SE 4C03 Winter 2008

04 Internet Protocol (IP)

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22 January 2008

Internet Protocol (IP)

- IP provides a connectionless packet delivery service between internet hosts.
  - Connectionless: packets bounce across a sea of computers.
  - Best-effort delivery: service is designed to deliver every packet.
  - Unreliable: packet delivery is not guaranteed.
- IP defines a mechanism consisting of:
  - A basic unit of data transfer called an internet or IP datagram.
  - Software for routing datagrams.
  - Rules for how hosts (and routers) should process datagrams.

Internet Datagrams

- Similar to physical network frames.
  - Have header and data areas.
  - Header contains source and destination IP addresses.
- Unlike frames, datagrams are generally manipulated by software, not hardware.
- Datagrams are transferred across networks in the data area of a physical frame.
- Ideally, the whole datagram is encapsulated in the physical frame, but this cannot always be done .

Fragmentation

- Each network has a maximum transfer unit (MTU), the limit on how much data can be transferred per frame.
  - The MTU for Ethernet is 1500 octets.
  - The MTU for FDDI is about 4500 octets.
- The maximum size allowed for a datagram is $2^{16} = 65,536$ octets.
- Fragmentation occurs when the length of a datagram is bigger than the MTU for the network on which it is to be transferred.
  - The host or router forwarding a datagram divides the datagram into fragments which have the same format as a full datagram.
  - The fragments are not reassembled until they arrive that their final destination.
  - Reassembly fails if any fragments are lost.

Fields in Datagram Header Area (1)

- Version, the version of IP used to create the datagram.
- Header length, the length of the header area.
- Service type specifies how the datagram should be handled.
- Total length of the datagram.
- Identification number of the datagram which is used, for example, to identify the fragments of the same datagram.
- Flags contain information for controlling fragmentation (do not fragment and more fragments bits).
- Fragment offset is used to reassemble fragments.

Fields in Datagram Header Area (2)

- Time to live holds the maximum number of routers the datagram is allowed to visit.
- Protocol holds the type of the datagram.
- Header checksum is used for checking the integrity of the datagram's header.
- Source IP address.
- Destination IP address.
- IP options is an optional field that may be used for holding testing information.

IP Options

- The field contains a string of IP options each consisting of a single octet option code, a single octet length field, and a variable length data field.
- Example IP options:
  - Record route holds the list of IP addresses that the datagram has visited.
  - Source route prescribes a route (represented as a partial or total list of IP addresses) through the internet for the datagram to take.
  - Timestamp holds the list of IP addresses that the datagram visited with each address timestamped with the Universal Time when the datagram was handled.

IP Routing

- IP routing is the process of choosing a path across an internet for a datagram to travel.
- Routing may also be used in individual physical networks.
- IP routing is performed by internet routers as well as by each host on the internet.
- IP routing can be both static and dynamic.
  - Static routing is configured by hand by system administrators.
  - Dynamic routing is configured automatically by routing protocols.

Kinds of Datagram Delivery

- There are three kinds of datagram delivery:
  1. Immediate: The datagram is delivered to the host that is processing the datagram.
  2. Direct: The datagram is transmitted via a directly connected SPN to the destination host.
  3. Indirect: The datagram is transmitted via a directly connected SPN to a "next hop" router which will forward the datagram.
- For both direct and indirect delivery, the router needs to determine:
  1. The IP address of the next host h that is to receive the datagram .
  2. The interface to the physical network on which h resides.

Routing Tables (1)

- Each host and router h contains an IP routing table.
- Routing for direct and indirect delivery is usually done on the basis of the network portion of the datagram's destination address .
- Each entry in the table for direct delivery is of the form (a, i) where:
  1. a is the IP network address of an SPN N directly connected to h.
  2. i is the network interface that connects h to N.

Routing Tables (2)

- Each entry in the table for indirect delivery is of the form (a, r, i) where:
  1. a is the IP network address of some SPN.
  2. r is the IP address of the next hop router on an SPN N directly connected h.
  3. i is the network interface that connects h to N.
- The table may contain a default route of the form $(*, r, i)$ where:
  1. $*$ matches any network address.
  2. r is the IP address of the default router on an SPN N directly connected to h.
  3. i is the network interface that connects h to N.

Routing Tables (3)

- The table may contain entries for host-specific routes of the form (a, r, i) where:
  1. a is a host IP address.
  2. r is the IP address of the next hop router on an SPN N directly connected to h.
  3. i is the network interface that connects h to N.
- Notice that the table contains no information about SPNs (such as physical addresses) except for IP addresses and network interfaces.

Basic Routing Algorithm

1. Extract destination IP address d from datagram.
2. Deliver datagram to the host if d matches one of the IP addresses of the host (for incoming datagrams only),
3. Otherwise extract the destination network address d' from d,
4. Forward the datagram as specified by the first entry in the host's routing table that matches d or d'.
5. Otherwise declare a routing error.

Special Cases

- Routing in single-homed hosts.
  - Need to route outgoing datagrams.
  - Usually should not route incoming datagrams.
- Sending a datagram to the source host itself.
  - Route the datagram to the loopback interface (which will cause the datagram to be added to the incoming datagram queue).
  - Route the datagram for direct delivery to one of the other local SPNs (which will cause the datagram to be redirected to the loopback interface).

Class Network Problem for Routing

- Underlying assumption: There is a one-to-one mapping between SPNs and class networks such that, if SPN N is mapped to class network C, then the address of each interface on N is a member of C.
- This assumption is problematic because class networks are too rigid and too few.
- Need a way of sharing a single class network of addresses among several SPNs.

Solution 1: CPNs

- Use special routers to combine one or more SPNs into a compound physical network (CPN) that behaves like a SPN.
- Transparent router scheme.
  - Transparent routers manipulate IP datagrams.
  - They lack the full status of an IP router, and in particular, their interfaces are not assigned IP addresses.
- Proxy ARP scheme.
  - Proxy ARP routers manipulate physical frames.
  - They allow ARP requests and replies to be sent from one SPN to another.

Solution 2: Anonymous Networks

- The interfaces on a point-to-point network are not assigned IP addresses.
- The interface hardware does not use a next hop address so it can be whatever one wants.

Solution 3: Subnetting

- Divide a class network into several subnets.
  - Called subnetting or subnet addressing.
- New underlying assumption: There is a one-to-one mapping between SPNs and subnets such that, if SPN N is mapped to subnet S, then the address of each interface on N is a member of S.
- Subnetting should be kept simple within an organization:
  - All subnet masks should be contiguous (i.e., a string of 1s followed by a string of 0s).
  - All the subnets of the organization should have the same mask.
  - All hosts in the organization should participate in subnetting.

Solution 4: Supernetting

- Combine a range of class networks into a subnet.
  - Called supernetting, supernet addressing, or classless addressing.
- Benefits:
  - Several Class C networks can be used instead of a class B network.
  - Routing tables are smaller.
  - Internet Service Providers (ISPs) can manage a collection of class C networks.
- Routing is complicated because an address does not self-identify the subnet it belongs to.

Subnet Routing

Each host or router h contains a routing table with entries of the form (a, m, r, i) where:

1. a is the subnet address of an SPN N.
2. m is the subnet mask of N.
3. r is the IP address of the next hop router on N or $*$ (which signifies that the next hop is the destination address of the datagram).
4. i is the network interface that connects h to N.

Special cases

- A class A network route has the form $(a, 255.0.0.0, r, i)$ where a is the network address of the class.
- A class B network route has the form $(a, 255.255.0.0, r, i)$ where a is the network address of the class.
- A class C network route has the form $(a, 255.255.255.0, r, i)$ where a is the network address of the class.
- A host-specific route has the form $(a, 255.255.255.255, r, i)$ where a is the address of the host.
- A default route has the form $(0.0.0.0, 0.0.0.0, r, i)$.

Unified Routing Algorithm

1. Extract the destination IP address d from datagram.
2. Deliver the datagram to the host if d matches one of the IP addresses of the host (for incoming datagrams only).
3. Otherwise forward the datagram as specified by the first entry (a, m, r, i) in the host's routing table such that

$$d \text{ bitwise-and } m = a.$$

4. Otherwise declare a routing error.

Delivery Failure

- The delivery of an IP datagram may fail because:
  - Networking hardware and software are not functioning correctly.
  - The destination host or intermediate routers are down.
  - The routing tables of the source host or intermediate routers are misconfigured.
  - The routing path is too long (and therefore the time-to-live limit is surpassed).
  - Datagram traffic is too congested.
- There needs to be a mechanism for reporting network failures.
  - Cannot be implemented in hardware.
  - Must use the IP protocol.

Internet Control Message Protocol (ICMP)

- ICMP is for:
  - Reporting network failures.
  - Controlling network traffic.
- ICMP reports but does not correct errors.
  - Errors are reported only to the source address of the IP datagram that could not be delivered.
  - Fixing errors requires cooperation between host administrators and network administrators.
- ICMP also provides basic network services like the ping.
- ICMP messages are encapsulated in IP datagrams.
  - The protocol field of the IP datagram is set to 1 (for ICMP).
  - The ICMP message is held in the IP datagram's data area.

When ICMP is Not Used

ICMP messages are not sent in response to:

- An ICMP message.
- A datagram with a broadcast destination address.
- A datagram with a source address that does not define a single host (i.e., zero address, loopback address, broadcast address, or multicast address).
- A noninitial IP datagram fragment .

Format of an ICMP Message

- Header:
  - Type (8 bits) identifies type of message.
  - Code (8 bits) identifies subtype of message.
  - Checksum (16 bits) holds checksum of entire message.
- Data area:
  - Header of the failed IP datagram.
  - First 64 data bits of failed IP datagram.

Destination Unreachable Messages

- Destination unreachable messages have type 3, code 0–15.
- Means router cannot forward or deliver IP datagram.
  - Message is sent to the datagram's source address.
  - Router drops the datagram.
- Network unreachable message (code 0) usually means there is a routing error.
- Host unreachable message (code 1) means that the datagram could not be directly delivered.
- Port unreachable message (code 3) means that no server is listening at the requested port.

Source Quench Messages

- Source quench messages have type 4, code 0.
- Means a router has to drop a message due to traffic congestion.
- Types of congestion:
  - Too many datagrams coming from one host.
  - Too many datagrams coming from several hosts together.

Redirect Messages

- Redirect message have type 5, code 0–3.
- Used by a router to tell a host to change one of its routes.
  - Router and host must be on the same SPN.
  - Does not solve the general problem of propagating routes.
- Allows a host to boot with minimal routing information.

Ping Service

- The ping service uses echo request (type 8, code 0) and echo reply (type 0, code 0) to test if a specified destination IP address is reachable.
- A successful request/reply shows:
  - Source host has IP working and can route IP datagrams.
  - Intermediate routers can route IP datagrams to the destination correctly.
  - Destination host is running, has IP working, can route IP datagrams, and has ICMP working.
- Sophisticated versions of ping will provide statistics about datagram loss and response times.
- Ping can be used by hackers to probe networks.

Miscellaneous Messages

- Time exceeded message (type 11, code 0–1).
  - For code 0, means time-to-live limit was exceeded.
  - For code 1, means fragment assembly time limit was exceeded.
- Parameter problem message (type 12, code 0–1).
  - Usually means format of datagram's header is wrong.
- Clock synchronization service.
  - Uses timestamp request (type 13, code 0) and timestamp reply (type 14, code 0) to ask another machine for the time.
- Subnet mask determination service (obsolete).
  - Uses subnet mask request (type 17, code 0) and subnet mask reply (type 18, code 0) to ask another machine for the subnet mask of the local network.