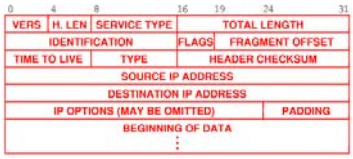
Virtual Packets

- Because routers can connect heterogeneous networks, they cannot just transmit an exact copy of the frame that arrives on one network across another.
- To accommodate heterogeneity, an internet must define a hardware-independent packet format.

IP Datagrams

- A packet sent across a TCP/IP internet is called an IP datagram. Each datagram consists of a header followed by data. Source and destination addresses in the datagram header are IP addresses.
- The size of a datagram is determined by the application that sends data. Allowing the size of datagrams to vary makes IP adaptable to a variety of applications.

The IP Datagram Header Format



VERS – 4-bit protocol version number
H.LEN – 4-bit header length (specifies # of 32-bit quantities)
SERVICE TYPE – specifies sender preference of min. delay or max. throughput
TOTAL LENGTH – 16-bit integer that specifies # of octets
IDENTIFICATION, FLAGS, & FRAGMENT OFFSET – covered later
TIME TO LIVE – used to prevent a forever loop
HEADER CHECKSUM – ensures that bits of the header are not changed in transit
DESTINATION IP ADDRESS – IP address of the final destination
PADDING – ensures that the header length is a complete 32-bit multiple
IP SOURCE ADDRESS – contains the internet address of the sender.
TYPE – specifies the type of data.

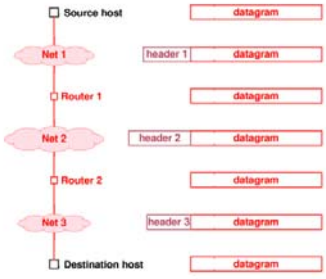
IP Encapsulation

- A datagram is encapsulated in a frame for transmission across a physical network.
- The destination address in the frame is the address of the next hop to which the datagram should be sent.

An IP datagram encapsulated in a hardware frame. The entire datagram resides in the frame data area.

Internet Transmission

- When a datagram arrives in a network frame, the receiver extracts the datagram from the frame data area and discards the frame header.



An IP datagram as it appears at each step during a trip across an internet. Whenever it travels across a physical network, the datagram is encapsulated in a frame appropriate to the network.

Destination & Next-Hop Address

- The destination address in an IP datagram header always refers to the ultimate destination.
- When a router forwards the datagram to another router, the address of the next hop does not appear in the IP datagram header.
- The address in the MAC layer frame is always the address of the next hop.

Best-Effort Delivery

- Because IP is designed to operate over all types of network hardware, the underlying hardware may misbehave.
- As a result, IP datagrams may be lost, duplicated, delayed, delivered out of order, or delivered with corrupted data.
- Higher layers of protocol software are required to handle each of these errors.

Connectionless Service

- Packets are sent on the network with no initial setup.
- Each IP packet contains the IP address of the destination.
- Packets to the same destination might follow different routes.

IP Addressing Scheme

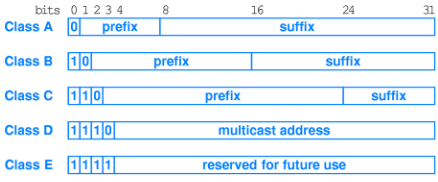
- An Internet Address is a unique 32-bit binary number assigned to a host and used for all communication with the host.
- Each packet sent across an internet contains the 32-bit IP address of the sender as well as the intended recipient.

Internet Addresses

- An Internet Address is composed of two parts, a netid and a hostid.
- The hostid identifies the particular host on a network.
- The netid identifies the network where the host is connected.
- A computer physically connected to two networks needs two Internet addresses.

IP Addressing Classes

- The prefix or NetID identifies a network, and the suffix or HostID is unique to a host on that network. The class is determined by the first few bits.



IP Routing

- If a host has the IP name of the destination but does not know the IP address, it must send a request to the DNS.
- If a host does not know the MAC address of a destination computer on it's local network, it must use ARP to find the address.

Domain Name Servers

- Domain Name Servers (DNS) map Internet Names to Internet Addresses.
- A DNS maintains a distributed database of names and addresses.
- Computers can send a request to a DNS to get the IP address of a computer.
- Hosts and DNS cache addresses they have found.

Address Resolution Protocol (ARP)

- Used by a computer to find the MAC or physical address of another computer on the **same** network.
- To find a MAC address, ARP broadcasts a request containing the desired IP address to all computers.
- The computer with the matching IP address replies with its MAC address.

Local Routing Decision

- When sending an IP datagram, the source computer must decide if it can send the packet directly to the destination on the local network or if it must send the packet to a router or gateway.
- Each host must be aware of the address of its local DNS and default gateway.

Local Destinations

- If the NetID of the destination's IP address is the same as the NetID of the source's IP address, then the destination is in the same Internet domain.
- The frame can be sent directly to the destination.
- ARP may be needed to find the destination's MAC address.

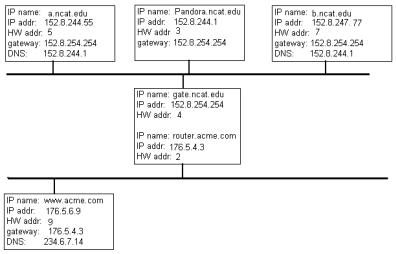
Global Desitnations

- If the NetID of the destination's IP address is different from the NetID of the source's IP address, then the destination is in another Internet domain.
- The frame must be sent to a gateway.
- ARP may be needed to find the gateway's MAC address.
- The IP destination address will be the IP address of the final destination.

IP Routing Example

- Assume that all computers were just powered on and have no additional information other than their IP configuration.
- **`a.ncat.edu`** wants to send one packet to **`b.ncat.edu`**

Example Network



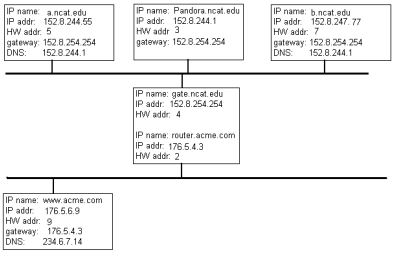
Packets Sent

Source HW addr	Dest HW addr	Source IP addr	Dest. IP addr	Purpose
5	broadcast	152.8.244.55	152.8.244.1	ARP DNS
3	5	152.8.244.1	152.8.244.55	DNS ARP reply
5	3	152.8.244.55	152.8.244.1	Ask DNS for addr
3	5	152.8.244.1	152.8.244.55	DNS sends addr
5	broadcast	152.8.244.55	152.8.247.77	ARP for B
7	5	152.8.247.77	152.8.244.55	B's ARP reply
5	7	152.8.244.55	152.8.247.77	A sends data

Follow-on Example

- Assume all of the traffic from the previous example has just occurred. Information learned by these exchanges has been cached.
- **`a.ncat.edu`** wants to send another packet to **`b.ncat.edu`**

A sends the datagram to B



Source HW addr	Dest HW addr	Source IP addr	Dest IP addr
5	7	152.8.244.55	152.8.247.77

Another IP Routing Example

- Assume that all computers were just powered on and have no additional information other than their IP configuration.
- **`a.ncat.edu`** wants to send one packet to **`www.acme.com`**

Packets Sent

Source HW addr	Dest HW addr	Source IP addr	Dest. IP addr	Purpose
5	broadcast	152.8.244.55	152.8.244.1	ARP DNS
3	5	152.8.244.1	152.8.244.55	DNS ARP reply
5	3	152.8.244.55	152.8.244.1	Ask DNS for addr
3	5	152.8.244.1	152.8.244.55	DNS sends addr
5	broadcast	152.8.244.55	152.8.254.254	ARP gateway
4	5	152.8.254.254	152.8.244.55	gateway ARP reply
5	4	152.8.244.55	**176.5.6.9**	send data to router
2	broadcast	176.5.4.3	176.5.6.9	gateway ARP www
9	2	176.5.6.9	176.5.4.3	www ARP reply
2	9	**152.8.244.55**	1176.5.6.9	send data to www