CPSC 471: Computer Communications

Basic Internetworking and IP

Figures from Computer Networks: A Systems Approach, version 6.02dev (Larry L. Peterson and Bruce S. Davie)

Definitions

- Internetwork (or internet)
  - Collection of networks interconnected to provide a host-to-host packet delivery service
  - A network of networks
  - A logical network
- Network
  - Also called physical networks
- Routers connect physical networks

Internetwork Example

- Allows all nodes/networks to function as a single logical network

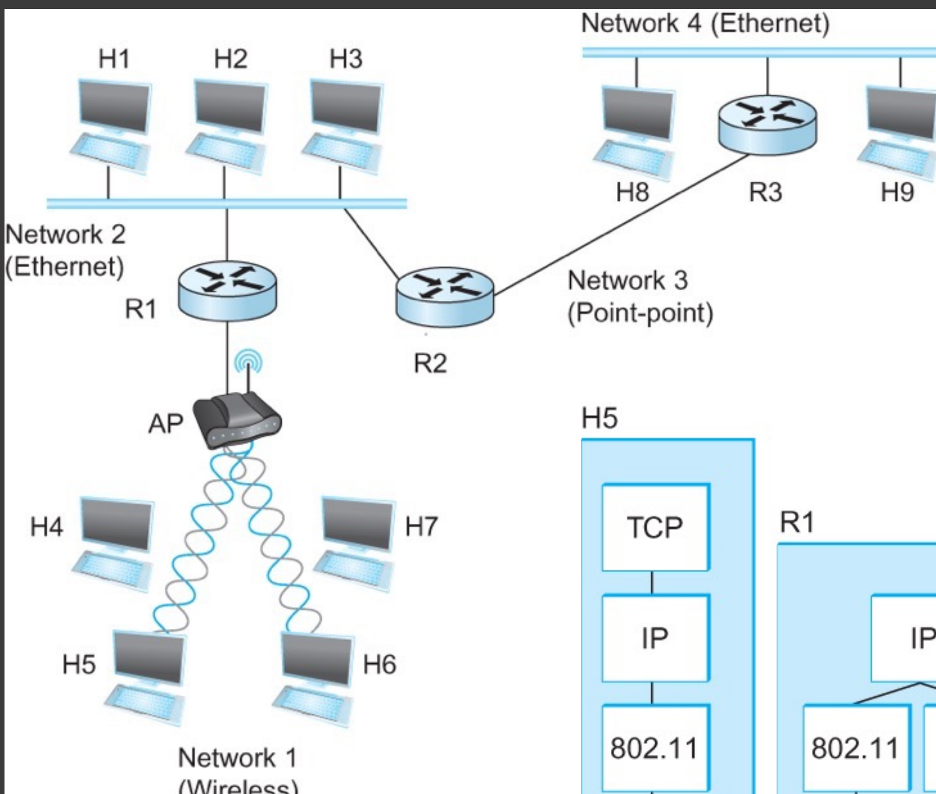


Figure 70

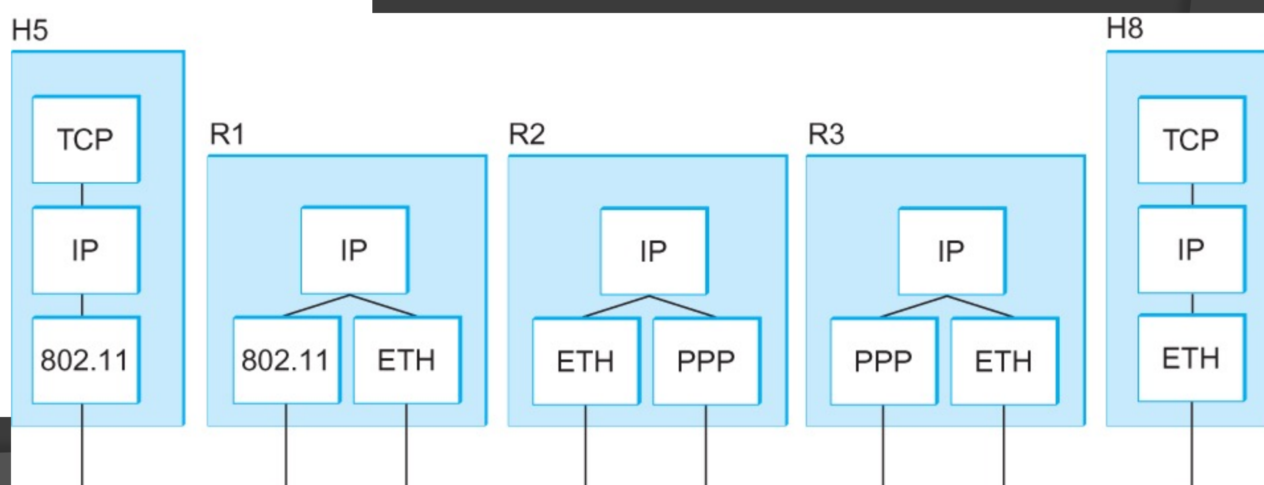


Figure 71

Service Model

- The host-to-host services you want to provide
- Can provide it only if service can be provided over each of the underlying physical networks

Internet Protocol (IP)

- Addressing scheme
  - Identifies all hosts in the internetwork
- Datagram method of data delivery
  - A best effort service
    - Also called an unreliable service
  - Simplest service
    - Keeps routers simple
    - IP runs over anything
- Higher-level protocols must be aware of potential failures

IP ver. 4 Packet Format

- Version (of IP)
- HLen
  - Header Length in 32-bit words
- TOS
  - Type of service
  - Allows for special treatment of packets based on app. needs
- Length (of datagram in bytes: max is 65,535)
  - Includes header

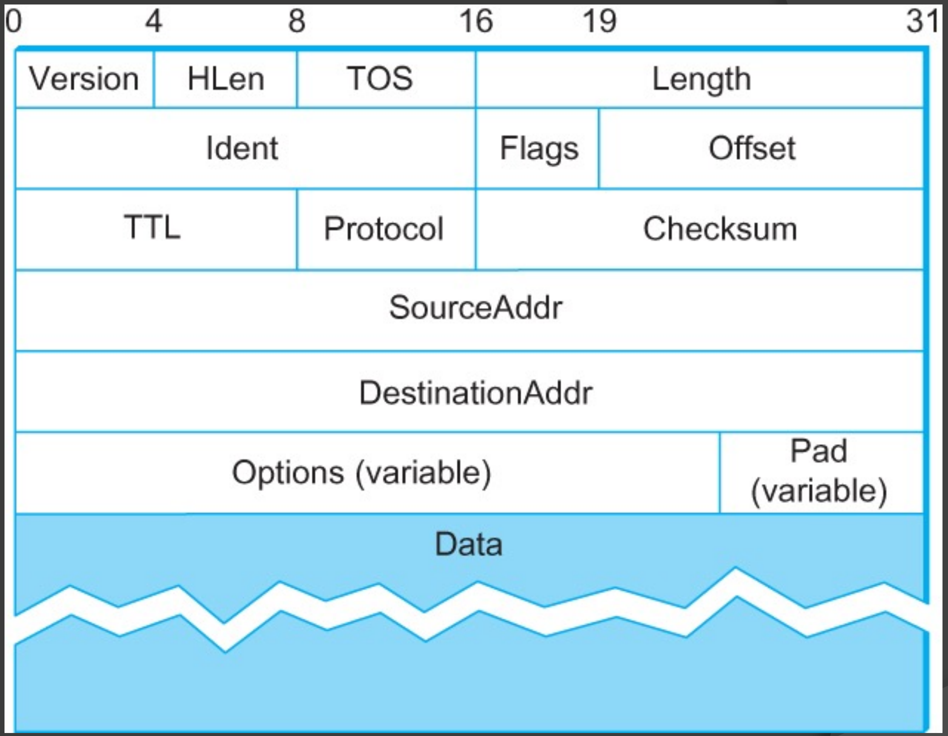


Figure 72

Fragmentation and Reassembly

- Not all physical networks have the same MTU
  - Maximum transmission unit
  - Largest datagram it can carry in a frame
- Fragmentation occurs when:
  - Router must forward datagram though network with MTU < datagram size
- Reassembly usually occurs at receiver
  - What if a fragment is lost?

Fragmentation Example

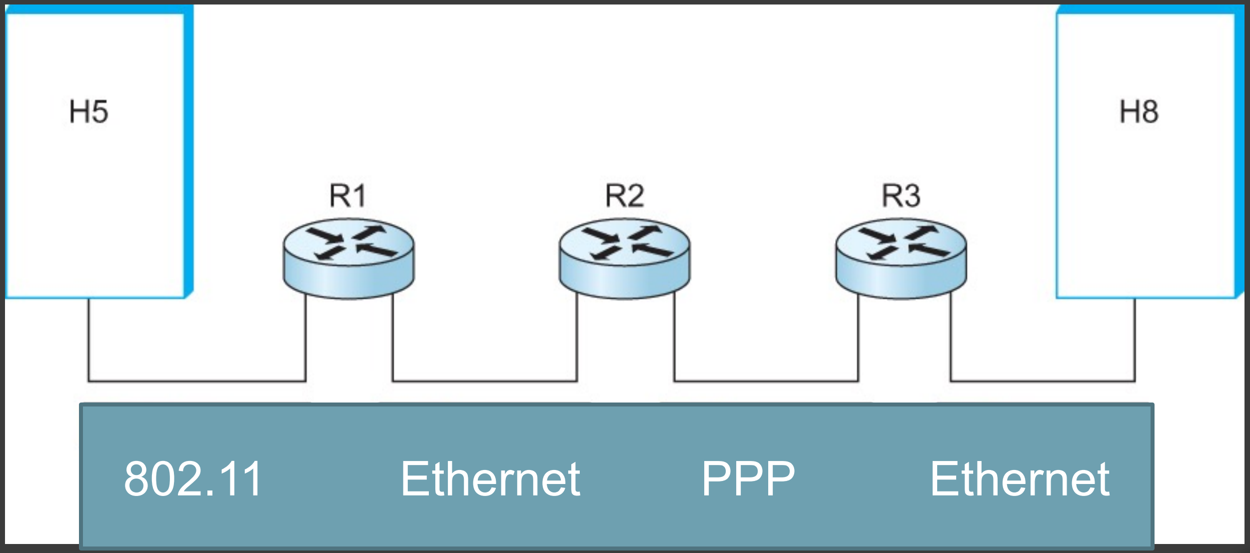


Figure 73

Fragmentation Example

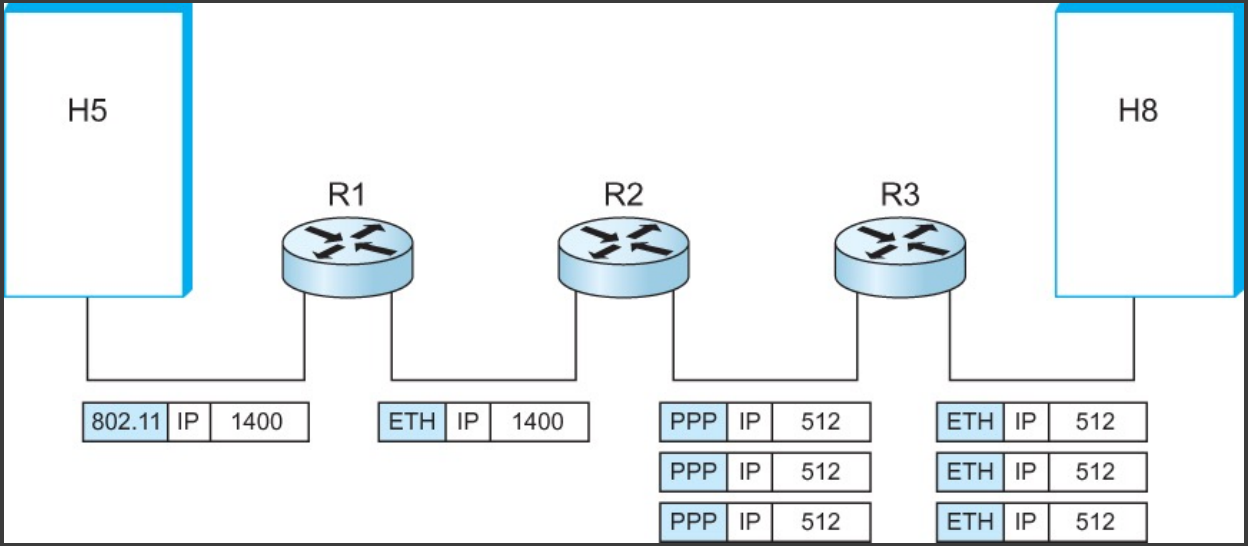


Figure 73

Fragmentation Headers

- Ident
  - Unique Identifier
- Flags
  - M-bit
    - Means more fragments follow
- Offset
  - Fragmentation should happen on 8-byte boundaries

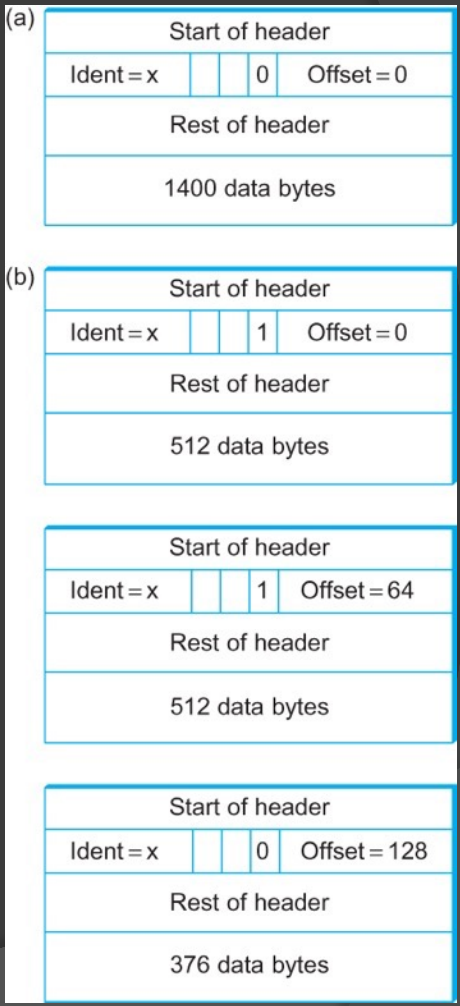


Figure 74

IP ver. 4 Packet Format

- TTL
  - Time-to-live
    - Catch packet going around in a routing loop
- Protocol
  - Demultiplexing key for higher-level protocol
  - TCP = 6
  - UDP = 17
- Checksum on header

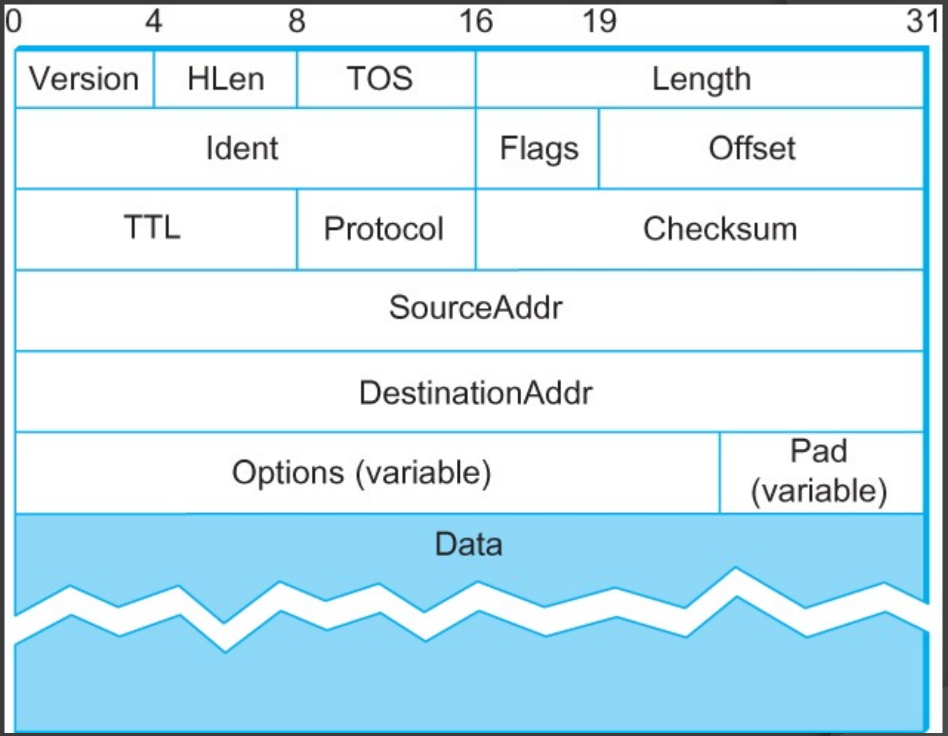


Figure 72

IP Addresses

- Example:
  - Ethernet addresses have no structure
    - Provide few clues to routing protocols
- IP addresses are hierarchical
  - Made up of
    - Network part
    - Host part
- IP addresses belong to interfaces, not hosts

IP Addresses

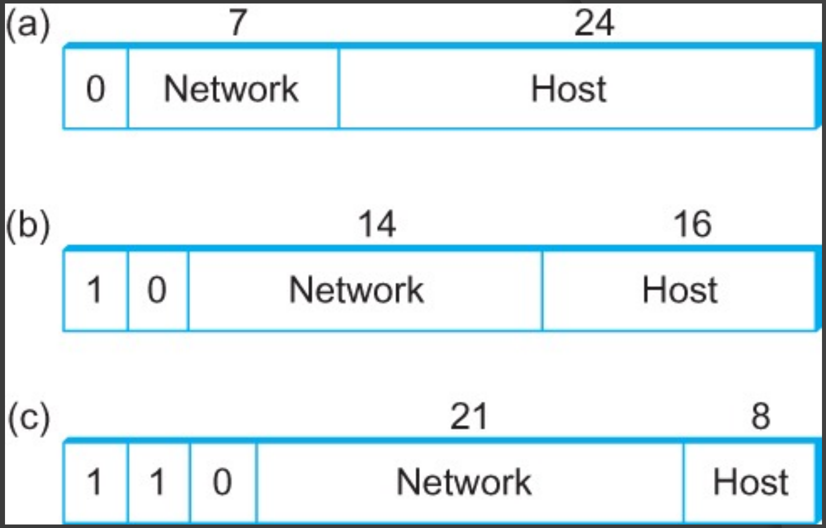


Figure 75

- 32 bits long
- Class A
  - 126 class A networks
  - About 16 million hosts each
- Class B
  - 65,534 hosts per network
- Class C
  - 254 hosts per network
- Today, IP addresses are classless

Forwarding vs. Routing

- Take a packet on an input and send it out on the appropriate output

- Build up to forwarding tables

Datagram Forwarding in IP from sender's point-of-view

- Is receiver connected to same physical network?
  - Yes → Directly deliver datagram over network
  - No → Must forward datagram to a router
    - Choose the best router to get the datagram closer to its destination
    - Forwarding table has pairs of: <NetworkNum, NextHop>

IP Datagram Forwarding

- H1 to H3?
- H1 to H6?
- H1 to H9?

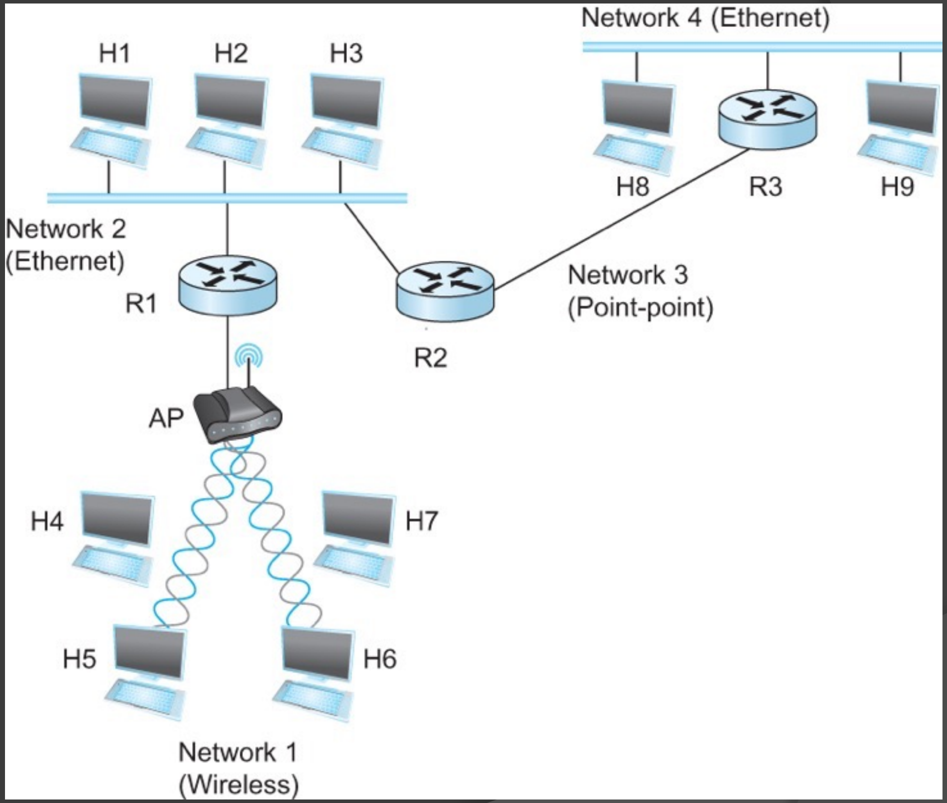


Figure 70

Switch vs. Router

- Layer 2 device—forwards Ethernet frames, ATM cells, etc.

- Forwards IP datagrams

Class Addressing Wastes Addresses

- Class A
  - 126 class A networks, about 16 million hosts each
- Class B
  - 65,534 hosts per network
- Class C
  - 254 hosts per network

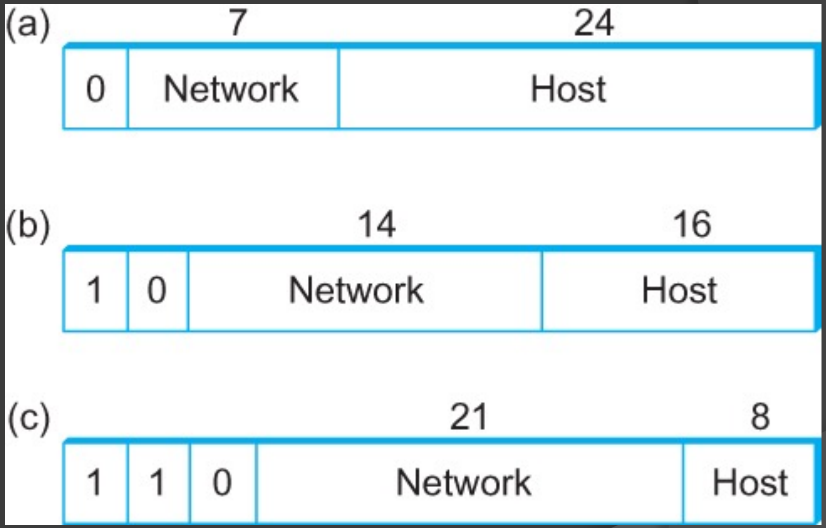


Figure 75

- What if a network has 2 hosts?
- What if a network has 260 hosts?

Subnetting

- Allocate the IP addresses of one IP network number to several physical networks
  - These are called subnets
- Share a single network number by using a subnet mask
    - Introduces a subnet number

Subnetting

- Physical networks should be close to each other

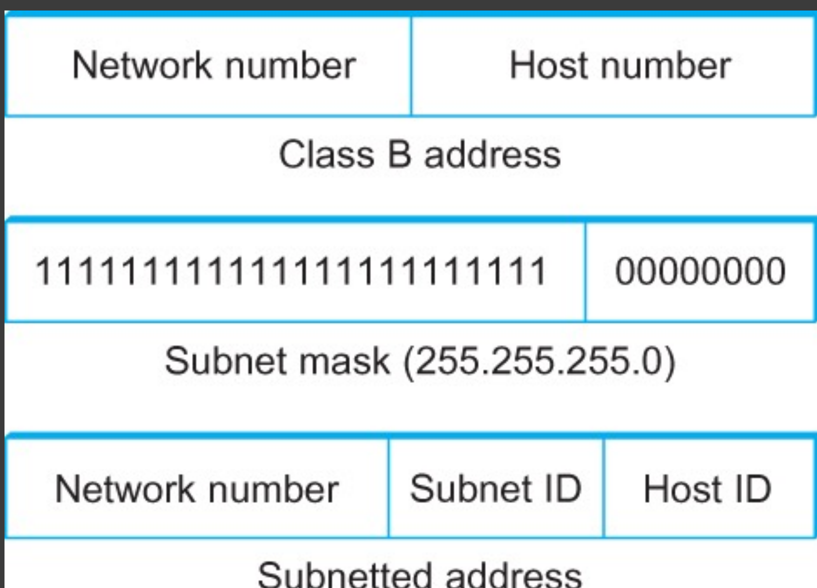


Figure 76

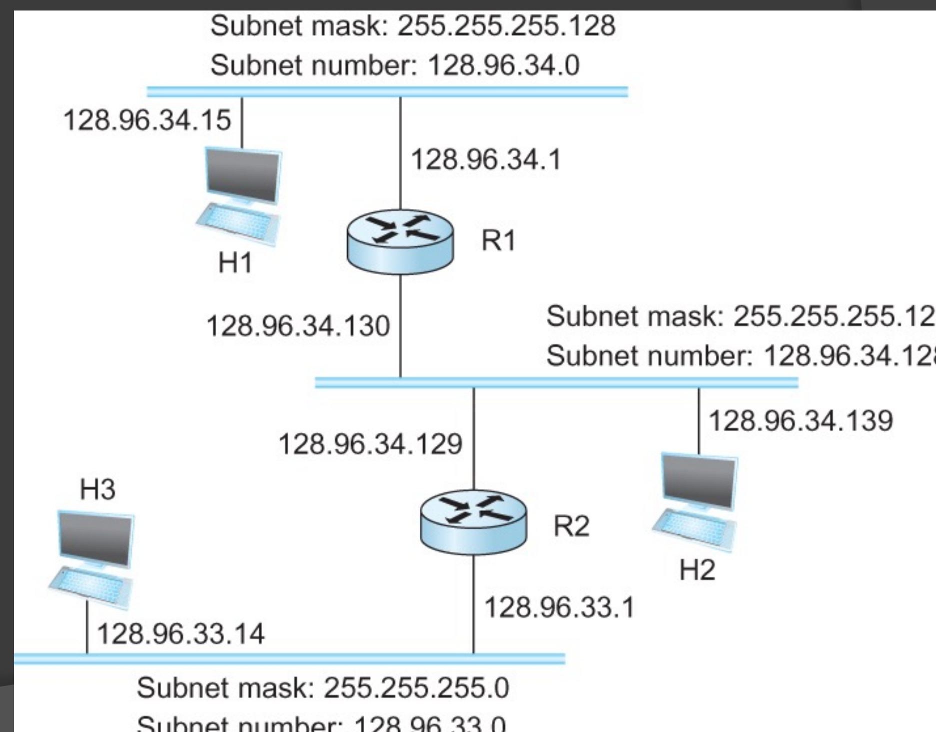


Figure 77

Forwarding with IP subnets from sender's point-of-view

- Is receiver connected to same physical network?
  - **Perform bitwise AND of its own subnet mask and receiver's IP address**
  - Yes → Directly deliver datagram over network
  - No → Must forward datagram to next hop router
    - **Forwarding table has: <SubnetNum, SubnetMask, NextHop>**

Subnetting Example Question

- Which hop will be these packets be delivered to by a router using the following routing table?
  - Packet with address 128.96.171.92
  - Packet with address 128.96.167.151
  - Packet with address 128.96.163.151

SubnetNumber	SubnetMask	Nexthop
128.96.170.0	255.255.254.0	Interface0
128.96.168.0	255.255.254.0	Interface1
128.96.166.0	255.255.254.0	R2
128.96.164.0	255.255.252.0	R3
<default>	--	R4

Subnetting Example Solution

- Packet with address 128.96.171.92
  - To Interface 0
- Packet with address 128.96.167.151
  - To Router R2
- Packet with address 128.96.163.151
  - To Router R4

Supernetting

- What if a company has 256 hosts?
- Could use subnetting to split a class B address
  - 256/65535 = 0.39% efficiency
- Or could assign multiple class C addresses
  - Requires more entries in router forwarding tables

Supernetting continued

- Could use a number of contiguous class C addresses
- Example:
  - 192.4.16 to 192.4.31
    - The top 20 bits are the same
- CIDR
  - Classless interdomain routing

CIDR

- Requires a new notation
- 192.4.16/20
  - /20 is the prefix length in bits
- Class C network number uses 24 bits
- Also provides route aggregation

Route Aggregation

- Eight customers of ISP have continuous IP numbers

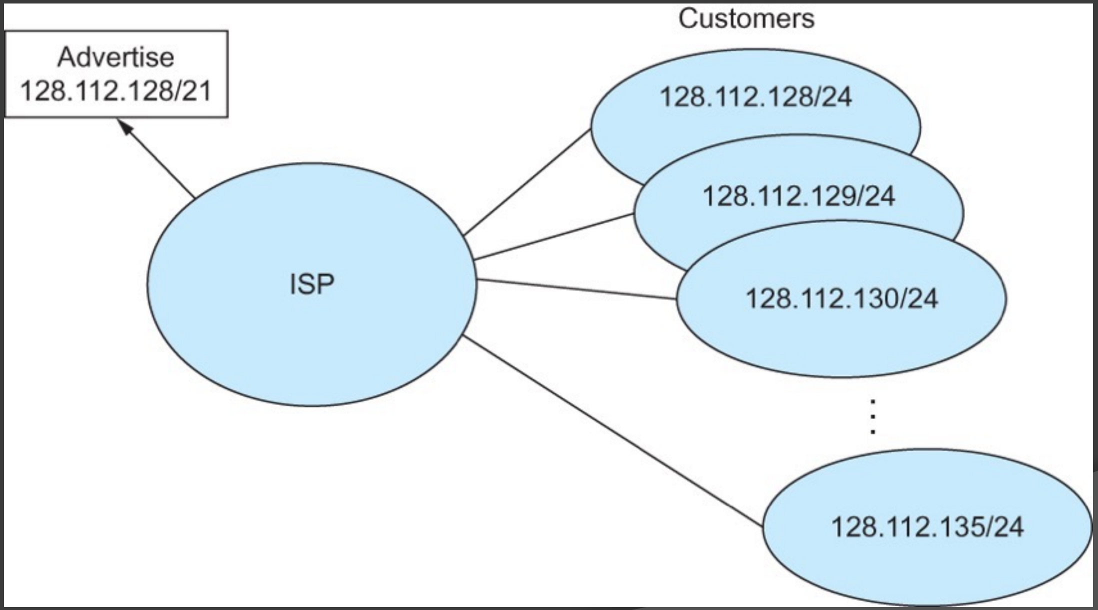


Figure 78

Route Aggregation continued

- Prefixes in forwarding tables of routers may "overlap"
  - Example: 171.69/16 and 171.69.10/24
- What to do with a packet whose destination is 171.69.10.5?
- What to do with a destination of 171.69.20.5?

CIDR Example Question

- If a router using CIDR has the following routing table, then to which hop will be the following packets be delivered?
  - Packet with address C4.4B.31.2E
  - Packet with address C4.5E.05.09
  - Packet with address C4.4D.31.2E
  - Packet with address C4.5E.03.87

Net/MaskLength	Nexthop
C4.5E.2.0/23	A
C4.5E.4.0/22	B
C4.5E.C0.0/19	C
C4.5E.40.0/18	D
C4.4C.0.0/14	E
C0.0.0.0/2	F
80.0.0.0/1	G

CIDR Example Solution

- Packet with address C4.4B.31.2E
  - To F
- Packet with address C4.5E.05.09
  - To B
- Packet with address C4.4D.31.2E
  - To E
- Packet with address C4.5E.03.87
  - To A

Address Translation

- Need to translate the IP address to a physical address
- Most general approach:
  - Each host maintains a table of address pairs mapping IP addresses to physical addresses
    - Let each host dynamically learn this
    - Use ARP

ARP: Address Resolution Protocol

- Entries stored in an ARP table/cache
  - Has a timeout (usually 15 min)
- If host wants to send IP datagram to host or router on same network
  - Checks for mapping in the ARP cache
  - If no match found, invokes ARP on network

ARP continued

- Broadcast an ARP query
  - Contains target IP address
- Each host checks their IP address against address in ARP query
  - If it matches, it sends a response message back to originator containing its link-level address
  - Originator adds entry to its ARP cache

ARP Query continued

- ARP query also contains sender's IP address and link-level address
  - Each host on the network learns this info
    - Target host adds the entry
    - Other hosts
      - If already have entry, "refresh" it, otherwise ignore it

ARP Header Format

- IP-to-Ethernet address mappings

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)		

Figure 79

IP Recap

- Provides heterogeneity and scale
  - Heterogeneity
    - Best-effort model
    - Fragmentation to deal with different MTU's of physical networks
    - Global address space
  - Scale
    - IP address contains network and host components to reduce amount of info needed to forward packets

Host Configuration

- IP addresses must
  - Be unique on a given network
  - Reflect the structure of the internetwork
- Ethernet addresses configured by manufacturer
- Cannot do this for IP addresses
  - How to assign IP addresses?

Host Configuration continued

- Host needs to know address of a default router
  - Where to send packets when destination address is not on the same network
- Can manually configure this, or
- Automatically configure with DHCP
  - Dynamic Host Configuration Protocol

DHCP

- Requires a DHCP server
- Provides configuration info to hosts
- Simplest form:
  - Centralized repository for host configuration info
- Better usage:
  - DHCP server contains pool of available addresses
  - Hands these out to hosts on demand

DHCP Server Discovery

- Newly booted or attached hosts send a DHCPDISCOVER message on network
- One node on network may be DHCP server and would reply
  - Downsides to this requiring this
- DHCP relay agent may be used

DHCP Relay Agent and Message Format

- Relay agent is configured with IP address of DHCP server

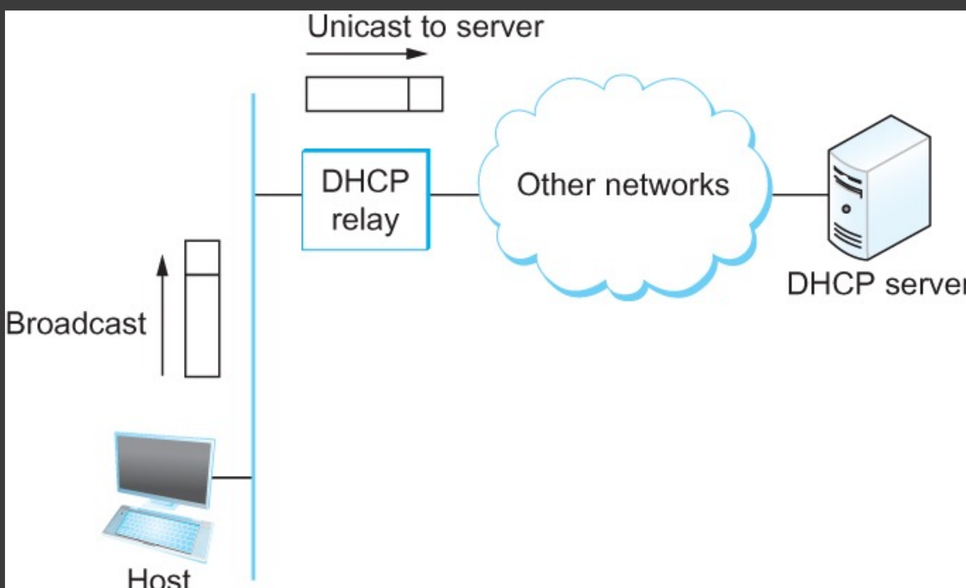


Figure 80

<table>
<tr><td>Operation</td><td>HType</td><td>HLen</td><td>Hops</td></tr>
<tr><td colspan="4">Xid</td></tr>
<tr><td colspan="2">Secs</td><td colspan="2">Flags</td></tr>
<tr><td colspan="4">ciaddr</td></tr>
<tr><td colspan="4">yiaddr</td></tr>
<tr><td colspan="4">siaddr</td></tr>
<tr><td colspan="4">giaddr</td></tr>
<tr><td colspan="4">chaddr (16 bytes)</td></tr>
<tr><td colspan="4">sname (64 bytes)</td></tr>
<tr><td colspan="4">file (128 bytes)</td></tr>
<tr><td colspan="4">options</td></tr>
</table>

Figure 81

DHCP continued

- DHCP allows addresses to be leased for some period of time
  - Cannot depend on host to return address
- Once lease expires, server returns the address to the pool
- Host needs to renew the lease periodically

Error Reporting

- ICMP: Internet Control Message Protocol
- Defines a collection of error messages
  - Examples:
    - Destination host is unreachable
    - The reassembly process failed
    - TTL reached 0
    - IP header checksum failed
    - etc.

ICMP continued

- Also defines control messages
- Example:
  - ICMP-Redirect
    - Tells source host there is a better route to the destination
    - Provides the basis for ping and traceroute

Virtual Networks and Tunnels

- May want controlled connectivity instead of unrestricted connectivity
  - Example: VPN—virtual private network
- Corporations may want private networks

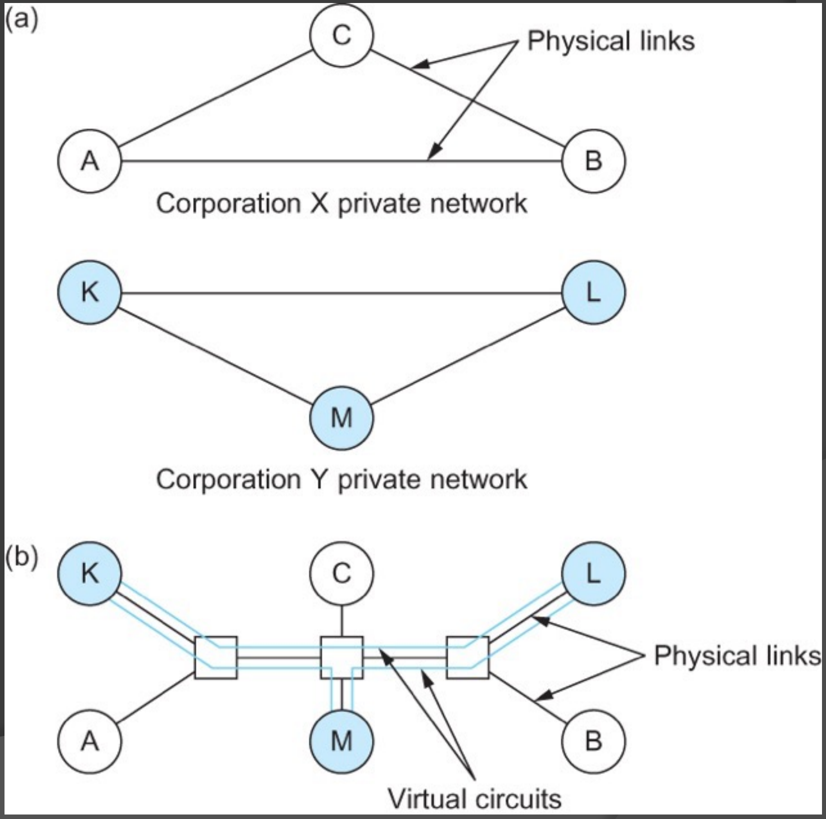


Figure 82

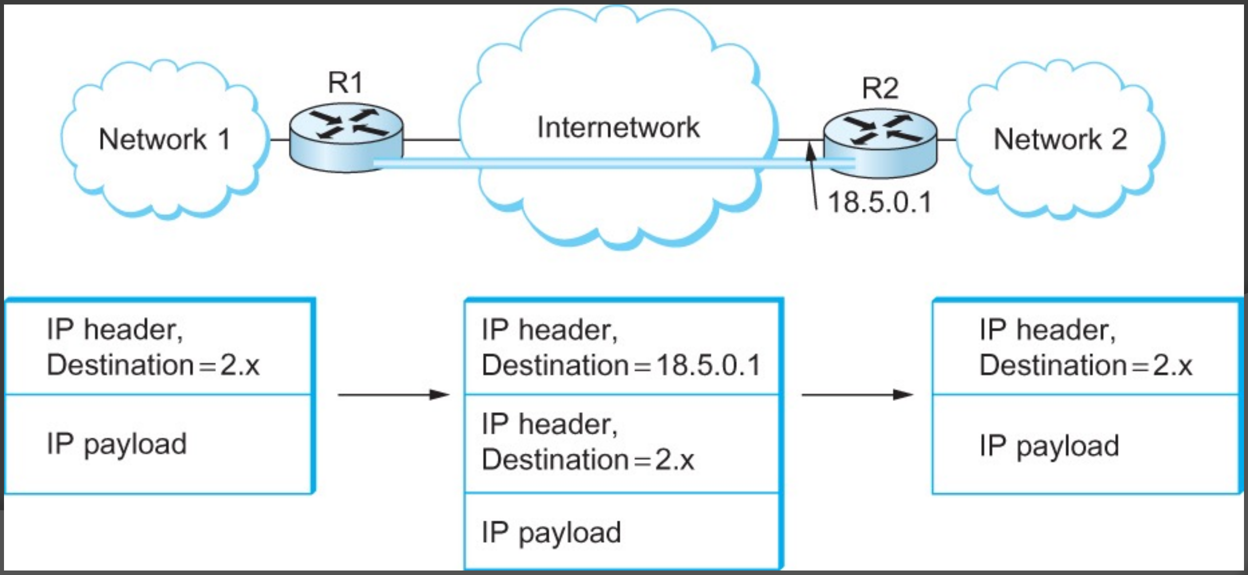
IP Tunnels

- Can use an IP network instead
  - Cannot connect company sites to an internetwork
  - Use an IP tunnel instead
    - Virtual point-to-point link between a pair of nodes separated by a number of networks

IP Tunnels continued

- Packet encapsulated in an IP datagram
  - Source address: Encapsulating router
  - Destination address: Router at the other end of tunnel
- Destination router removes IP header and forwards packet onto network

Figure 83



IP Tunnels continued

- Advantages
  - Security
  - Carry packets from protocols other than IP across an IP network
  - Others…
- Disadvantages
  - Increases the length of packets
    - More susceptible to fragmentation
  - Require routers to do more work
  - Must manage setup and maintenance of tunnels