计算机网络

10. Internetworking and IP Addressing

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PART III Internetworking

Ch 17 Internetworking: Concepts, Architecture, and Protocols

网络互联：概念、结构与协议

20.2 The Motivation for Internetworking

- 需求：一个网络技术，适应不同应用场景
  - 假设某组织有不同的网络，为其选择不同的物理网络类型
    - connecting computers and site: Ethernet
    - connect sites across cities: a leased (租用) data circuit
- 现状
  - 各自为政：近距离LAN技术，远距离WAN技术
  - No single networking technology is best for all needs!

17.3 The Concept of Universal Service

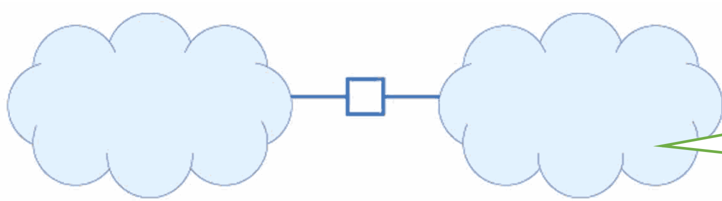
- 相同网络类型的主机才能通信，网络变成孤岛
- **Universal service (通用服务)** allows arbitrary pairs of computers to communicate.
  - 统一网络技术 v.s. 多个网络技术、统一网络服务？
  - 网络间的不兼容使得仅通过导线连接不同网络是不可能的
  - Extension techniques such as **bridging (桥接) cannot be used with heterogeneous network technologies**
    - 因为帧格式不一样

17.5 Internetworking

- **Internetworking (网络互联)**
  - universal service among heterogeneous networks
  - The scheme uses both hardware and software
  - The resulting system of connected physical networks is known as an **internetwork** or **internet (互联网)**
- An internet is not restricted in size. 网可大可小

17.6 Physical Network Connection with Routers

- **The basic hardware component used to connect heterogeneous network is a router (路由).**
  - an independent hardware system dedicated to the task of interconnecting networks
  - contains a processor and memory as well as a separate I/O interface for each network to which it connects
  - connect two LANs; a LAN and a WAN; or two WANs



cloud to depict each network
云说明网络类型不必相同

Figure 20.1 Two physical networks connected by a router, which has a separate interface for each network connection. Computers can attach to each network.

17.7 Internet Architecture

- Routers
  - connect arbitrary physical networks into an internet
    - Commercial routers can connect more than 2 networks
  - There are reasons for multiple connections:
    - Load-balancing and speed
    - Redundancy improves internet reliability

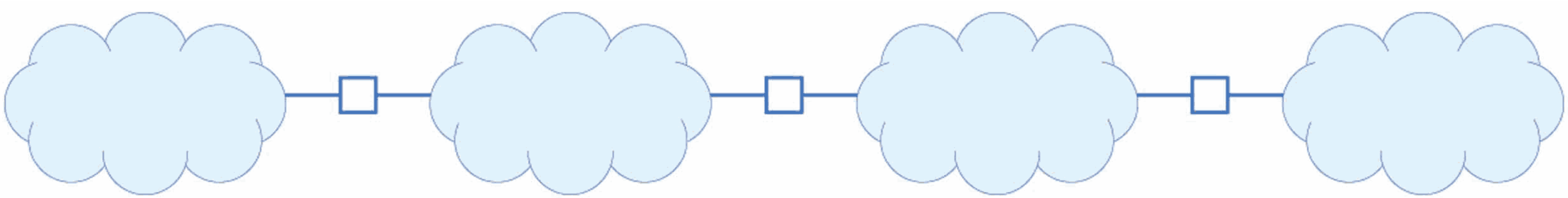


Figure 20.2 An internet formed by using three routers to interconnect four physical networks.

20.7 Internet Architecture

- An organization must choose a design that meets the organization's need for
  - Reliability; Capacity; Cost
- The exact details of internet topology to be chosen often depend on the following
  - bandwidth of the physical networks
  - expected traffic
  - organization's reliability requirements
  - cost
  - performance of available router hardware

17.8 Achieving Universal service

- Routers must agree to forward information
- The task is complex because
  - frame formats and addressing schemes used by the underlying networks can differ
- Protocol software makes universal service possible
  - when written with an uppercase I, the term Internet refers to the current global Internet and the associated protocols
- Internet protocols overcome differences in frame formats and physical addresses
  - to make communication possible among networks that use different technologies

20.9 A Virtual Network

- Internet provides the appearance of a single seamless communication system
  - a combination of hardware and software provides the illusion of a uniform network system
- Internet software hides the details of
  - physical network connections
  - physical addresses
  - routing information

20.9 A Virtual Network

- Users or apps are not supposed to be aware of the underlying phys. networks or the routers that connect
  - We say that an internet is a virtual network system because the communication system is an abstraction
- Fig. 20.3: virtual network concept, physical structure

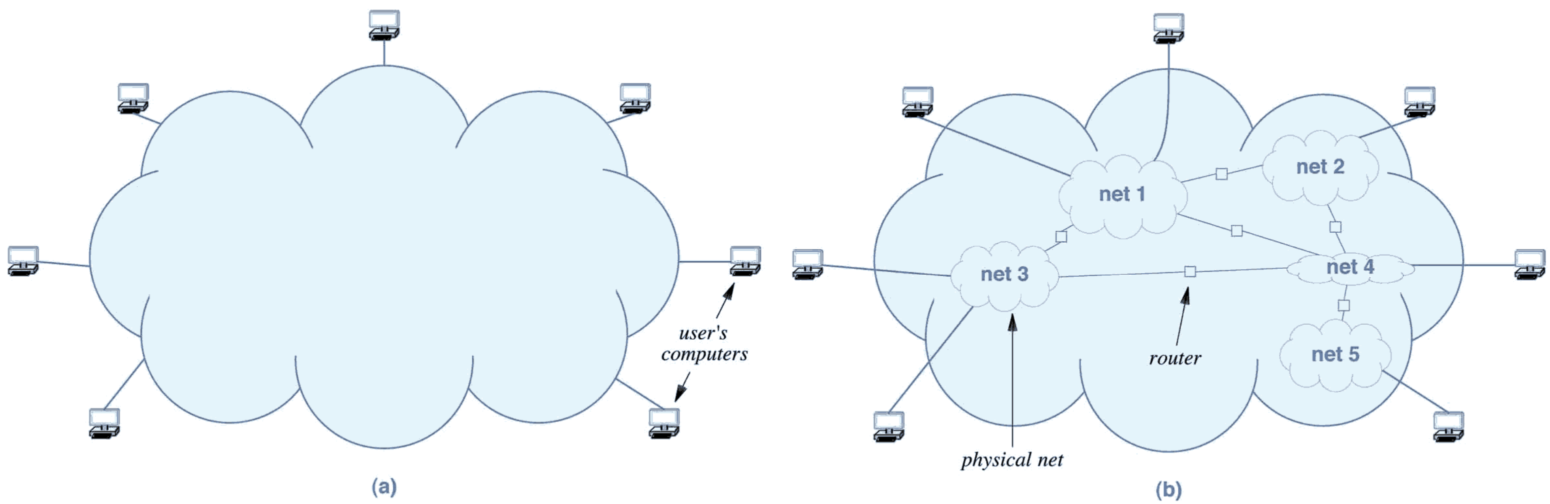


Figure 20.3 The Internet concept. (a) The illusion of a single network provided to users and applications, and (b) the underlying physical structure with routers interconnecting networks.

17.10 Protocols for Internetworking

- The TCP/IP (Transmission Control Protocol and the Internet Protocol) suite
  - Several protocols have been proposed for use with internets
  - acronyms for two of the most important protocols
- TCP/IP was developed at the same time as the Internet
  - The same researchers who proposed TCP/IP also proposed the Internet architecture described above
  - Work on TCP/IP began in the 1970s,
    - approximately the same time that LANs were being developed
  - Work continued until the early 1990s
    - when the Internet became commercial

20.11 Review of TCP/IP Layering

- We have already explored three of the layers
- Chapters in this part of the text consider the two remaining layers in detail:
  - Layer Internet
    - Layer 3 (IP) specifies the format of packets sent across the Internet
    - Also specifies mechanisms used to forward packets
  - Layer Transport
    - Layer 4 (TCP) specifies the messages
    - Provides procedures that are used to insure reliable transfer

17.13 Host computers, Routers, and Protocol Layers

- Host computer to refer to any computer system that connects to an internet and runs applications.
- Both hosts and routers need TCP/IP protocol software.
  - Routers do not use protocols from all layers.
- A host can be as small as a cell phone or as large as a mainframe
  - a host's CPU can be slow or fast
  - the memory can be large or small
  - and the network can operate at high or low speed

17.13 Host computers, Routers, and Protocol Layers

- TCP/IP protocols make it possible for any pair of hosts to communicate
  - despite hardware differences
- Both hosts and routers need TCP/IP protocol software
  - However, routers do not use protocols from all layers
    - a router does not need layer 5 protocols
    - because routers do not run conventional applications

PART III Internetworking

Ch 18 IP: Internet Protocol Addresses

IP：互联网协议地址

从硬件到软件

- 物理层次：异构网络的编址“各自为政”
- 软件层次：需要一个编址来隐藏异构的物理细节
- 相互独立

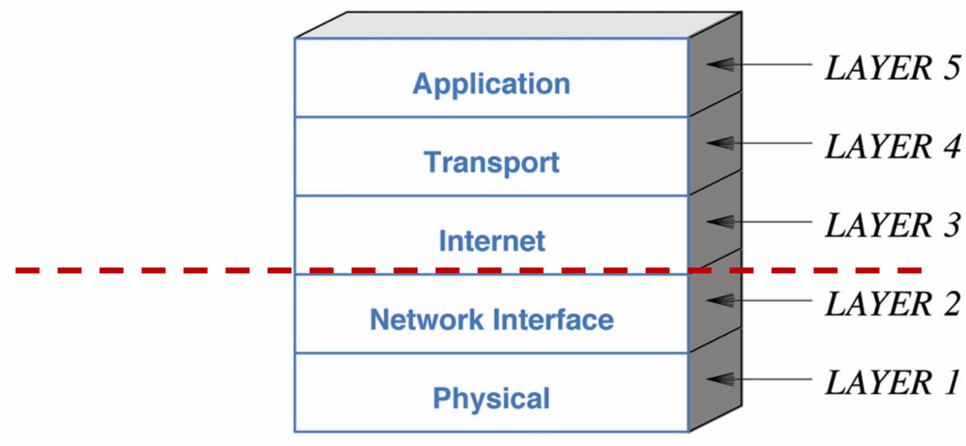


Figure 1.1 The layering model used with the Internet protocols (TCP/IP).

21.2 Addresses for the Virtual Internet

- To achieve a seamless communication system
  - protocol software must hide the details of physical networks
  - it should offer the illusion of a single, large network
- From the point of view of an application
  - the virtual Internet operates like any network
    - allowing computers to send and receive packets
- The main difference between the Internet and a physical network is
  - that the Internet is an abstraction imagined by its designers and created entirely by protocol software

21.2 Addresses for the Virtual Internet

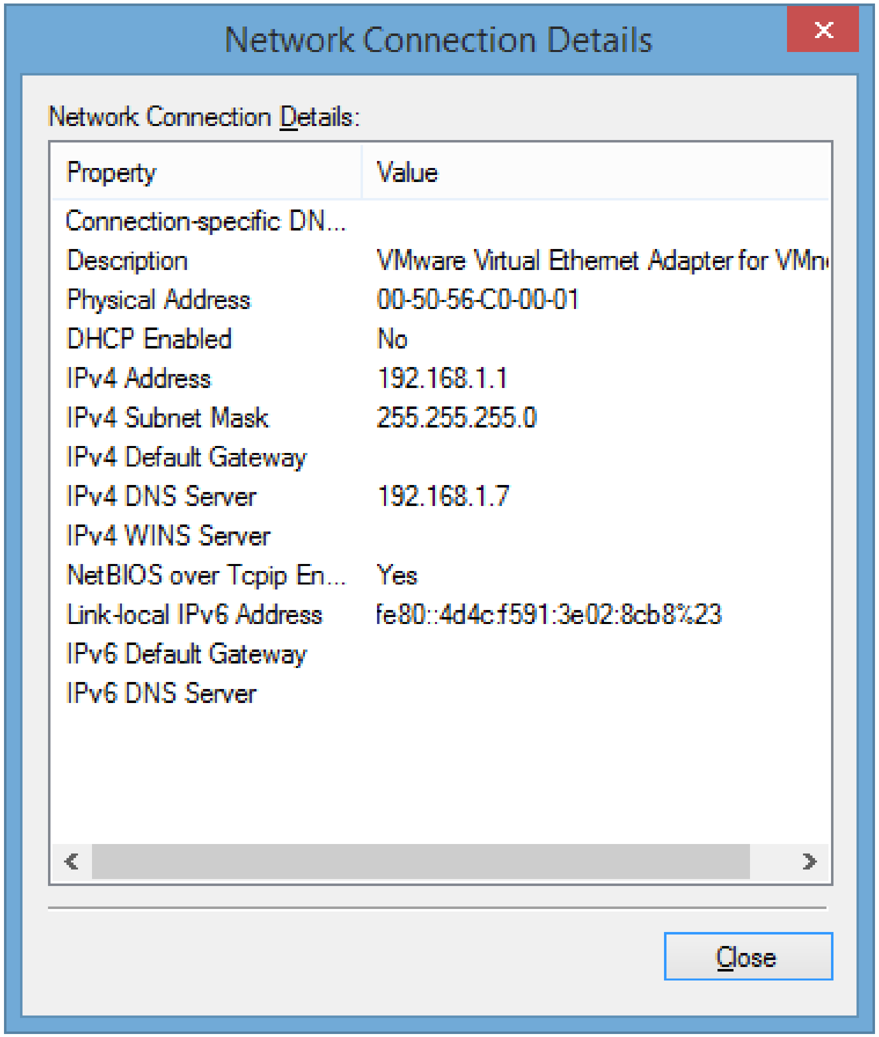
- Thus, the designers chose
  - addresses, packet formats, and delivery techniques independent of the details of the underlying hardware
- Addressing is a critical component of the Internet
- All host computers must use a uniform addressing scheme
- Each address must be unique

21.2 Addresses for the Virtual Internet

- MAC addresses do not suffice because
  - the Internet can include multiple network technologies
  - and each technology defines its own MAC addresses
- The advantage of IP addressing lies in uniformity:
  - an arbitrary pair of application programs can communicate without knowing the type of network hardware or MAC addresses being used
- IP addresses are supplied by protocol software
  - They are not part of the underlying network
- Many layers of protocol software use IP addresses

21.3 The IP Addressing Scheme

- **In the TCP/IP protocol stack, addressing is specified by the Internet Protocol (IP) .**
- **Each host is assigned a unique 32-bit number**
  - **known as the host's IP address or Internet address**
- **To transmit information across a TCP/IP internet, a computer must know the IP address of the remote computer to which the information is being sent.**



IP地址

192.168.1.1

21.4 The IP Address Hierarchy

- IP address (IP地址) 32-bit，全球唯一
  - A **prefix (前缀)**
    - identifies the physical network to which the host is attached
    - Each network in the Internet is assigned a unique network number
    - 需要全球协调
  - A **suffix (后缀)**
    - identifies a specific computer (host/node) on the network
    - Each computer on a given network is assigned a unique suffix
    - 局域网内协调

传统分类地址

ABCDE类

21.5 Original Classes of IP Addresses

- How many bits to place in each part of an IP address?
  - The prefix needs sufficient bits to allow a unique network num. to be assigned to each physical network in the Internet
  - The suffix needs sufficient bits to permit each computer attached to a network to be assigned a unique suffix
- No simple choice was possible to allocate bits!
  - Choosing a large prefix accommodates many networks
    - but limits the size of each network
  - Choosing a large suffix means each physical network can contain many computers
    - but limits the total number of networks

21.5 Original Classes of IP Addresses

- **Internet contains a few large physical networks and many small networks**
  - **the designers chose an addressing scheme to accommodate a combination of large and small networks**
- **The original classful IP addressing divided the IP address space into three (3) primary classes**
  - **each class has a different size prefix and suffix**
- **The first four bits of an IP address determined the class to which the address belonged**
  - **It specifies how the remainder of the address was divided into prefix and suffix**

18.5 Original Classes of IP Addresses

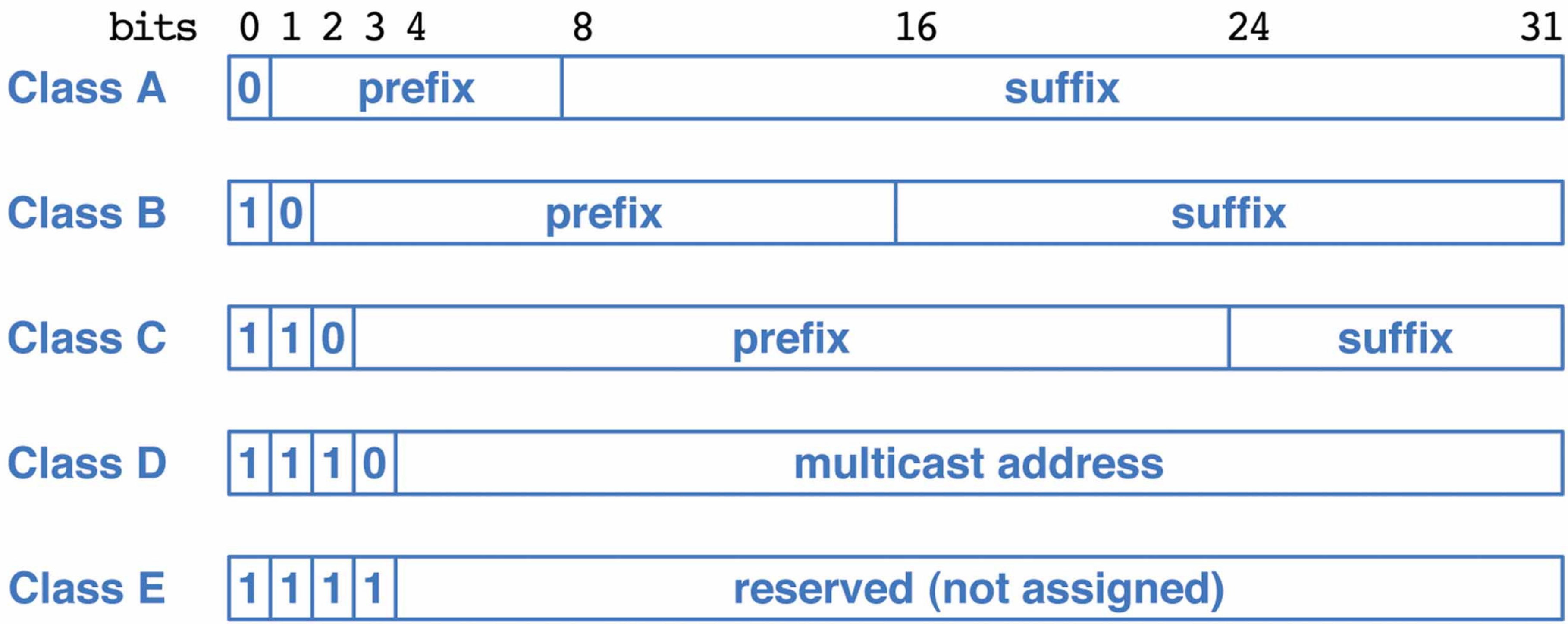


Figure 21.1 The five classes of IP addresses in the original classful scheme.

18.6 Computing The Class of An Address

- Whenever it handles a packet, IP software needs to separate the dest. address into a prefix and suffix .
- Classful IP addresses were called self identifying.

First Four Bits of Address	Table Index (in decimal)	Class of Address	First Four Bits of Address	Table Index (in decimal)	Class of Address
0	0	A	1000	8	B
1	1	A	1001	9	B
10	2	A	1010	10	B
11	3	A	1011	11	B
100	4	A	1100	12	C
101	5	A	1101	13	C
110	6	A	1110	14	D
111	7	A	1111	15	E

21.6 Dotted Decimal Notation

- **Dotted decimal notation**
  - Notation accepted is express each 8-bit section of a 32-bit as a decimal value use periods to separate the sections
- **Figure 21.2 illustrates examples of binary numbers and the equivalent dotted decimal notation**

32-bit Binary Number	Equivalent Dotted Decimal
10000001 00110100 00000110 00000000	129 . 52 . 6 . 0
11000000 00000101 00110000 00000011	192 . 5 . 48 . 3
00001010 00000010 00000000 00100101	10 . 2 . 0 . 37
10000000 00001010 00000010 00000011	128 . 10 . 2 . 3
10000000 10000000 11111111 00000000	128 . 128 . 255 . 0

Figure 21.2 Examples of 32-bit binary numbers and their equivalent in dotted decimal notation.

21.6 Dotted Decimal Notation

- **Dotted decimal treats each octet (byte) as an unsigned binary integer**
  - **the smallest value, 0**
    - **occurs when all bits of an octet are zero (0)**
  - **the largest value, 255**
    - **occurs when all bits of an octet are one (1)**
  - **dotted decimal addresses range 0.0.0.0 through 255.255.255.255**

21.9 Division of the Address Space

- The classful scheme divided the address space into unequal sizes
- The designers chose an unequal division to accommodate a variety of scenarios
  - For example, although it is limited to 128 networks, class A contains half of all addresses
    - The motivation was to allow major ISPs to each deploy a large network that connected millions of computers
  - Similarly, the motivation for class C was to allow an organization to have a few computers connected on a LAN

21.9 Division of the Address Space

- Figure 21.3 summarizes the maximum number of networks available in each class and the maximum number of hosts per network

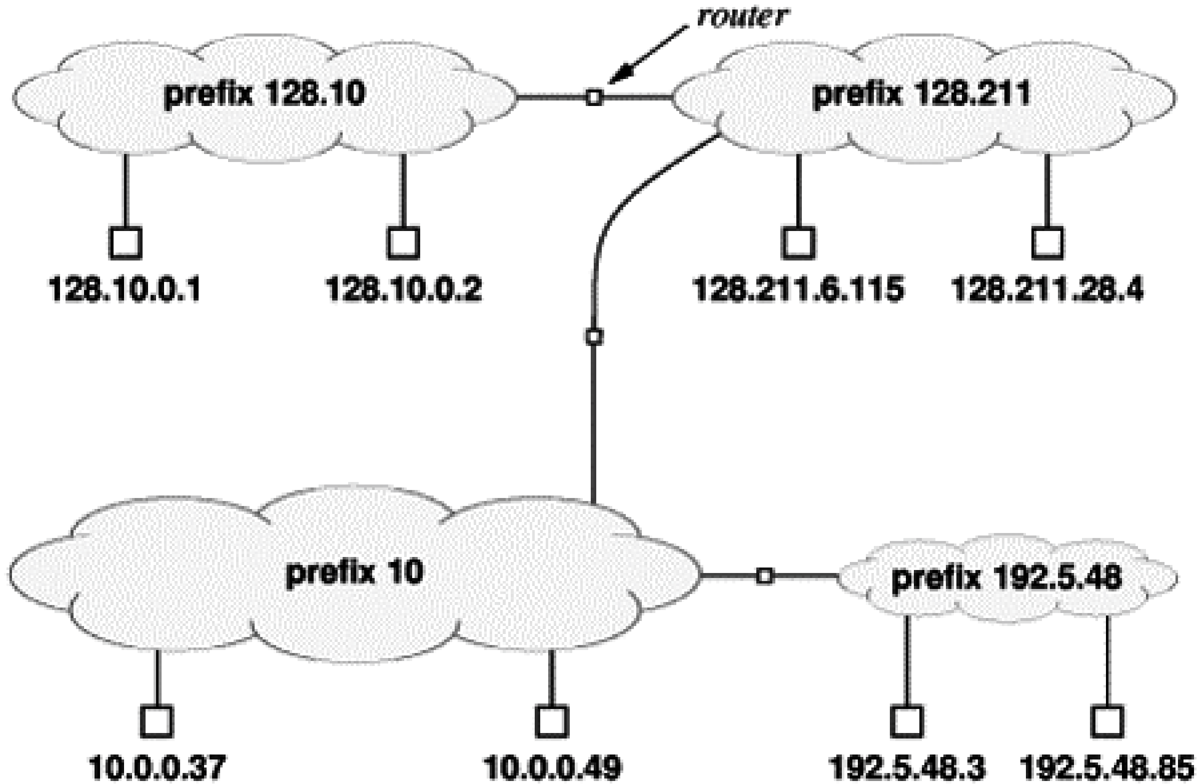
Address Class	Bits In Prefix	Maximum Number of Networks	Bits In Suffix	Maximum Number Of Hosts Per Network
A	7	128	24	16777216
B	14	16384	16	65536
C	21	2097152	8	256

Figure 21.3 The number of networks and hosts per network in each of the original three primary IP address classes.

21.8 Authority for Addresses

- Internet Corporation for Assigned Names and Numbers (ICANN) authority has been established
  - to handle address assignment and adjudicate disputes
- ICANN does not assign individual prefixes
  - Instead, ICANN authorizes a set of registrars to do so
- Registrars make blocks of addresses available to ISPs
  - ISPs provide addresses to subscribers
- To obtain a prefix
  - a corporation usually contacts an ISP

18.11 A Classful Addressing Example



无类地址

划分子网

21.9 Subnet and Classless Addressing

- **As the Internet grew**
  - **the original classful addressing scheme became a limitation**
- **Everyone demanded a class A or class B address**
  - **So they would have enough addresses for future growth**
    - **but many addresses in class A and B were unused**
  - **Many class C addresses remained, but few wanted to use them**

21.9 Subnet and Classless Addressing

- Two mechanisms were invented to overcome the limitation:
  - Subnet addressing
  - Classless addressing
- The two mechanisms are closely related
  - they can be considered to be part of a single abstraction:
    - instead of having three distinct address classes, allow the division between prefix/suffix on an arbitrary bit boundary

21.9 Subnet and Classless Addressing

- Subnet addressing was initially used within large organizations
- Classless addressing extended the approach to all Internet
- The motivation for using an arbitrary boundary?

21.9 Subnet and Classless Addressing

- **Consider an ISP that hands out prefixes, suppose a customer requests a prefix for a network of 55 hosts**
  - **classful addressing requires a complete class C prefix**
    - **4 bits of suffix are needed to represent all possible host val.**
      - **means 219 of the 254 possible suffixes would never be assigned**
    - **most of the class C address space is wasted**
  - **classless addressing allows the ISP to assign**
    - **a prefix that is 26 bits long**
    - **a suffix that is 6 bits long**

21.9 Subnet and Classless Addressing

- Assume an ISP owns a class C prefix
  - Classful addressing assigns the entire prefix to one organization
- With classless addressing
  - the ISP can divide the prefix into several longer prefixes
  - and assign each to a subscriber
- Fig. 21.4 illustrates how classless addressing allows an ISP to divide a class C prefix into 4 longer prefixes
  - each one can accommodate a network of up to 62 hosts
  - the host portion of each prefix is shown in gray

21.9 Subnet and Classless Addressing

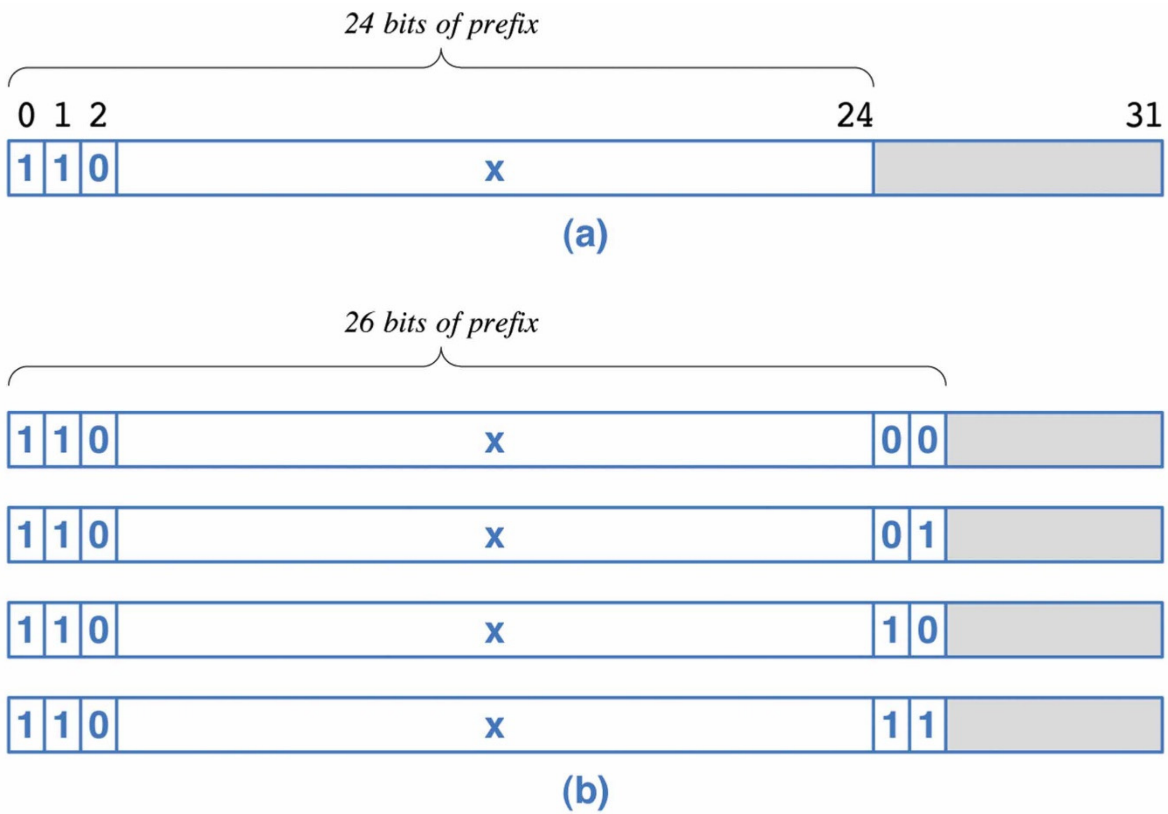


Figure 21.4 (a) A class C prefix, and (b) the same prefix divided into four classless prefixes.

21.9 Subnet and Classless Addressing

- The original class C address has 8 bits of suffix
  - and each of the classless addresses has 6 bits of suffix
- Assuming that the original class C prefix was unique
  - each of the classless prefixes will also be unique
- Thus, instead of wasting addresses
  - ISP can assign each of the four (4) classless prefixes to a subscriber

21.10 Address Masks

- Suppose a router is given
  - a destination address, *D*
  - a network prefix represented as a 32-bit value, *N*
  - a 32-bit address mask, *M*
- Assume the top bits of *N* contain a network prefix, and the remaining bits have been set to zero

21.10 Address Masks

- To test whether the destination lies on the specified network, the router tests the condition:

$$N == (D \,\&\, M)$$

- The router
  - uses the mask with a "logical and (&)" operation to set the host bits of address D to zero (0)
  - and then compares the result with the network prefix N

21.10 Address Masks (Example)

- Consider the following 32-bit network prefix:
  - 10000000 00001010 00000000 00000000 = 128.10.0.0
- Consider a 32-bit mask:
  - 11111111 11111111 00000000 00000000 = 255.255.0.0
- Consider a 32-bit destination address, which has a
  - 10000000 00001010 00000010 00000011 = 128.10.2.3
- A logical and between the destination address and the address mask extracts the high-order 16-bits
  - 10000000 00001010 00000000 00000000 = 128.10.0.0

21.11 CIDR Notation

- Classless Inter-Domain Routing (CIDR)
  - The name is unfortunate because CIDR only specifies addressing and forwarding
  - Designers wanted to make it easy for a human to specify a mask
- Consider the mask needed for the e.g. in Fig. 21.4b
  - It has 26 bits of 1s followed by 6 bits of 0s
  - In dotted decimal, the mask is: 255.255.255.192

21.11 CIDR Notation

- The general form of CIDR notation is:
  - ddd.ddd.ddd.ddd/m
    - ddd is the decimal value for an octet of the address
    - m is the number of one bits in the mask
- Thus, one might write the following: 192.5.48.69/26
  - which specifies a mask of 26 bits
- Figure 21.5 lists address masks in CIDR notation
  - along with the dotted decimal equivalent of each

21.11 CIDR Notation

Length (CIDR)	Address Mask	Notes
/0	0 . 0 . 0 . 0	All 0s (equivalent to no mask)
/1	128 . 0 . 0 . 0	
/2	192 . 0 . 0 . 0	
/3	224 . 0 . 0 . 0	
/4	240 . 0 . 0 . 0	
/5	248 . 0 . 0 . 0	
/6	252 . 0 . 0 . 0	
/7	254 . 0 . 0 . 0	
/8	255 . 0 . 0 . 0	Original Class A mask
/9	255 . 128 . 0 . 0	
/10	255 . 192 . 0 . 0	
/11	255 . 224 . 0 . 0	
/12	255 . 240 . 0 . 0	
/13	255 . 248 . 0 . 0	
/14	255 . 252 . 0 . 0	
/15	255 . 254 . 0 . 0	
/16	255 . 255 . 0 . 0	Original Class B mask
/17	255 . 255 . 128 . 0	
/18	255 . 255 . 192 . 0	
/19	255 . 255 . 224 . 0	
/20	255 . 255 . 240 . 0	
/21	255 . 255 . 248 . 0	
/22	255 . 255 . 252 . 0	
/23	255 . 255 . 254 . 0	
/24	255 . 255 . 255 . 0	Original Class C mask
/25	255 . 255 . 255 . 128	
/26	255 . 255 . 255 . 192	
/27	255 . 255 . 255 . 224	
/28	255 . 255 . 255 . 240	
/29	255 . 255 . 255 . 248	
/30	255 . 255 . 255 . 252	
/31	255 . 255 . 255 . 254	
/32	255 . 255 . 255 . 255	All 1s (host specific mask)

Figure 21.5 A list of address masks in CIDR notation and in dotted decimal.

21.12 A CIDR Example

- Assume an ISP has the following block 128.211.0.0/16
- Suppose the ISP has 2 customers
  - one customer needs 12 IP addresses and the other needs 9
- The ISP can assign
  - customer1 CIDR: 128.211.0.16/28
  - customer2 CIDR: 128.211.0.32/28
  - both customers have the same mask size (28 bits), the prefixes differ

21.12 A CIDR Example

- The binary value assigned to customer1 is:
  - 10000000 11010011 00000000 0001 0000
- The binary value assigned to customer2 is:
  - 10000000 11010011 00000000 0010 0000
- There is no ambiguity
  - Each customer has a unique prefix
  - the ISP retains most of the original address block
    - it can then allocate to other customers

21.13 CIDR Host Addresses

- Once an ISP assigns a customer a CIDR prefix
  - the customer can assign host addresses for its network users
  - suppose an organization is assigned 128.211.0.16/28
- Figure 21.6 illustrates that the organization will have 4-bits to use as a host address field
  - the highest/lowest addresses in binary and dotted decimal
  - avoids assigning the all 1s and all 0s host addresses

21.13 CIDR Host Addresses

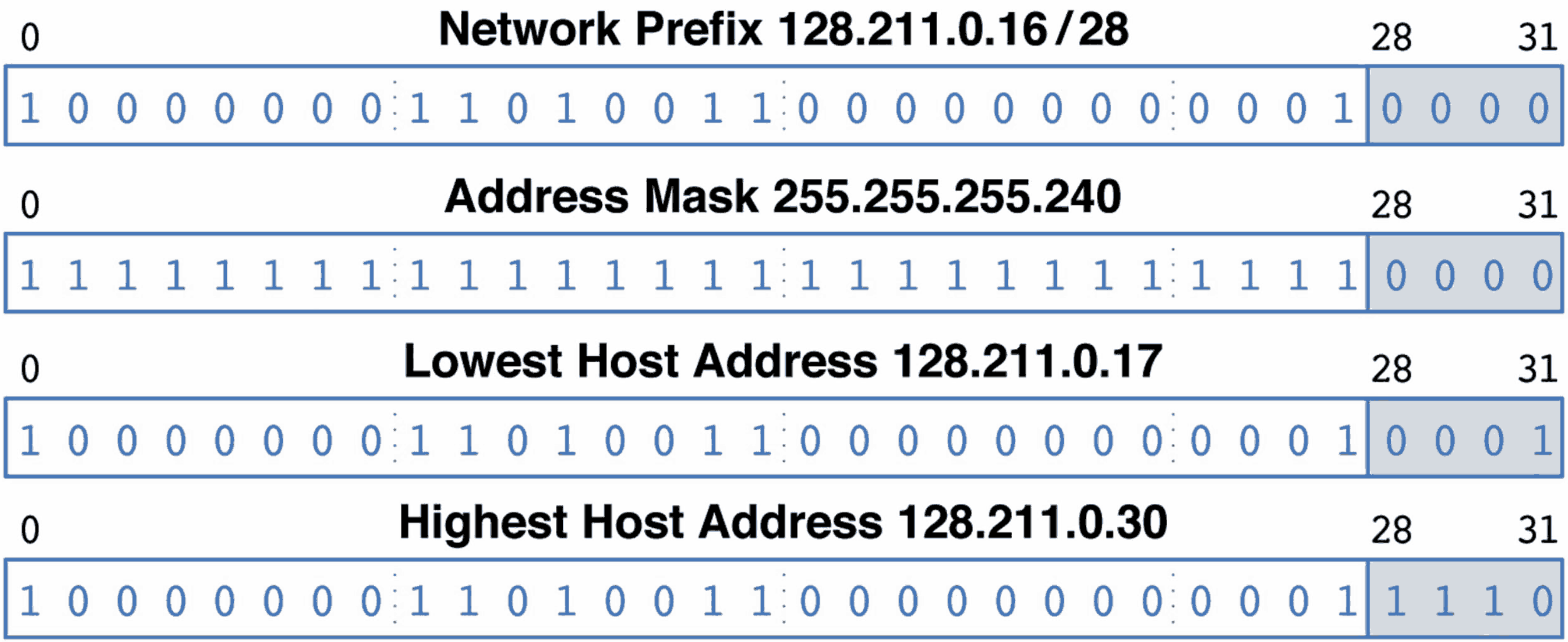


Figure 21.6 Illustration of CIDR addressing for an example / 28 prefix.

21.14 Special IP Addresses

- A set of special address forms are reserved
  - special addresses are never assigned to hosts
- This section describes both the syntax and semantics of each special address form
  - Network address (网络地址)
  - Directed Broadcast Address (直接广播地址).
  - Limited Broadcast Address (有限广播地址).
  - This Computer address (本机地址).
  - Loopback address (回送地址).

21.14.1 Network Address

- One of the motivations for defining special address forms can be seen in Figure 21.6
- It is convenient to have an address that can be used to denote the prefix assigned to a given network
- IP reserves host address zero
  - and uses it to denote a network

21.14.1 Network Address

- Thus, the address 128.211.0.16/28 denotes a network
  - because the bits beyond the 28 are zero
- A network address should never appear as the destination address in a packet
- Note: Section 21.16 discusses the Berkeley broadcast address form, which is a nonstandard exception

21.14.2 Directed Broadcast Address

- To simplify broadcasting (send to all)
  - IP defines a directed broadcast address for each physical network
- When a packet is sent to a network's directed broadcast
  - a single copy of the packet travels across the Internet
    - until it reaches the specified network
  - the packet is then delivered to all hosts on the network
- The directed broadcast address for a network is formed by adding a suffix that consists of all 1 bits to the network prefix

21.14.2 Directed Broadcast Address

- How does broadcast work?
- If network hardware supports broadcast
  - a directed broadcast will be delivered using the hardware broadcast capability
- If a particular network does not have hardware support for broadcast
  - software must send a separate copy of the packet to each host on the network

21.14.3 Limited Broadcast Address

- **Limited broadcast** refers to a broadcast on a directly-connected network:
  - informally, the broadcast is limited to a "**single wire**"
- Limited broadcast is used during **system startup**
  - by a computer that does not yet know the network number
- IP reserves the address consisting of **32-bits of 1s**
  - refer to limited broadcast
- Thus, IP will broadcast any packet sent to the all-1s address across the local network

21.14.4 This Computer Address

- **A computer needs to know its IP address**
  - **before it can send or receive Internet packets**
- **TCP/IP contains protocols a computer can use to obtain its IP address automatically when it boots**
  - **Startup protocols also use an IP to communicate (DHCP)**
- **When using such startup protocols**
  - **a computer cannot supply a correct IP source address**
  - **To handle such cases**
    - **IP reserves the address that consists of all 0s to mean this computer**

21.14.5 Loopback Address

- **Loopback** address used to test network applications
- It is used for preliminary debugging after a network application has been created
- A programmer must have two application programs that are intended to communicate across a network
  - Each application includes the code needed to interact with TCP/IP

21.14.5 Loopback Address

- Instead of executing each program on a separate computer
  - the programmer runs both programs on a single computer
  - and instructs them to use a loopback address when communicating
- When one application sends data to another
  - data travels down the protocol stack to the IP software
  - then forwards it back up through the protocol stack to the second program

21.14.5 Loopback Address

- A programmer can test the program logic quickly
  - without needing two computers and without sending packets across a network
- IP reserves the prefix 127/8 for use with loopback
- The host address used with 127 does not matter
  - all host addresses are treated the same
  - programmers often use host number 1
  - so it makes 127.0.0.1 the most popular loopback address

21.14.5 Loopback Address

- **During loopback testing no packets ever leave a computer**
  - **the IP software forwards packets from one application to another**
- **The loopback address never appears in a packet traveling across a network**

21.15 Summary of Special IP Addresses

Prefix	Suffix	Type Of Address	Purpose
all-0s	all-0s	this computer	used during bootstrap
network	all-0s	network	identifies a network
network	all-1s	directed broadcast	broadcast on specified net
all-1s	all-1s	limited broadcast	broadcast on local net
127/8	any	loopback	testing

Figure 21.7 Summary of the special IP address forms.

21.17 Routers and the IP Addressing Principle

- **Each router is assigned two or more IP addresses**
  - **one address for each network to which the router attaches**
- **To understand why, recall two facts:**
  - **A router has connections to multiple physical networks**
  - **Each IP address contains a prefix that specifies a physical network**

21.17 Routers and the IP Addressing Principle

- A single IP address does not suffice for a router
  - because each router connects to multiple networks
  - and each network has a unique prefix
- The IP scheme can be explained by a principle:
  - An IP address does not identify a specific computer
  - each address identifies a connection between a computer and a network
  - A computer with multiple network connections (e.g., a router) must be assigned one IP address for each connection

21.17 Routers and the IP Addressing Principle

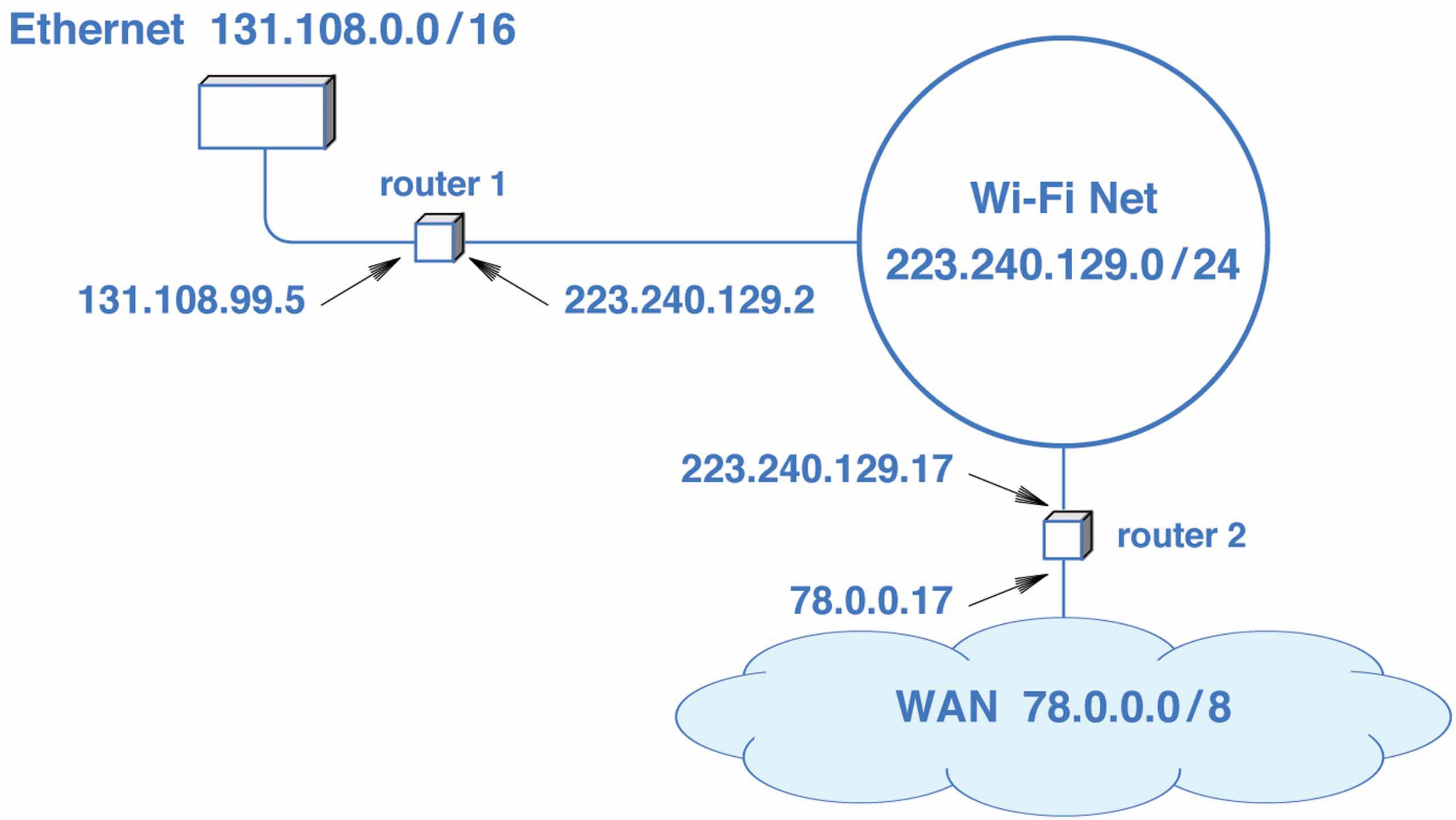


Figure 21.8 An example of IP addresses assigned to two routers.

21.18 Multi-Homed Hosts

- **Can a host connect to multiple networks? Yes**
- **A host computer with multiple network connections is said to be multi-homed**
- **Multi-homing is sometimes used to increase reliability**
  - **if one network fails, the host can still reach the Internet through the second connection**

21.18 Multi-Homed Hosts

- Alternatively, multi-homing is used to increase performance
  - connections to multiple networks can make it possible to send traffic directly and avoid routers, which are sometimes congested
- Like a router, a multi-homed host has multiple protocol addresses
  - one for each network connection

10.

THANK YOU.

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