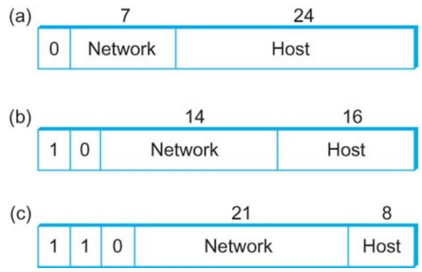
Global Addresses

- Properties
  - globally unique
  - hierarchical: network + host
  - 4 Billion IP address, half are A type, ¼ are B type, and 1/8 are C type
- Format



(a) Class A, (b) Class B, (c) Class C

- Dot notation
  - 10.3.2.4
  - 128.96.33.81
  - 192.12.69.77

Global Addresses

Class	1st Octet Decimal Range	1st Octet High Order Bits	Network/ Host ID (N=Network, H=Host)	Default Subnet Mask	Number of Networks	Hosts per Network (Usable Addresses)**
A	1 – 126*	0	N.H.H.H	255.0.0.0	126 ($2^7 – 2$)	16,777,214 ($2^{24} – 2$)
B	128 – 191	10	N.N.H.H	255.255.0.0	16,382 ($2^{14} – 2$)	65,534 ($2^{16} – 2$)
C	192 – 223	110	N.N.N.H	255.255.255.0	2,097,150 ($2^{21} – 2$)	254 ($2^8 – 2$)
D	224 – 239	1110	Reserved for Multicasting			
E	240 – 254	1111	Experimental; used for research			

Note: *Class A addresses 127.0.0.0 to 127.255.255.255 cannot be used and are reserved for loopback and diagnostic functions.

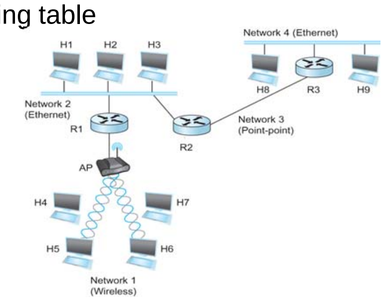
** host 255 is for broadcast, host 0 is not a valid host – identifies the network

IP Datagram Forwarding

Chapter 3

- Strategy
  - every datagram contains destination's address
  - if directly connected to destination network, then forward to host
  - if not directly connected to destination network, then forward to some router
  - forwarding table maps network number into next hop
  - each host has a default router
  - each router maintains a forwarding table
- Example (router R2)

NetworkNum	NextHop
1	R1
2	Interface 1
3	Interface 0
4	R3



IP Datagram Forwarding

Chapter 3

- Algorithm

```
if (NetworkNum of destination = NetworkNum of one of my
   interfaces) then
   deliver packet to destination over that interface
else
   if (NetworkNum of destination is in my forwarding table)
   then
       deliver packet to NextHop router
   else
       deliver packet to default router
```

For a host with only one interface and only a default router in its forwarding table, this simplifies to

```
if (NetworkNum of destination = my NetworkNum)then
   deliver packet to destination directly
else
   deliver packet to default router
```

Subnetting

Chapter 3

- Take one IP network number and break it up into subnets
- Adds another level to address/routing hierarchy: *subnet*
- *Subnet masks* define variable partition of host part of class A and B addresses
- Subnets visible only within site of base IP network
- Allows for smaller number of hosts to be handled more efficiently
  - If a network is to connect 300 hosts
    - Need 2 class C networks – requires 2 Network addresses in tables
    - 1 class B network – requires one network address, but wastes over 65,000 hosts

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Subnetting

Chapter 3

- For class B networks, its mask is 255.255.0.0
- For a Subnet of a Class B network, use 255.255.XXX.0
- Have three levels now
  - Network Id (first 16 bits)
  - Subnet ID (next 8 bits)
  - Host ID (last 8 bits)
- Subnet mask does not align on 8 bit boundaries
- Using multiple subnets on a single network forces hosts to use routers

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Subnetting

Chapter 3

- Assign a Class B network to a group that creates a subnet
  192.11.0.0 to 192.11.255.255
- Router advertises network address192.11.0.0/16 (/16 indicates first 16 bits as the network address)
  - Subnet mask is 255.255.XXX.0
  - The third octet of mask determines how the Class B network is subnetted

Start Address	End Address	Subnet Mask	Subnet IP
192.11.128.0	192.11.255.255	255.255.128.0	192.11.128.0
192.11.64.0	192.11.127.255	255.255.64.0	192.11.64.0
192.11.16.0	192.11.31.255	255.255.16.0	192.11.16.0
192.11.48.0	192.11.63.255	255.255.48.0	192.11.48.0

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Subnetting

Chapter 3

- Private networks and Subnets
- Three network ranges have been reserved for intranets – for internal use

Network address range	Default mask
10.0.0.0 - 10.255.255.255	255.0.0.0
172.16.0.0 - 172.31.255.255	255.240.0.0
192.168.0.0 - 192.168.255.255	255.255.0.0

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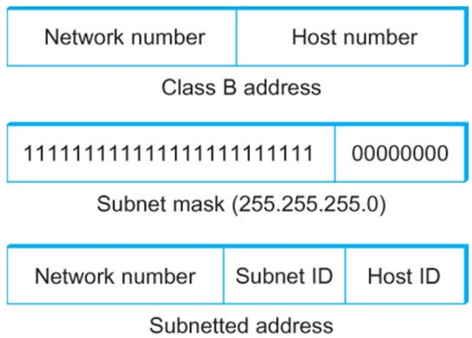
Subnetting

Chapter 3

- Add another level to address/routing hierarchy: *subnet*
- *Subnet masks* define variable partition of host part of class A and B addresses
- Subnets visible only within site



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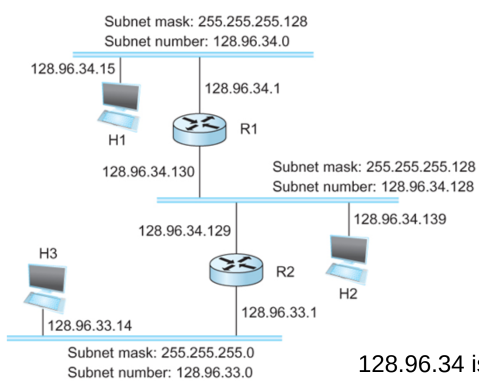
Subnetting

Chapter 3



128.96.34 is split
into 2 networks with 128 hosts each

- Forwarding Table at Router R1

SubnetNumber	SubnetMask	NextHop
128.96.34.0	255.255.255.128	Interface 0
128.96.34.128	255.255.255.128	Interface 1
128.96.33.0	255.255.255.0	R2

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Subnetting

Chapter 3

Forwarding Algorithm

```
D = destination IP address
for each entry < SubnetNum, SubnetMask, NextHop>
   D1 = SubnetMask & D
   if D1 = SubnetNum
      if NextHop is an interface
         deliver datagram directly to destination
      else
         deliver datagram to NextHop (a router)
```

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Subnetting

Chapter 3

Notes

- Would use a default router if nothing matches
- Not necessary for all ones in subnet mask to be contiguous
- Can put multiple subnets on one physical network
- Subnets not visible from the rest of the Internet

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Classless Addressing

Chapter 3

- Classless Inter-Domain Routing (CIDR)
  - A technique that addresses two scaling concerns in the Internet
    - The growth of backbone routing table as more and more network numbers need to be stored in them
    - Potential exhaustion of the 32-bit address space
  - Addresses assignment efficiency
    - Arises because of the IP address structure with class A, B, and C addresses
    - IP address structure forces us to hand out network address space in fixed-size chunks of three very different sizes
      - A network with two hosts needs a class C address
        - Address assignment efficiency = 2/255 = 0.78
      - A network with 256 hosts needs a class B address
        - Address assignment efficiency = 256/65535 = 0.39

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Classless Addressing

Chapter 3

- Exhaustion of IP address space centers on exhaustion of the class B network numbers
- Solution
  - Say “NO” to any Autonomous System (AS) that requests a class B address unless they can show a need for something close to 64K addresses
  - Instead give them an appropriate number of class C addresses
  - For any AS with at least 256 hosts, we can guarantee an address space utilization of at least 50%
- What is the problem with this solution?

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Classless Addressing

- Problem with this solution
  - Excessive storage requirement at the routers.
- If a single AS has, say 16 class C network numbers assigned to it (4080 hosts),
  - Every Internet backbone router needs 16 entries in its routing tables for that AS
  - This is true, even if the path to every one of these networks is the same
- If we had assigned a class B address to the AS
  - The same routing information can be stored in one entry
  - But Efficiency(% used) = 16 × 255 / 65, 536 = 6.2%

Classless Addressing

- CIDR tries to balance the desire to minimize the number of routes that a router needs to know against the need to hand out addresses efficiently.

- CIDR uses aggregate routes
  - Uses a single entry in the forwarding table to tell the router how to reach a lot of different networks
  - Breaks the rigid boundaries between address classes

Classless Addressing

Chapter 3

- Consider an AS with 16 class C network numbers.
- Instead of handing out 16 addresses at random, hand out a block of contiguous class C addresses
- Suppose we assign the class C network numbers from 192.4.16 through 192.4.31
- Observe that top 20 bits of all the addresses in this range are the same (11000000 00000100 0001)
- We have created a 20-bit network number (which is in between class B network number and class C number)

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Classless Addressing

Chapter 3

- Requires to hand out blocks of class C addresses that share a common prefix
- The convention is to place a /X after the prefix where X is the prefix length in bits
- For example, the 20-bit prefix for all the networks 192.4.16 through 192.4.31 is represented as 192.4.16/20
- By contrast, if we wanted to represent a single class C network number, which is 24 bits long, we would write it 192.4.16/24

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Classless Addressing

- How do the routing protocols handle this classless addresses?
  - It must understand that the network number may be of any length
  - Represent network number with a single pair
    `<length, value>`
  - All routers must understand CIDR addressing

Subnetting

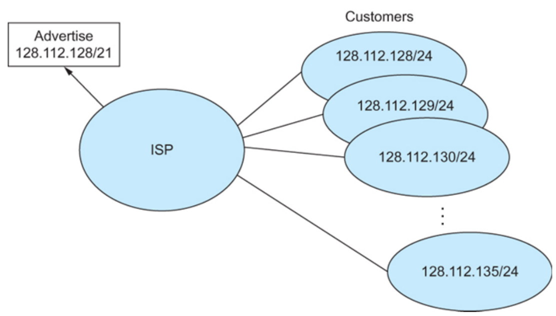
Chapter 3

- Want a network router to handle 8 class C networks
  192.11.64.XXX to 192.11.71.XXX
- Router advertises network address192.11.64/21 (/21 indicates first 21 bits as the network address)
  - Subnet mask is 255.255.248.0
  - The third octet of IP addresses are masked with 11111000

Third Octet	3rd Octet Binary	Masked	Subnet IP
63	00111111	00111000	192.11.56.0
64	01000000	01000000	192.11.64.0
71	01000111	01000000	192.11.64.0
72	01001000	01001000	192.11.72.0

Classless Addressing

Chapter 3



Route aggregation with CIDR

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IP Forwarding Revisited

Chapter 3

- IP forwarding mechanism assumes that it can find the network number in a packet and then look up that number in the forwarding table
- We need to change this assumption in case of CIDR
- CIDR means that prefixes may be of any length, from 2 to 32 bits

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IP Forwarding Revisited

Chapter 3

- It is also possible to have prefixes in the forwarding tables that overlap: Some addresses may match more than one prefix
- For example, we might find both 171.69 (a 16 bit prefix) and 171.69.10 (a 24 bit prefix) in the forwarding table of a single router
- A packet destined to 171.69.10.5 clearly matches both prefixes - The rule is based on the principle of “longest match” 171.69.10 in this case
- A packet destined to 171.69.20.5 would match 171.69 and not 171.69.10

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Address Translation Protocol (ARP)

Chapter 3

- Map IP addresses into physical (MAC) addresses
  - destination host
  - next hop router
- Techniques
  - encode physical address in host part of IP address
  - table-based
- ARP (Address Resolution Protocol)
  - table of IP to physical address bindings
  - broadcast request if IP address not in table
  - target machine responds with its physical address
  - table entries are discarded if not refreshed

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ARP Packet Format

0	8	16	31
Hardware type = 1		ProtocolType = 0x0800	
HLen = 48	PLen = 32	Operation	
SourceHardwareAddr (bytes 0–3)			
SourceHardwareAddr (bytes 4–5)		SourceProtocolAddr (bytes 0–1)	
SourceProtocolAddr (bytes 2–3)		TargetHardwareAddr (bytes 0–1)	
TargetHardwareAddr (bytes 2–5)			
TargetProtocolAddr (bytes 0–3)			

- HardwareType: type of physical network (e.g., Ethernet)
- ProtocolType: type of higher layer protocol (e.g., IP)
- HLEN & PLEN: length of physical(MAC) and protocol(IP) addresses
- Operation: ARP request or ARP response
- Source/Target Physical(Ethernet)/Protocol(IP) addresses

Host Configurations

- Ethernet addresses are configured into network by manufacturer and they are unique
- IP addresses must be unique on a given internetwork but also must reflect the structure of the internetwork
- Most host Operating Systems provide a way to manually configure the IP information for the host
- Drawbacks of manual configuration
  - A lot of work to configure all the hosts in a large network
  - Configuration process is error-prone
- Automated Configuration Process is required

Dynamic Host Configuration Protocol (DHCP)

Chapter 3

- DHCP server is responsible for providing configuration information to hosts
- There is at least one DHCP server for an administrative domain
- DHCP server maintains a pool of available addresses
- DHCP leases an address to a host. Host must renew the lease periodically
  - Handles cases where a host becomes disconnected

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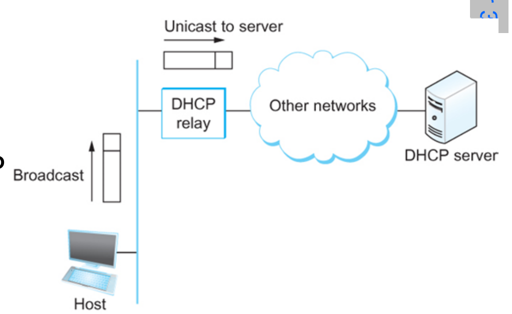
DHCP

Chapter 3

- Newly booted or attached host sends DHCPDISCOVER message to a special IP address (255.255.255.255)
- DHCP relay agent unicasts the message to DHCP server and waits for the response
- Sent using the User Datagram Protocol(UDP)



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Internet Control Message Protocol (ICMP)

Chapter 3

- Defines a collection of error messages that are sent back to the source host whenever a router or host is unable to process an IP datagram successfully
  - Destination host unreachable due to link /node failure
  - Reassembly process failed
  - TTL had reached 0 (so datagrams don't cycle forever)
  - IP header checksum failed
- ICMP-Redirect: Router sends a source host better route information
- Debugging tools
  - ping – uses ICMP to see if a host is alive and reachable
  - traceroute – uses ICMP to determine the routers on the path to a destination

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Virtual Networks and Tunnels

Chapter 3

- VPN – virtual Private Network
  - Use Virtual point-to-point links on a shared network
  - For IP, use a concept called tunneling
- IP Tunnel
  - Router to Router transmission of an IP Packet
  - IP packet transmitted on a tunnel encapsulates the entire IP packet from a source host to a destination host.
  - Router connected to the source host encapsulates the IP packet for the destination host in an IP packet with an address for the router of the destination host
  - Routers use a next hop entry of virtual interface 0, 1, … in their forwarding table

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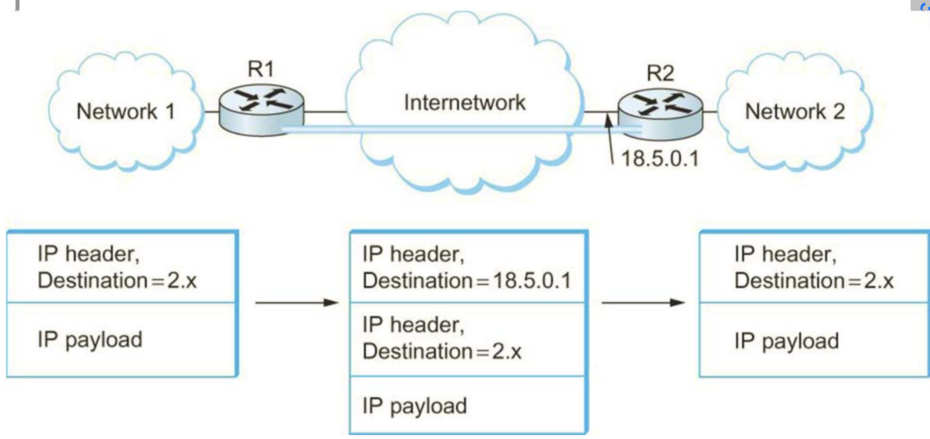
Virtual Networks and Tunnels

Chapter 3



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IP Tunnels

Chapter 3

- IP Tunnel Advantages
  - Provides security of transmissions
  - Routers with unique capabilities not available on networks between the connection can use these unique capabilities.
  - Can carry packets from protocols different from IP
  - Can force a packet to be delivered to a particular destination even if its original header specifies a different destination – used with mobile hosts
- IP Tunnel Disadvantages
  - Longer packets are created – may cause fragmentation
  - Performance implications at the routers – more work is required
  - Management cost for setting up and maintaining the tunnels

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