

IP Layer

CSC 790

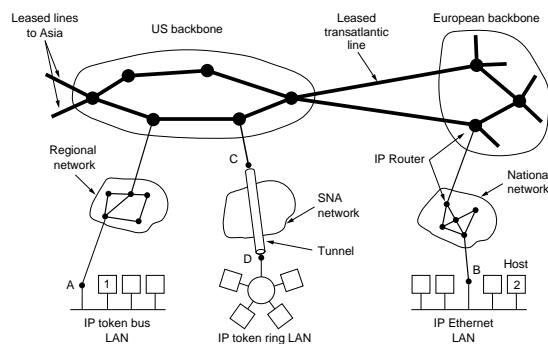
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Fall 2009

Network Layer in the Internet

- At the network layer, the Internet can be viewed as a set of Autonomous Systems that are connected together



- AS are connected via
 - LANs, backbone networks, leased lines, ...
- The network layer is what allows the pieces to interconnect

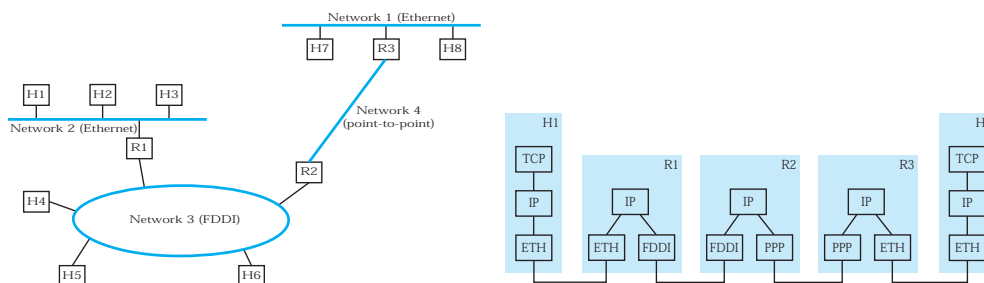
What Does IP Provide?

The Internet Protocol (IP) provides

- **Best Effort** (BE) transport of datagrams
 - *Packets delivered as quickly as possible*
 - Unreliable service
- Routing from source to destination
 - Can route to different AS
 - Datagram network → routes can be static or dynamic

Is IP suitable for multimedia applications? Why or why not?

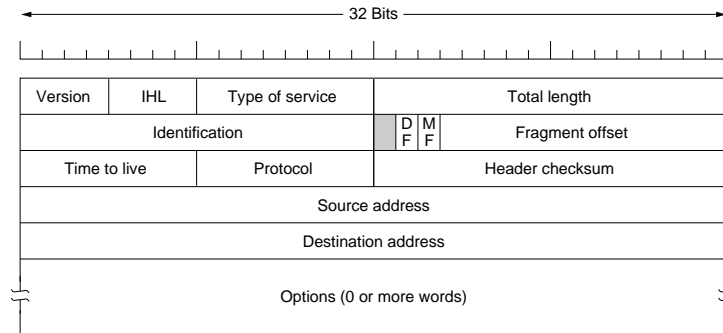
Internet Operation Overview



- Network layer takes data streams and breaks into datagrams
 - Datagram can be up to 64KB each, average is 1500 bytes
- Each datagram is transmitted through the Internet
 - Possibly fragmented
- Pieces arrive at destination, reassembled into original datagram
- Datagram is passed to the transport layer

IP Protocol Datagrams

- Datagram (packet) consists of a header part and data part
- Header consists of: 20 byte *fixed part* and an *optional part*



- Transmitted in big endian order (left → right) also called **network byte order**
 - SPARC is big endian, while Pentium is little endian

IP Header: ToS Field

Type of Service (ToS) is 8 bits

- Indicates the type of service expected, has sub-fields
 1. First three bits are the precedence (priority) sub-field
 - Range from 0 (normal) to 7 (control packet)
 - “*which is ignored today*” - Stevens
 2. Next four bits request different types of service

Application	Min Delay	Max Throughput	Max Reliability	Min Cost	Hex Value
Telnet	1	0	0	0	0x10
FTP data	0	1	0	0	0x08
SNMP	0	0	1	0	0x04

3. One unused bit
- ToS feature is not supported by most IP implementations

IP Header: TTL

- Time To Live (TTL, 8 bits)
 - Counter to limit packet lifetime
 - Maximum lifetime of packet (in seconds)
What is the maximum maximum lifetime?
 - Time spent at every router is subtracted
 - Actually decremented once per hop
 - Once zero is reached, a control packet is sent back
What problem does TTL attempt to prevent?

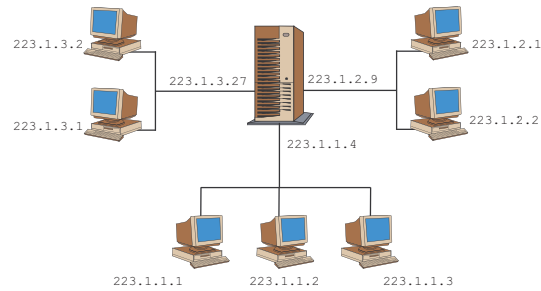
IPv4 Addresses

Every host or router (actually interface) has a unique IP address

- IP addresses are 32 bits long (IP version 4) and are used in the source and destination fields of the IP datagram
- *Dotted-decimal notation* is used to represent each address, each byte is represented via a decimal number
 - 193.32.216.9 \Rightarrow [11000001 00100000 11011000 00001001]
- Addresses are hierarchical and encode two numbers, **network** and **host**

IP Network Example

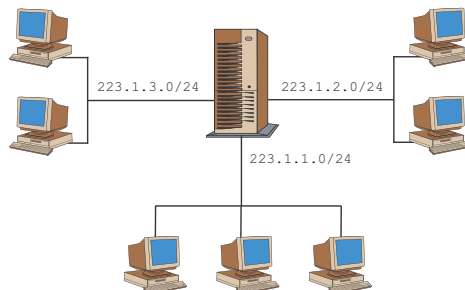
Consider one router and seven hosts (*one address per interface*)



- Three hosts at bottom have similar addresses, $223.1.1.x$
 - The leftmost 24 bits they share is the **network** portion
 - Remaining 8 bits is the **host** portion

How many hosts can connect to the $223.1.1.x$ network?

- Hosts of $223.1.1.x$ form a network, interconnected via a LAN
 - The network address is $223.1.1.0/24$
 - The $/24$ is also called the **network mask** or **network prefix**
 - * Indicates the 24 leftmost bits define the network address
 - Any additional host that would attach to this network must have a unique address of the form $223.1.1.x$
- The remaining networks have a similar structure



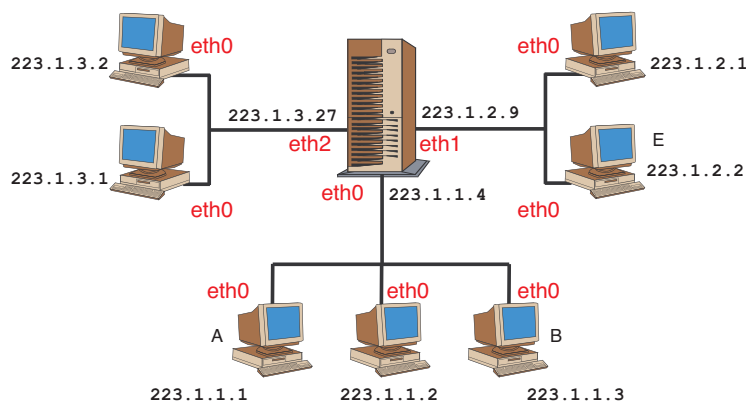
Routing Tables

How does a source host send a datagram to a destination host?

- The IP layer maintains a **routing table** in memory
 - Remember, routing tables are *next hop* oriented
 - Multiple hop paths are not recorded
- Each entry in the routing table has the following information^a
 1. Destination address, either *host* or *network* address
 2. IP address of the *next-hop router*
 3. Flags specifying if next hop is host or network
 4. Identification of the interface the datagram should be passed to (e.g. multiple Ethernet cards attached)

^aAbbreviated list of items, more later.

Example Routing Tables



- In the diagram, each interface (Ethernet card) is labeled (in red)
- For example, the router has 3 interfaces (eth0, eth1, and eth2)
 - Each interface must be uniquely identified, since it attaches a unique network

- An abbreviated routing table for host A would be

Routing Table for A		
Destination	Next Hop	Interface
223.1.1.0/24		eth0
223.1.2.0/24	223.1.1.4	eth0
223.1.3.0/24	223.1.1.4	eth0

- First entry indicates 223.1.1.0/24 is the local network
- The second and third entries indicate datagrams for destinations on network 223.1.2.0/24 or 223.1.3.0/24 must be sent to 223.1.1.4
- eth0 is the Ethernet interface (only one card on A)

Each network is represented with one entry, how many would be required if each host had a separate entry?

- An abbreviated routing table for the router would be

Routing Table for Router		
Destination	Next Hop	Interface
223.1.1.0/24		eth0
223.1.2.0/24		eth1
223.1.3.0/24		eth2

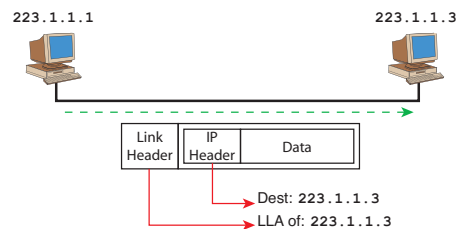
- First entry indicates 223.1.1.0/24 is local on eth0
- Second entry indicates 223.1.2.0/24 is local on eth1
- Third entry indicates 223.1.3.0/24 is local on eth2

IP Routing Steps

- IP routing performs the following actions
 1. Search routing table for complete destination address, if found send packet to the next-hop entry
 2. Search routing table for an entry that matches the destination network number, if found send packet to the next-hop entry
 - Must take into account possible subnet mask
 3. Search for *default* entry, if found send to next-hop router
- IP search order is, host address → host network → default
- If all the steps fail, then the datagram is not deliverable

Routing Example: A → B

Assume A (223.1.1.1) sends datagram to B (223.1.1.3)



- There is no host entry for 223.1.1.3
- There is a network entry for 223.1.1.0/24
- A link layer frame (containing the datagram) is created and addressed to the link layer address of 223.1.1.3

We are at layer 3, how do we get a layer 2 address?

- Ethernet frame is sent and received by host B

Routing Example: A → E

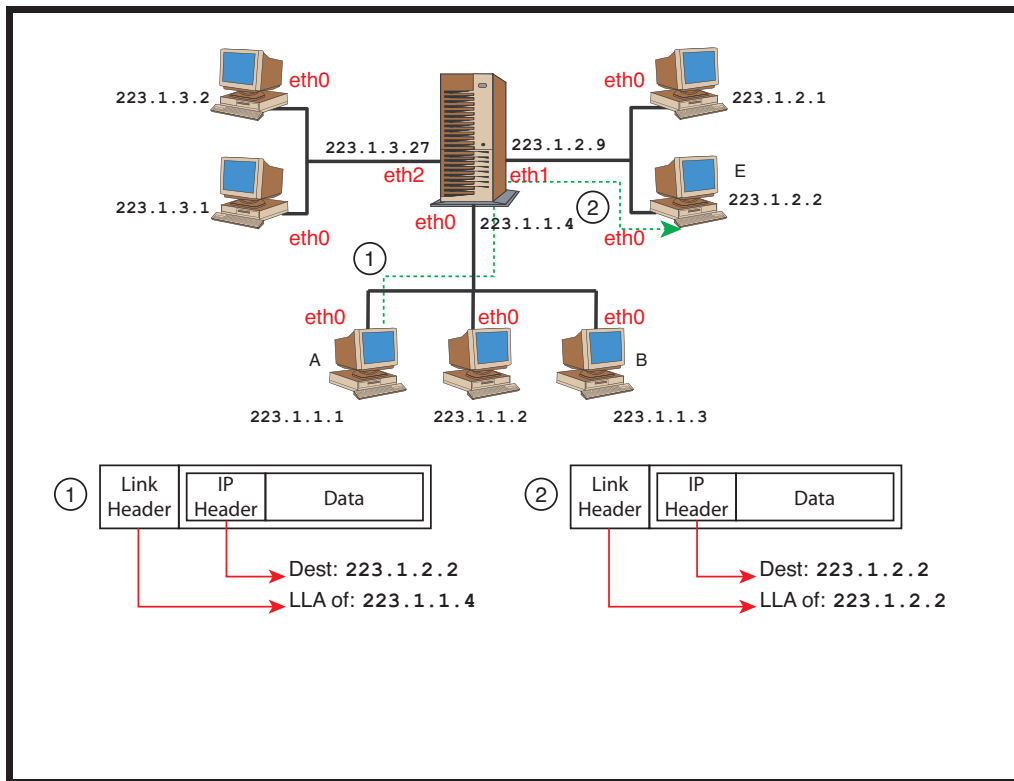
Assume A (223.1.1.1) sends datagram to E (223.1.2.2)

Routing Table for A		
Destination	Next Hop	Interface
223.1.1.0/24		eth0
223.1.2.0/24	223.1.1.4	eth0
223.1.3.0/24	223.1.1.4	eth0

Routing Table for Router		
Destination	Next Hop	Interface
223.1.1.0/24		eth0
223.1.2.0/24		eth1
223.1.3.0/24		eth2

- Host A finds entry for 223.1.2.0/24 network
 - Requires sending packet to 223.1.1.4
- Host A creates and sends link-layer frame (containing datagram) addressed to the link-layer address of 223.1.1.4
 - Therefore, the next-hop entry is used for the link-layer address
 - IP destination address remains unchanged

- Router 223.1.1.4 receives frame and removes datagram
 - Destination address is 223.1.2.2
 - Router is allowed to forward datagrams
- Router finds entry for 223.1.2.0/24 network
 - This is directly connected via eth1
 - Datagram will be forwarded
- Router creates and sends link-layer frame (containing datagram) addressed to the link-layer address of 223.1.2.2 on eth1
- Frame received by host E, datagram removed and processed
- N.B. operation of host and router are equivalent, except routers are allowed to forward datagrams



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Static versus Dynamic IP Routing

- Already know how IP packets are routed using routing tables
 - *How were the entries generated... statically or dynamically?*
- In static routing entries are manually adjusted
 - Acceptable for small networks
- For larger networks, dynamically change table entries
 - Routes should change based on network conditions
 - Allow routers to pass route information to one another
 - Use variations of Bellman-Ford and Dijkstra's
- N.B. This will **not** change the way IP datagrams are routed, just how/when the routing table contents change

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Internet and Autonomous Systems

- Internet is a collection of connected networks
 - Local, regional, national, and international ISPs
- Autonomous Systems (AS)
 - Collection of routers/hosts under an administration control
 - May consist of multiple networks
 - Why is it important to divide into autonomous systems?*
- Within this hierarchy classify routing algorithm as
 - **Intra-AS** route within one autonomous system
 - **Inter-AS** route among autonomous systems

Intra-AS Routing

- Used to configure and maintain routing tables within an AS
- Also called **Interior Gateway Protocols (IGP)**
- Historically three routing protocols have been used
 - Routing Information Protocol (RIP)
 - Open Shortest Path First (OSPF)
 - Enhanced Interior Gateway Routing Protocol (EIGRP)
Cisco propriety