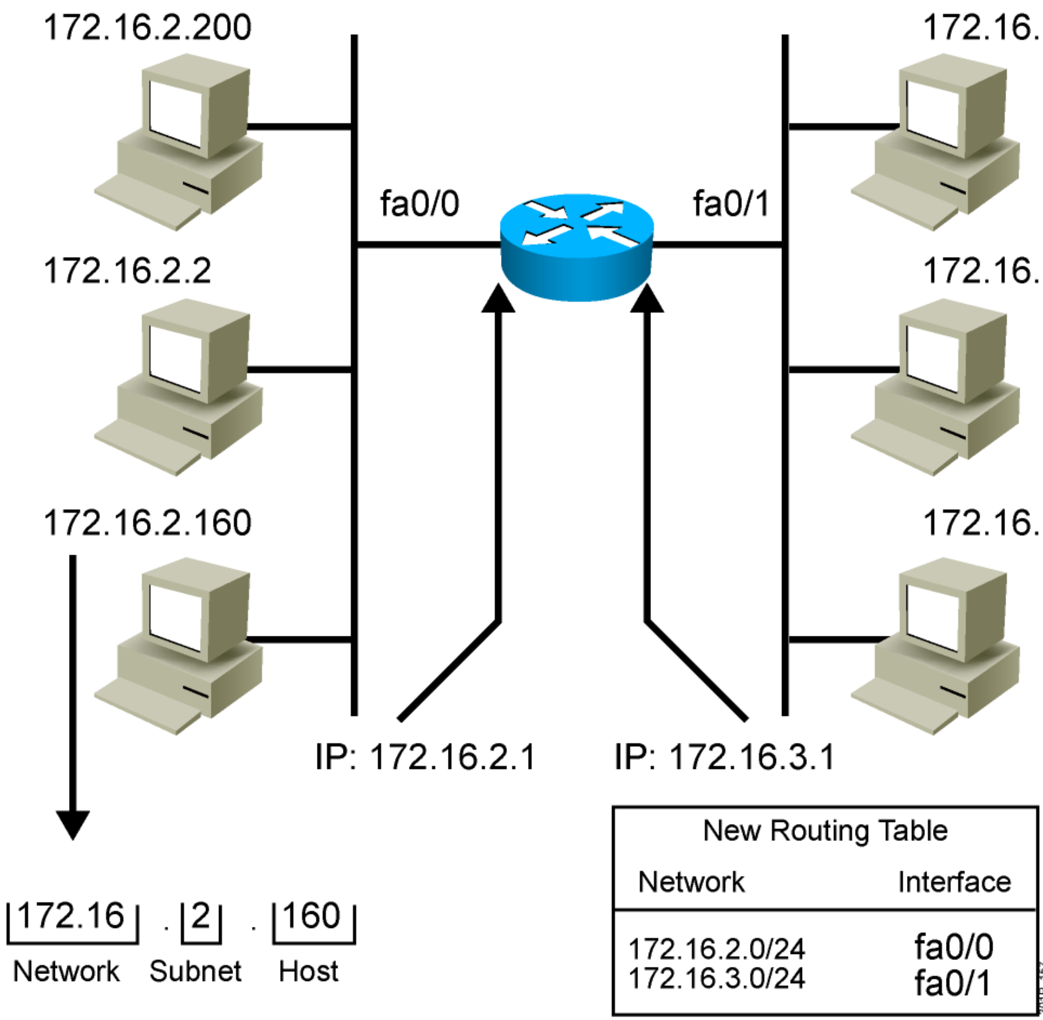
End System Subnet Mask Operation



How Routers Use Subnet Masks

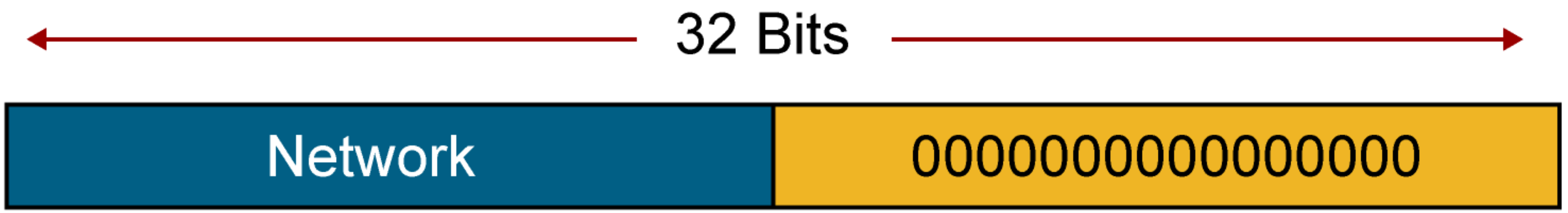


Applying the Subnet Address Scheme

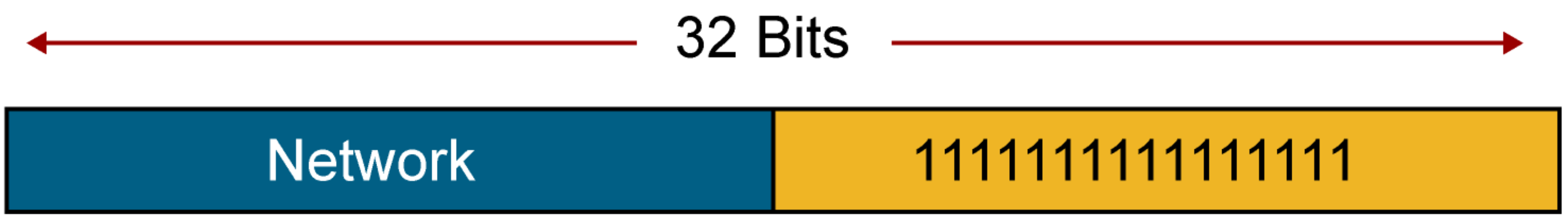


*Remember: Reserved Address

- Network Addresses



- Broadcast Addresses



Eight Easy Steps for Determining Subnet Addresses

IP Address: 192.168.221.37 Subnet Mask /29

Step	Description	Example
1.	Write the octet that is being split in binary.	Fourth octet: 00100101
2.	Write the mask or classful prefix length in binary.	Assigned mask: 255.255.255.248 (/29) Fourth octet: 11111000
3.	Draw a line to delineate the significant bits in the assigned IP address. Cross out the mask so you can view the significant bits in the IP address.	Split octet (binary): 00100|101 Split mask (binary): 11111|000

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Eight Easy Steps for Determining Subnet Addresses (Cont.)

Step	Description	Example
4.	Copy the significant bits four times.	00100 000 (network address) 00100 001 (first address in subnet) 00100 110 (last address in subnet) 00100 111 (broadcast address)?
5.	In the first line, define the network address by placing all zeros in the significant bits.	
6.	In the last line, define the broadcast address by placing all ones in the significant bits.	**Completed Subnet Addresses** Network address: 192.168.221.32 Subnet mask: 255.255.255.248 First subnet: 192.168.221.32 First host address: 192.168.221.33 Last host address: 192.168.221.38 Broadcast address: 192.168.221.39 Next subnet: 192.168.221.40
7.	In the middle lines, define the first and last host number.	
8.	Increment the subnet bits by one.	00101 000 (next subnet)

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Example: Applying a Subnet Mask for a Class C Address

IP Address 192.168.5.139   Subnet Mask 255.255.255.224

IP Address	192	168	5	139	
IP Address	11000000	10101000	00000101	10001011	
Subnet Mask	11111111	11111111	11111111	11100000	/27
Subnetwork	11000000	10101000	00000101	10000000	
Subnetwork	192	168	5	128	
First Host	192	168	5	10000001=129	
Last Host	192	168	5	10011110=158	
Directed Broadcast	192	168	5	10011111=159	
Next Subnet	192	168	5	10100000=160	

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Subnet Calculator

- **You must know the following:**
  - What is an IP address?
  - Why and how is it used?
  - What is a subnet?
  - What is a subnet mask?
  - How is a subnet mask used?

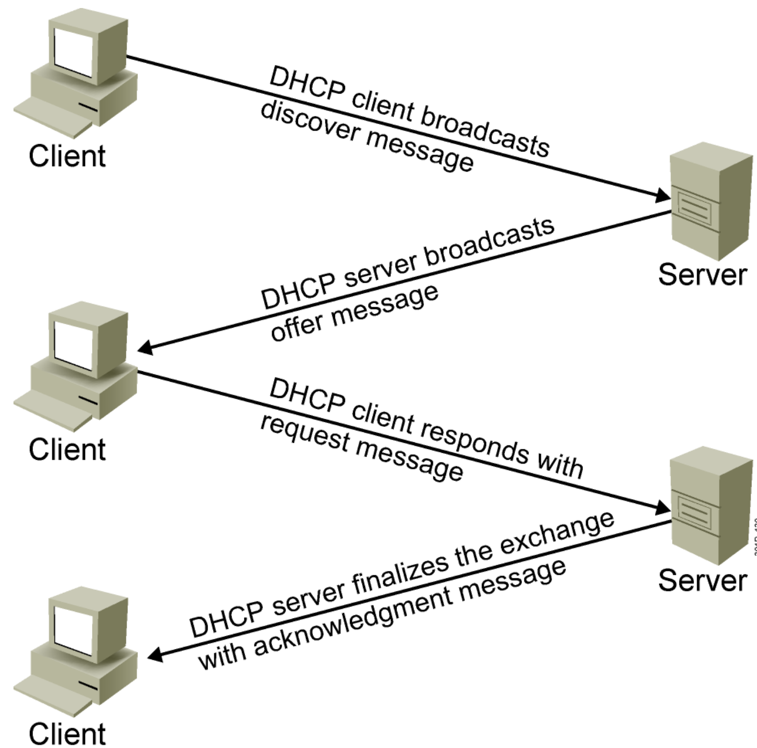
- **Use a subnet calculator**

Dynamic Host Configuration Protocol (DHCP)

- **Every device needs an IP address**
  - Used to be manual on every machine
- **Dynamically assigns IP addresses**
  - IP address
  - Subnet mask
  - Default-gateway
  - Primary DNS server
  - Secondary DNS server
- **Server service**
  - Windows, Linux, Router
- **UDP**
  - Ports 67 & 68

DHCP – (DORA)

- **Client**
  - Discover Request – (Broadcast)
- **Server**
  - Offer
- **Client**
  - Request
- **Server**
  - Acknowledgement



IPv6 Summary

- **128 Bits**
- **No broadcasts**
- **Not compatible with IPv4**
- **Dual Stack**
- **Address Compression Strategies**
- **Link-local and global addresses**

Why IPv6

- **IPv4 address depletion**
  - Developing countries
  - Mobile IP
  - IoT
  - Rise in price of v4 addresses (commodity)
  - NAT workarounds

- **End-to-end connectivity**

- **Security**

Barriers to IPv6

- **Not compatible with IPv4**
- **IPv6 Security**
  – Firewalls
  – Tunneling
- **Trained and experienced professionals to support IPv6**
- **Buy in**
  – ISP vs. Business

IPv4 and IPv6 Comparison

Feature	IPv4	IPv6
IP Address Length	32 bits	128 bits
IP Security (IPSec) Header Support	Optional	On through traffic
Prioritized Delivery Support	Some	Expanded
Packet Fragmentation	Performed by hosts and routers	Performed by hosts only
Minimum MTU	576 bytes	1280 bytes
Checksum in Packet Header	Yes	No
Options in Packet Header	Yes	No
Link-Layer Address Resolution	ARP (broadcast)	Multicast ND messages
Multicast Membership Protocol	Internet Group Management Protocol (IGMP)	Multicast Listener Discovery (MLD)
Router Discovery	Optional	Required
Uses Broadcast Messages	Yes	No
Configuration	Manual, Dynamic Host Control Protocol (DHCP)	Manual, Automatic, DHCP version 6 (DHCPv6)
Domain Naming System (DNS) Queries	Uses A records	Uses AAAA records
DNS Reverse Queries	Uses IN-ADDR.ARPA	Uses IP6.ARPA

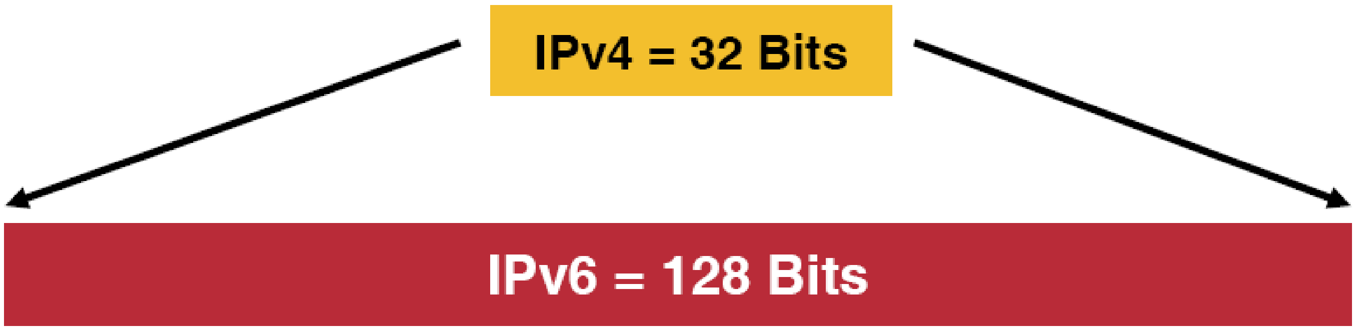
Transition Mechanisms

- **Dual stack**
  - Both stacks can operate independently or in parallel
- **Tunneling**
  - ISATAP
  - Teredo
  - 6to4
  - 6over4
  - 6rd (IPv6 Rapid Deployment)
- **Transition**
  - NAT64

IPv6 Advantages

- **Increased address space**
- **Streamlined IP header**
- **End-to-end connectivity**
- **Removal of IP broadcasts**
- **Mobile IPv6**

Addressing



•IPv4 - 32 bits, 2^{32}

=~ 4,200,000,000 possible addressable nodes

•IPv6 - 128 bits, 2^{128}

= 340,282,366,920,938,463,463,374,607,431,768,211,456 nodes

IPv6 Address Syntax

- IPv6 address in binary form
  - 0010000000000001000011011011100000000 0000000000000101111001110110 00000010101010100000000011111111111111 10001010001001110001011010

- Divided along 16-bit boundaries
  - 0010000000000001   0000110110111000 0000000000000000   0010111100111011 0000001010101010   0000000011111111 1111111000101000   1001110001011010

IPv6 Address Syntax

- **Each 16-bit block is converted to hexadecimal and delimited with colons**
  - Each 16-bit block is called a hextet
  - 2001:0DB8:0000:2F3B:02AA:00FF:FE28:9C5A

- **Leading zeroes in any 16-bit hextet can be omitted (or reduced)**
  - 2001:0DB8:0000:2F3B:02AA:00FF:FE28:9C5A
  - 2001:DB8:0:2F3B:2AA:FF:FE28:9C5A

Addressing Tricks – Compressing Zeros

- **A single contiguous sequence of 16-bit blocks set to 0 can be compressed to "::" (double-colon)**
  - Example:
    - ***FE80:0:0:0:2AA:FF:FE9A:4CA2 becomes FE80::2AA:FF:FE9A:4CA2***
    - ***FF02:0:0:0:0:0:0:2 becomes FF02::2***
    - ***FF02:0:0:0:0:0:0:0 becomes FF02::***
  - Double-colon "::" can appear once in an address
  - Cannot use zero compression (double-colon) to include part of a 16-bit block
    - ***FF02:30:0:0:0:0:0:5 does not become FF02:3::5, but FF02:30::5***

Addressing Tricks – Compressing Zeros

- **A hextet with all zeros can be reduced to a single zero**
  - This is used when the double-colon has already been used
    - ***2001:DB8::12:0000:0000:FE becomes 2001:DB8::12:0:0:FE***

- **Typically, upper vs. lower case doesn't matter**

IPv6 Challenges

- **IPv6 awareness**
- **Measuring adoption**
- **Security**
- **Security Tools**

Questions?

Lab

Appendix

Time Savers: Subnet number

- **“Magic number” Strategy**
  - Use mask to determine trouble byte
    - ***/10 255. 1100 0000 . 0. 0***
    - ***/20 255.255. 1111 0000 .0***
    - ***/14 255. 1111 1100 .0.0***
    - ***/29 255.255.255. 1111 1000***
  - Determine decimal value of such
    - ***192***
    - ***240***
    - ***252***
    - ***248***

Time Savers: Subnet number

- **"Magic number" Strategy … cont**
  - Subtract decimal value from 256
    - ***256 - 192 = 64***
    - ***256 - 240 = 16***
    - ***256 - 252 = 4***
    - ***256 - 248 = 8***

Magic Number

  - Find multiple of magic number closer but not greater than IP address value on similar octet, each multiple is a valid subnet
    - ***100.100.100.100 /17***
      - 255.255.1000 0000.0   128 256-128 = 128
      - Subnets 0 and 128
      - 100.100.0.0 is the subnet number

Time Savers: Subnet number

- **More examples**
  - ***100.100.100.100 /18***
    - 255.255.1100 0000.0   192   256-192 = 64
    - Subnets 0, 64, 128, 192
    - 100.100.64.0 is the subnet number

  - ***100.100.100.100 /19***
    - 255.255.1110 0000.0   224   256-224 = 32
    - Subnets 0, 32, 64, 96, 128, 160, 192, 224
    - 100.100.96.0 is the subnet number

  - ***100.100.100.100 /20***
    - 255.255.1111 0000.0   240   256-240 = 16
    - Subnets 0, 16, 32, 48, 64, 80, 96, 112, 128……
    - 100.100.96.0 is the subnet number

Time Savers: Subnet Broadcast

- ***100.100.100.100 /18***
  - 255.255.1100 0000.0   192   256-192 = 64
  - Subnets 0, 64, 128, 192
  - 100.100.64.0 is the subnet number
  - 100.100.127.255 is the subnet broadcast address

- ***100.100.100.100 /19***
  - 255.255.1110 0000.0   224   256-224 = 32
  - Subnets 0, 32, 64, 96, 128, 160, 192,224
  - 100.100.96.0 is the subnet number
  - 100.100.127.255 is the subnet broadcast address

- ***100.100.100.100 /20***
  - 255.255.1111 0000.0   240   256-240 = 16
  - Subnets 0, 16, 32, 48, 64, 80, 96, 112, 128……
  - 100.100.96.0 is the subnet number
  - 100.100.111.255 is the subnet broadcast address