CprE 450/550x
Distributed Systems and Middleware

Basics of Computer Networks (cont.)

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Internetworking and the Internet Protocol (IP)

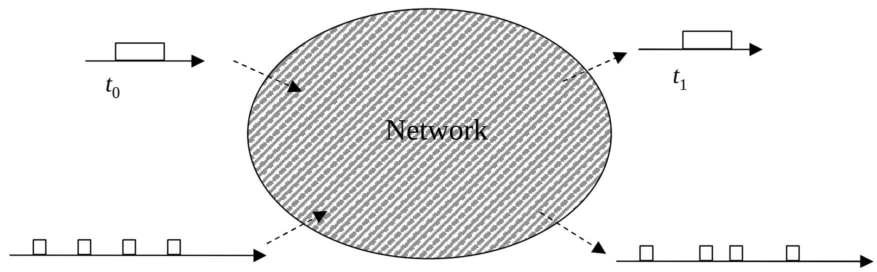
Network Layer Functions

- Network Layer Objectives
  - Transport (switch) packet from sending to receiving hosts
  - Network layer protocols in *every* host, router
- Three Necessary Functions
  - *Path Compuation:* route taken by packets from source to dest. *"Routing" algorithms*
  - *Switching:* move packets from router's input to appropriate router output
  - *Call Setup:* some network architectures require router call setup along path before data flows

Network Service Model

Q: What *service model* for "channel" transporting packets from sender to receiver?

- guaranteed bandwidth?
- preservation of inter-packet timing (no jitter)?
- loss-free delivery?
- in-order delivery?
- congestion feedback to sender?
- Virtual Circuit *vs*. Datagram service



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IP (Inter-networking) Protocol

- Challenges at Network Layer for Internetworks
- Service Models
  - Best Effort Service Model
  - Global Addressing Scheme
- Internetworking is the effective communication among users in different networks
  - Heterogeneity in networking technologies;
  - Applications should work on different types of networks and internetworks;
  - Internetworks should be scalable and leverage economies of scale.

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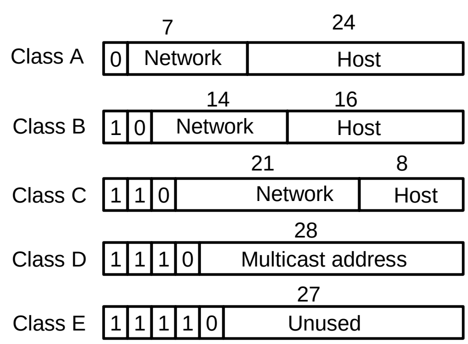
Challenge 1: Different Address Formats

- Provide one common format $\rightarrow$ map lower level addresses to a common format
- IPv4 address format: 32 bit length, hierarchical organization



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Challenge 2: Different Packet Sizes

- Define a maximum packet size over all networks. Why not?
- Implement fragmentation/re-assembly
  - who is doing fragmentation?
  - who is doing re-assembly?

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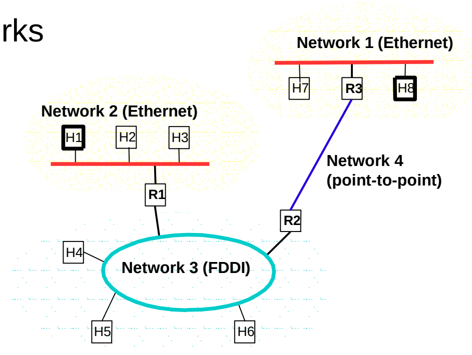
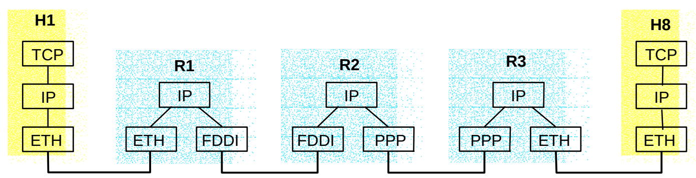
Other Challenges

- Errors $\rightarrow$ require end-to-end reliability
  - Add a transport layer on top of IP
- Different (routing) protocols $\rightarrow$ coordinate these protocols

IP Internets

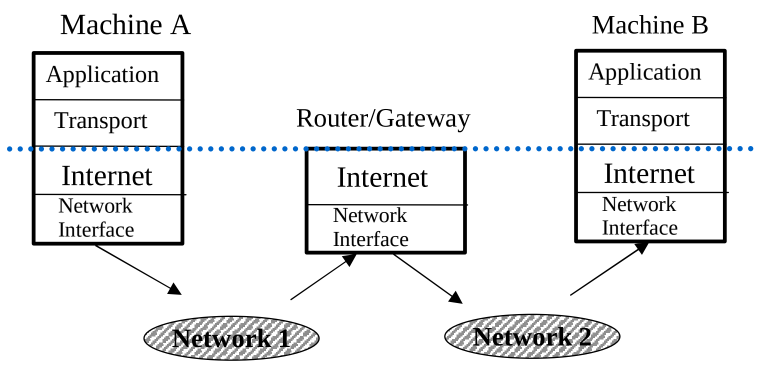
- Concatenation of Networks
- Protocol Stack



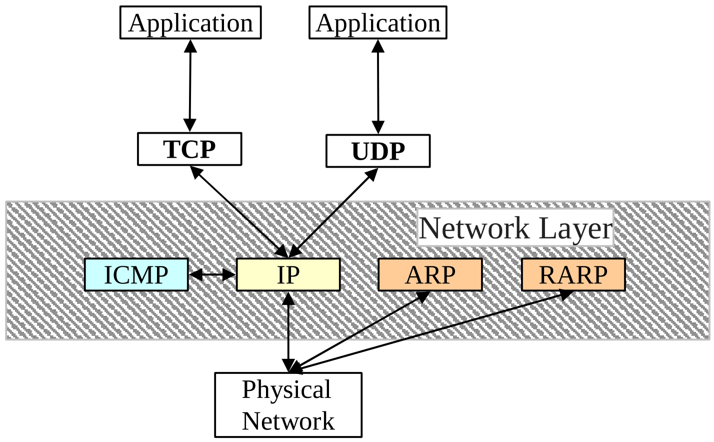


Network Layer on End-Points and Routers

- Routers ("gateways")

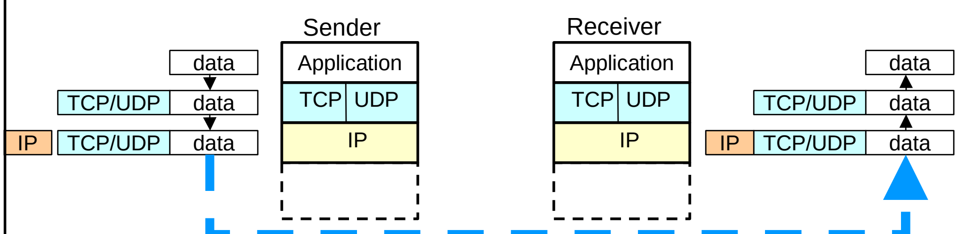


IP Related Protocols



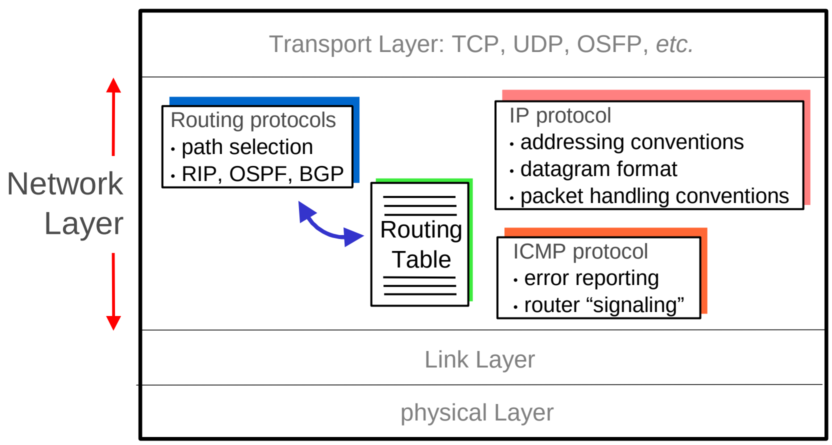
TCP/IP – Headers

- IP header → used by IP (Network Layer) for IP routing, fragmentation, error detection, *etc*.
- UDP header → used by UDP (Transport Layer) for multiplexing/demultiplexing, data error detection
- TCP header → used by TCP (Transport Layer) for multiplexing/demultiplexing, flow and congestion control



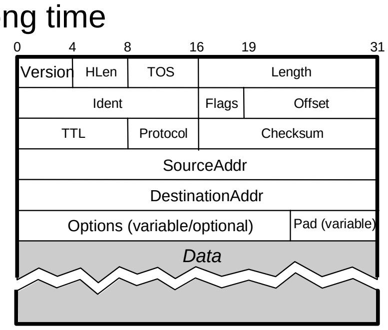
The Internet Network Layer

Host / Router network layer functions:



IPv4 Service Model

- IPv4 [RFC 791]
- Datagram-switching: Connectionless model.
- Best-effort delivery: Unreliable service
  – packets can get lost
  – packets can be delivered out of order
  – duplicate copies of a packet are delivered
  – packets can be delayed for a long time
- Datagram format
  – 64KB maximum size
  – IP Header (20B min)
    • Current version IPv4
    • IPv6 is next generation IP All vendors support it
  – IP datagram data payload



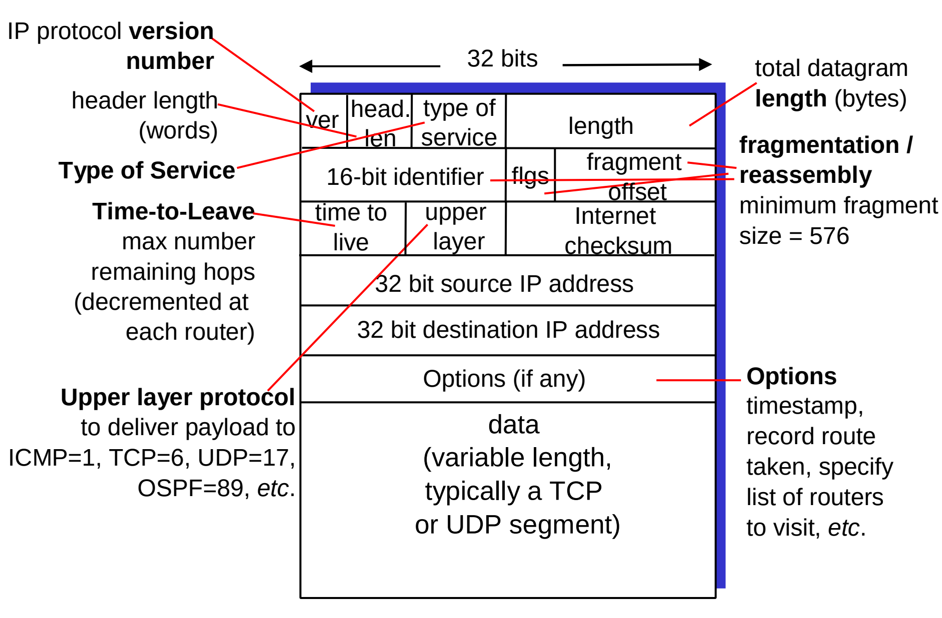
IP Datagram Format: IP Header

Max Size = 64KB

0	4	8	16	19	24 – 31
Version	IHL	Type of Service	Total Length		
Identification			Flags	Fragment Offset	
Time to Live		**Protocol**	Header Checksum		
Source IP Address					
Destination IP Address					
Options					Padding

- IP Header
  - HLen – header length in 32-bit words (5 ≤ HLen ≤ 15)
  - TOS (Type of Service): Reliability, Latency, Throughput. Now split in
    - Differentiated Service (DS) Field (6 bits)
    - other two bits used by ECN (Early Congestion Notification)
  - Length – the length of the entire datagram/segment; header + data
  - Flags: Don't Fragment (DF); More Fragments (MF)
  - Fragment Offset – all fragments excepting last one contain multiples of 8 bytes
  - Header Checksum - uses 1's complement (IP Checksum)

IP Datagram Format



IP Datagram Format: IP Header Fields

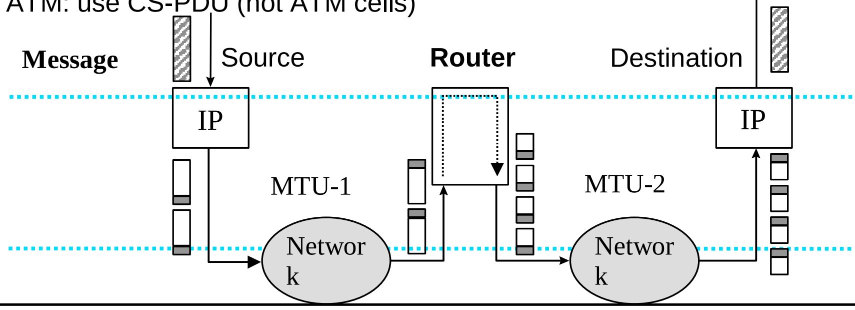
- IPversion [0.0..3] –
  - 4 = current, 6 = next generation IP “IPng” or IPv6, 5 = ST2 (a Real-Time stream protocol)
- Header Length [0.4..7] – in 32bit words
- Type of Service [0.8..15] – (preferences 4b, priorities 3b):
  - min delay, min $cost, max throughput, max reliability;
  - most routers ignore ToS; OSPF can use it;
  - DiffServ uses it as
    - differentiated Service (DS) Field (6 bits)
    - other two bits used by ECN (Early Congestion Notification).
- Total Length [0.16..31] – in bytes $\leq 2^{16}$
- Id, Flags, Offset [1.0..31] – used in fragmentation
- Time To Live (TTL) [2.0..7] – maximum number of hops DG can be forwarded.

IP Datagram Format: IP Header Fields

- Protocol [2.8..15] – the Transport Layer user of this DG:
  - ICMP = 1, TCP = 6, UDP = 17, OSFP = 89, *etc*.
- Header Checksum [2.16..31] – “IP Checksum” over the IP header fields [RFC 1071, RFC 1141]
- Source IP [3.0..31] / Destination IP[4.0..31] Addresses –
  - IP numbers of sending and receiving hosts
- Options [Variable Length] – Optional fields, requesting particular handling of current IP DG.
  - they complicate processing per IP DG in routers.
  - IPv6 allows more efficient handling of options via “extension headers”

Fragmentation and Reassembly

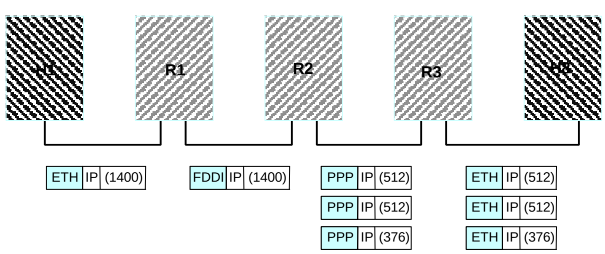
- Each network has some MTU
  - Maximum Transmission Unit (MTU) maximum packet size that can be carried by a L2 link. Path MTU := $\min_i \{ MTU_i \}$
- IP Strategy:
  - fragment when necessary (if MTU < Datagram); avoid fragmentation at source host
  - re-fragmentation is possible (if MTU < Fragment)
  - fragments are self-contained datagrams
  - delay reassembly until destination host
  - do not recover from lost fragments
  - ATM: use CS-PDU (not ATM cells)

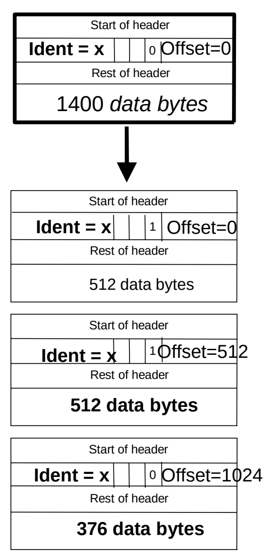


Fragmentation and Reassembly Example

- Maximum Transmission Units

DLL	MTU (Bytes)
802.3/802.2	1500
Ethernet	1492
FDDI	4352
802.5 (4/16)	4464/17914
X.25	576
PPP	296
Hyperchannel	65535





IP Addressing: Introduction

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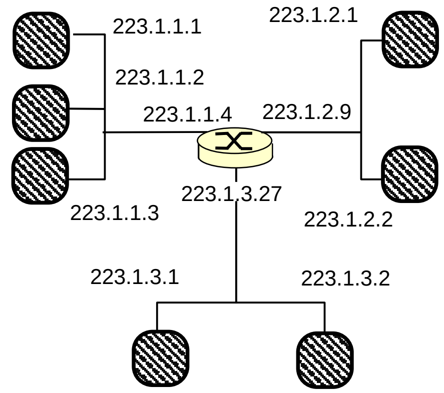
- IP Address: a unique 32-bit identifier for host, router *interface*
- *Interface (i/f):* connection between host / router and physical link
  - routers typically have multiple interfaces
  - host may have multiple interfaces
  - IP addresses associated with interface, not host or router



223.1.1.1 = 11011111 00000001 00000001 00000001

$\underbrace{11011111}_{223}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}\ \underbrace{00000001}_{1}$

IP Addressing

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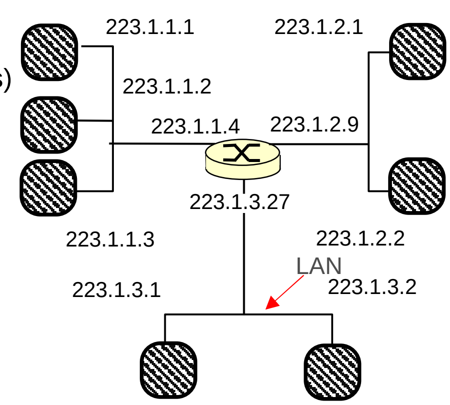
- IP Address: (Network, Host)
  - network part (high order bits)
  - host part (low order bits)
- *What's a network ?* (from IP address perspective)
  - device interfaces with *same network part* of IP address
  - can physically reach each other *without intervening* router



network consisting of 3 IP networks (for IP addresses starting with 223, first 24 bits are network address)

IP: Global Addresses

- Properties
  - globally unique, meaningful to IP layer;
  - hierarchical: network + host
- Five classes of IP addresses "Classful Addressing"

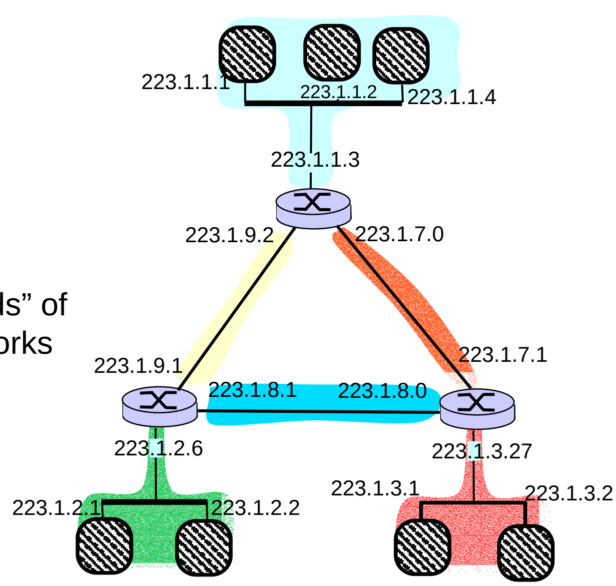
Bit position:	0 1 2 3	8	16	31
Class A	0	Net ID	Host ID	
Class B	1 0	Net ID		Host ID
Class C	1 1 0	Net ID		Host ID
Class D	1 1 1 0	Multicast Address		
Class E	1 1 1 1	Reserved for experiments		

IP Addressing

How to find the networks?

- Detach each interface from router, host
- Create "islands" of isolated networks

Interconnected system consisting of six networks



Getting a Datagram from Source to Dest

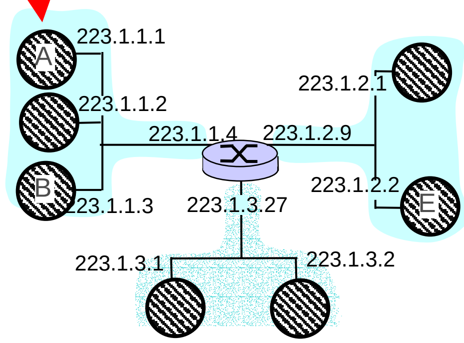
IP Datagram:

misc fields	source IP addr	dest IP addr	data

- **Datagram remains unchanged, as it travels source to destination**
- **Addr fields of interest here**

routing table in A

Dest. Net.	next router	Nhops
223.1.1		1
223.1.2	223.1.1.4	2
223.1.3	223.1.1.4	2



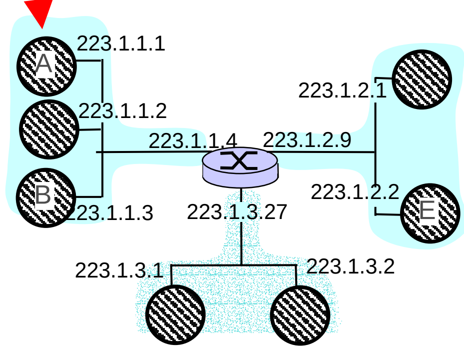
Getting a Datagram from Source to Dest

misc fields	223.1.1.1	223.1.1.3	data

Starting at A, given IP datagram addressed to B:

- **look up net. address of B**
- **find B is on same net. as A**
- **link layer will send datagram directly to B inside link-layer frame**
  - **B and A are directly connected**

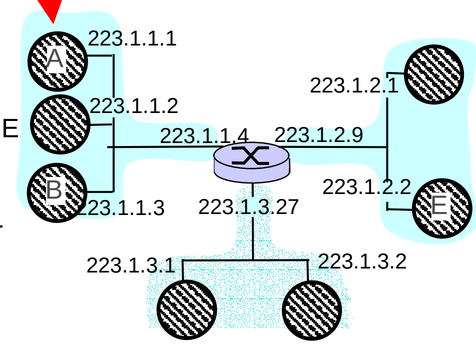
Dest. Net.	next router	Nhops
223.1.1		1
223.1.2	223.1.1.4	2
223.1.3	223.1.1.4	2



Getting a Datagram from Source to Dest

misc fields	223.1.1.1	223.1.1.3	data

Dest. Net.	next router	Nhops
223.1.1		1
223.1.2	223.1.1.4	2
223.1.3	223.1.1.4	2



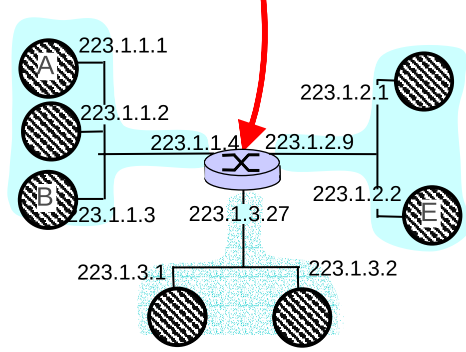
Starting at A, dest. E:

- look up network address of E
- E on *different* network
  - A, E not directly attached
- routing table: next hop router to E is 223.1.1.4
- link layer sends datagram to router 223.1.1.4 inside link-layer frame
- datagram arrives at 223.1.1.4
- continued…..

Getting a Datagram from Source to Dest

misc fields	223.1.1.1	223.1.1.3	data

Dest. network	next router	Nhops	interface
223.1.1	-	1	223.1.1.4
223.1.2	-	1	223.1.2.9
223.1.3	-	1	223.1.3.27



Arriving at 223.1.4, destined for 223.1.2.2

- look up network address of E
- E on *same* network as router's interface 223.1.2.9
  - router, E directly attached
- link layer sends datagram to 223.1.2.2 inside link-layer frame via interface 223.1.2.9
- datagram arrives at 223.1.2.2!!! (hooray!)

Subnetting

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

Original address	1	0	Net ID	Host ID	
Subnetted address	1	0	Net ID	***Subnet ID***	Host ID

Figure 8.6

Network number	Host number

Class B address

111111111111111111111111	00000000

Subnet mask (255.255.255.0)

Network number	Subnet ID	Host ID

Subnetted address

IP Datagram Forwarding Algorithm


```
D = destination IP address ;
for each entry ( SubnetNum, SubnetMask, NextHop ) do
   D1 = SubnetMask & D ;
   if ( D1 = SubnetNum ) then
      if ( NextHop is an interface ) then
         deliver datagram directly to D ;
      else
         deliver datagram to NextHop ;
```

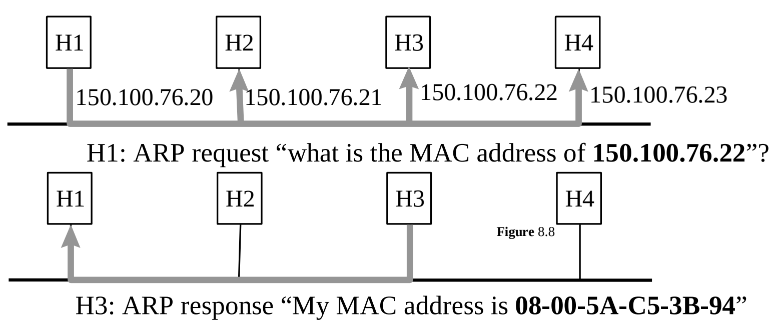
- Note:
  - Use a default router if nothing matches
  - Not necessary for all 1s in subnet mask to be contiguous
  - Can put multiple subnets on one physical network
  - Subnets not visible from the rest of the Internet

ARP Address Translation

- DLL requires L2 (MAC/hw) address to use for DA in the L2 frame.
- IP does not know L2 addresses.
- Mechanism to map IP (32b) numbers → physical addresses (48b)
  - destination host
  - next hop router
- Approaches
  - encode physical address in host part of IP address ;
  - table-based.

ARP Protocol

- ARP [RFC 826]
  - 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
- ARP Request and Response cycle



ARP Details

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- `arp -a` UNIX command for ARP cache
- Notes
  – table entries timeout in about 10 minutes
  – update table with source when you are the target
  – update table if already have an entry
  – do not refresh table entries upon reference
- RARP "Reverse ARP" [RFC 903] – What is the IP number of an interface with this h/w address?
  – Used to obtain IP numbers dynamically (BOOTP) from RARP server

ARP Packet Format

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0	8	16	31
Hardware type = 1		ProtocolT ype = 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)			

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

Internet Control Message Protocol (ICMP)

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- ICMP [RFC 792] is a “sibling” protocol with IP and it is used by hosts, routers, gateways to communicate network-level information among each other.
- ICMP is a Request / Reply protocol.
- Services:
  - ECHO Request / Reply (`ping`)
  - Timestamp Request / Reply (`ping`)
  - Redirect (from router to source host)
  - Destination unreachable (protocol, port, or host)
  - TTL exceeded (stop datagram endless “cycling”)
  - Checksum failed
  - Reassembly failed
  - Cannot fragment

ICMP: Internet Control Message Protocol

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- ICMP is used by hosts, routers, gateways to communicate network-level information
  - error reporting: unreachable host, network, port, protocol
  - echo request/reply (used by ping)
- network-layer “above” IP:
  - ICMP msgs carried in IP datagrams
- ICMP message: type, code plus first 8 bytes of IP datagram causing error
- ping
- traceroute

Type	Code	description
0	0	echo reply (ping)
3	0	dest. network unreachable
3	1	dest host unreachable
3	2	dest protocol unreachable
3	3	dest port unreachable
3	6	dest network unknown
3	7	dest host unknown
4	0	source quench (congestion control - not used)
5	x	redirects
8	0	echo request (ping)
9	0	route advertisement
10	0	router discovery
11	0	TTL expired
12	0	bad IP header
13	0	timestamp request, +
17	0	addrmask request, +

Commands

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- arp -a
  - The arp cache of the host; can also map IP name → IP number
- ifconfig -a
  - Lists all the interfaces of a host
- netstat
  - Very powerful command, with many parameters
- traceroute / ping
  - trace route and report RTTs from intermediate routers

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Any Questions?

See you next time.