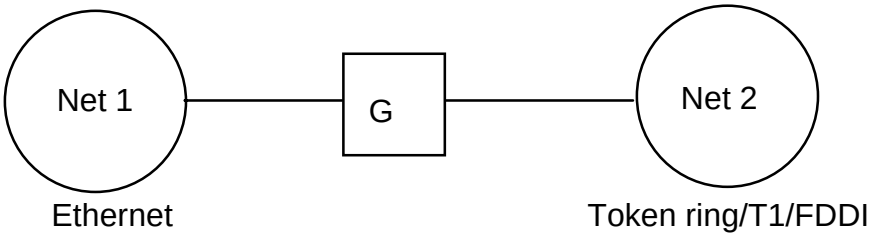
CS4984 -- Parallel and Distributed Computation
CS/EE 5516 -- Computer Networks
Lecture 9: IP Protocol
Comer, *Internetworking with TCP/IP, Vol. I*, Ch. 3, 4, 5, 7-8, 16.6

Lecture material:

- 3.3.3.1 Users desire universal interconnection
  Implications
  - Don't want to mandate any interconnect topology - organization can add LAN whenever it wants. Backbone graph need not be a star, ring, tree,etc.
  - Need 1 set of names/addresses used throughout internet
  - Network level operations should be independent of physical network topology. (Ethernet vs. radio net vs. T1)

- 3.5 How are networks interconnected to form an internet?

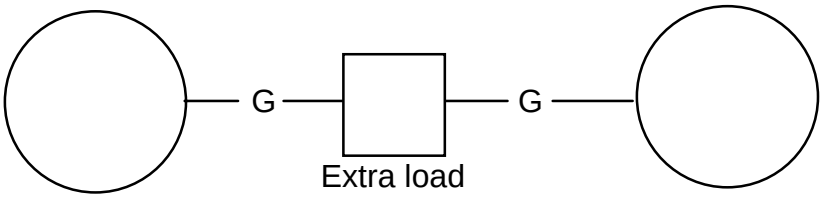


  - gateway or IP router vs:
    repeater -> forward (amplify) electrical signals
    bridge -> store and forward packets based on physical address

  - gateway does:
  - attaches >= 2 networks
  - routes packets based on destination network id (not destination host) -> smaller tables
  - can fragment packets if MTU (max transfer unit) < incoming datagram size
  - routing based on IP addresses
  - Routing table updated periodically
  - Small computer, perhaps w/ no disk.

	can connect networks	How packets are forwarded	Routing?
Repeater (Ethernet)	N = 1	Copy electrical signal	NO
Bridge	N = 2	Store,forward packet	Yes, on pys. addr.
IP Router/ Gateway	arbitrary but smal N	Store,forward packet	Yes, on IP address

- The internet model implies:
  - Your network may carry an extra load due to traffic on 2 networks that your network connects:



  - A "network" in TCP/IP view maybe
  - an Ethernet LAN
  - a wide area backbone (NSFnet - T3 links)
  - a point-to-point link between machines
  - a satellite link between machines
  - The above vary by a large range of delay, throughput, #nodes/network

- History:
  - 1970's: ARPANET was early experiment in **networking**
  - Early 1980's: TCP and IP protocols replace earlier ARPANET protocols; emphasis switches to **internetworking**
  - 1984: ARPANET + MILNET split
  - 1987: NSFNet links supercomputer centers, funds regional networks, allows ubiquitous network service

- Why TCP/IP?
  - Vendor-independent: a novelty in 1981
  - Single protocol runs on:
    - micros through CRAYs
    - both LANs and WANs
    - both big (900,000 host Internet) and small (2 machines in my home) networks
  - Lots of performance optimizations over the years
  - Biggest internet in the world runs it
  - Becoming defacto standard in U.S.: .edu, .com, and .gov use it

- Definitions
  - "I"nternet: the big one running TCP/IP (900,000 hosts)
  - "i"nternet: any old connection of networks possibly using non-TCP/IP protocol

- TCP/IP protocol suite: (Fig. 5.1)
  - TCP
  - UDP
  - ICMP (Internet Control Message Protocol):
    - When/how to report errors between gateways and hosts
    - Example: gateway says "slow down!" to source; elementary form of flow control
  - IP (and SLIP)
  - ARP (Address resolution protocol): Maps IP address to layer 2 address
    - Each host maintains IP/layer 2 mapping cache
    - When doing direct delivery from A to B, if B's layer 2 address is not in A's cache, then A broadcasts ARP packet containing IP address of B, and host B responds with its layer 2 address.
  - RARP (Reverse address resolution protocol): Maps layer 2 address into an Internet address - used by diskless workstation upon booting

- RARP client protocol in diskless workstation's ROM
- Upon booting, diskless host broadcasts RARP packet containing its layer 2 address
- One or more RARP servers receive packet, look up corresponding IP address in table, and return IP address

Note: IP discussion follows CS/EE 5516 notes, from Comer Vol. I

- IP addresses (Comer Ch. 4)
  - 2 sets of addresses:
    - Human readable: vtopus.cs.vt.edu
    - "Dotted decimal": 128.173.40.1, where:
      - 128.173 = .vt.edu
      - .40,.41 = .cs (.88=ee)
      - .1 = host id 1 (255 possible hosts in .cs.vt.edu)
  - Cat "/etc/hosts" for more examples
  - IP address = (netid, hostid)
  - Every LAN has a unique netid; it is 128.173 at .vt.edu
  - Gateways connect netid's together; therefore gateways know about netid's but not about hostid's
  - 5 forms of addresses (4 in Stevens, Fig. 5.2)
    - Each organization (.vt.edu) is generally assigned one netid
    - Q. How many Internet hosts are possible?
      A. About (see Fig. 4.3) 2**31 + 2**30 + 2**29 = 3.8x10**9. However, ranges of IP addresses are allocated to organizations. So we may run out of IP addresses much sooner.
    - Class A for lots of hosts on a few networks in an organization

    - Class C for a few hosts on each of many networks in an organization
    - Q. Which class is .vt.edu?
    A. 7 bits < 128.173=.vt.edu < 21 bits, so it must be class B
- Routing:
    - If (source netid=destination netid) then direct else indirect delivery
    - More later
- Special addresses (Comer Vol I, Fig. 4.3):
    - IP = (netid=0,hostid) means this network with specified host id
    - IP = all 1's means broadcast on the local network; a host could learn its netid this way from another host
    - IP (netid, hostid=1's) means broadcast to all hosts on specified netid.
    - Loopback: 127.0.0.1 at .vt.edu
- Q. If my VPI Unix host is sold to another university, can it retain its IP address?
    A. No: The IP address encodes the netid, which is organization specific. Even if host moves from CS to EE, its IP address must change: 128.173.40.x to 128.88.5.x
- Weaknesses of IP addressing:
    - If host moves from one network to another, its IP address must change
    - Because routing is based on destination netid of IP address, packets may take different routes to a multihomed host depending on which address is used. (Example: willow.cs.vt.edu and locust.cs.vt.edu are connected by both fddi and ethernet; IP address used in socket interface determines which network is used)
- Who assigns IP addresses?
    - *netids:* Network Information Center (NIC)
    - *hostids:* your organization decides

- IP protocol (Comer Ch. 7)

- Connectionless protocol for layer 3
- Unit of transfer: *datagram (DG)*
- Service provided:
  - *Unreliable:*
    - lost, duplicated, reorded, delayed delivery

        - *(Arpanet pioneers to ISO: "Boy, have we got a protocol for you!")*
    - *Connectionless:*
        - each datagram from host A to B can follow different path
        - fragments of a single datagram may follow different paths
    - *Best-error delivery:*
        - IP is unreliable *only* when network resources (e.g., gateway buffers, network bandwidth) are exhausted or network fails
- IP Functions
    - Defines unit of transfer in internet:
        - 2^16 byte limit on a packet
        - packet header format
    - Performs routing
    - Protocol for unreliable, connectionless delivery:
        - What does host/gateway do when datagram arrives
        - When can datagram be discarded?
        - When/how to report errors (ICMP - Internet Control Message Protocol)
- Fragmentation:
    - IP datagram has a maximum length of 2**16 bytes. Of the 2**16 bytes, normally 20 bytes are an IP header.
    - A network is said to have a *maximum transfer unit* (MTU), in units of bytes:
        - Ethernet: MTU=1500
        - FDDI: MTU=4532 (from RFC 1188)
    - IP says that a host or gateway must accept datagrams of length 576 bytes or the maximum of the MTU's of the networks to which the machine is attached, whichever is larger
    - In addition, a transport protocol - such as TCP - may try to match the segment size it gives IP to the underlying network. We will see this later. (TCP will use the MTU of the network, if the source and destination are on the same physical network; otherwise it uses 576-20-20

(the 20's are for the TCP and IP headers) as the maximum segment size (MSS).)

- Problem: What happens if a datagram must pass through multiple networks with different MTU's (Comer Fig. 7.6)?
  - Solution: Fragmentation (Comer Fig. 7.7)

    As a datagram traverses the network, it is continually broken into smaller pieces (down to the minimum IP datagram size of 576 bytes). The destination host must then reassemble the original datagram, and pass it to its transport layer.

    Q. Does G2 or HostB reassemble fragments (Comer Fig. 7.6)?
    A. HostB does, for simplicity; gateways need not store fragments.

    A fragment has almost the same header as the original datagram, except for bits indicating if it is a fragment, if it is the last fragment, and the offset.

    Note that fragments may arrive *out of order* at the destination, because they are all routed independently.

    Note that the destination must have enough buffer space to fully assemble one IP datagram (of max length 2**16), or *reassembly deadlock* will occur.

The destination starts a reassembly timer when the first fragment arrives. The timer is used discard fragments if a fragment is lost.

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- IP datagram header format (Comer Fig. 7.3)
  - *VERS* = 4
  - *HLEN* >= 5 (unit is 32-bit words; minimum header length is 5 words)
  - *SERVICE TYPE*:
    - 3 bits for one of 7 priority levels
    - High reliability desirable (on/off bit) (don't use radio network!)
    - High throughput desirable (on/off bit) (use high bandwidth link)

        - Low delay desirable (on/off bit)
          (do not use satellite link)
    - *TOTAL LENGTH*: in bytes, for *this* IP datagram (thus for a fragment TOTAL LENGTH is the fragment length)
    - 3 fields for fragmentation/reassembly
        - *IDENTIFICATION:* Unique id assigned to each datagram send by the source host (typically the value of a global counter incremented each time an IP packet is formed). Allows destination to tell which fragments belong to which datagrams.
        - *FLAGS:*
            - Do not fragment this datagram (useful for network testing)
            - More fragments (after this one)?
        - *FRAGMENT OFFSET:* offset of data in data field of original datagram in multiples of 8 bytes
    - *TIME TO LIVE:* each gateway dec by 1; discard if 0; detects loops in routing tables
    - *PROTOCOL:* 6 for TCP. This way, IP knows whether to send encapsulated message to UDP or TCP.
    - *HEADER CHECKSUM:* No check on corruption of user data
    - *SOURCE, DESTINATION IP ADDRESS*: Gateways *only* route based on destination address
    - Optional: *OPTIONS:*
        - *Record route:* record IP address of each gateway as datagram traverses internet
        - *Record timestamps:* records timestamps (and optionally IP addresses) of each gateway visited
        - *Source routing:* data field specifies IP addresses to use in routing; ignore routing tables; for tests
            - *strict:* datagram must follow the exact list of IP addresses
            - *loose:* datagram must pass through listed addresses, but can also go through others

- IP Routing (Comer, Ch 8)

- *Routing:* choosing a path over which to send packets
- *Router:* computer choosing path
- Charactersitics of IP routing:
    - Network layer (layer 3)

    - Every host and gateway in internet does routing (though gateways have routing tables that hosts normally do not use)
    - Routing could be based on:
        - network load
        - datagram length
        - can you think of others?
    - Internet routing today: based on estimated shortest path
- *Direct delivery:*
    - Used to deliver datagram from one to another machine attached to same network (same *netid)*
    - Used to deliver datagrams between any two .vt.edu hosts, since all share same *netid*
    - Exception: subnetting (described later)
- *Indirect delivery:*
    - Delivery via one or more gateways
- How to tell which to use:
    - *netid's equal:* use direct delivery
    - *netid's different:* use indirect delivery
- Direct delivery algorithm:
    - To transfer IP datagram from host A to host B:
        (1) A encapsulates DG in physical frame (layer 2)
        (2) A maps B's IP address to B's physical address
        (3) A uses network hardware (Ethernet, token ring) to directly deliver DG to B
    - Q. How is step 2 done?
        A. using ARP

- Address Resolution Protocol (ARP) (Comer Ch. 5)
    - Q. How do you think a machine maps an Ip address to a physical address?
    - A1. Give each computer a table mapping IP to physical addr. Disadvantage: Inserting, removing a computer on network requires updating *every* host table!
    - A2. Encode physical addr into hosst field of IP address. Disadvantages:

(1) 802.3, 802.5 use 6 byte physcial address (802.5) can use 2 byte, however
(2) Physical address on adaptor card must be customer selectable -- not true for Ethernet.

- A3. Dynamic binding (ARP) algorithm:
  a. Host A wants to map IP address I_B of host B to a phys addr. So it broadcasts on its network a special frame (ARP frame) with IP addr I_B.
  b. Host I_B responds with another ARP frame containing I_B's phys addr.

Q. Does ARP get executed *every* time a host sends a datagram?
A. No:
(1) Each host caches IP/phys addr pairs
(2) The requesting ARP frame from A *also* contains I_A's IP and phys addr so that other hosts can add it to their cache.

- Indirect delivery details (See Comer Fig. 8.2.)
  - IP routing is done by a *table* in each *gateway*
  - Table entry: (N,G)
    - If DG is destination to IP address with netid N,
    - then directly deliver it to gateway with IP address G
  - Implies that all G's in table are directly attached to host/gateway storing table
  - Table size is proportional to number of networks, not number of hosts
  - Table often does not have an entry for *every* netid; in this case gateway has *default gateway address* to use
  - *Hosts* usually have an empty table, in which case they always use default address
- Complete algorithm: (based on Comer Fig. 8.3)

```
Route_IP_Datagram(DG, RT) /* RT=routing table */
    D := destination IP address of DG
    DN := netid of D
    If DN matches any directly connected network then use
```

direct delivery to D
else if DN matches N in any table entry (N,G) in RT
then use direct delivery to G
else use direct delivery to default gateway address

- Implications:
  - Routing is load independent
  - All datagrams with the same Ip destination address take the same route *unless* the routing table is updated.
  - Routing does not share outgoing traffic over multiple links (unless routing table is updated)
- Later in course we'll discuss how routing tables are updated. (There are core gateways that run a shortest path algorithm to update tables.)

- Subnetting (Comer, Ch. 16.6)
  - Q. Ethernet direct delivery requires broadcast. A class B address has 2^16 hosts on one network. Isn't this too many hosts to do a broadcast to? If I send a message from host X to Y at .vt.edu, would all the other .vt.edu hosts "see" the message?

    A. No. Bridges would limit physical broadcast range, yet preserve ability to directly broadcast to all campus machines according to the IP routing protocol.

    A. No. Subnetting allows .vt.edu to be partitioned into a little internet of its own!

  - .vt.edu uses a 6 bit subnetid and a 10 bit host id

  - See Stevens Fig. 5.3, Comer Fig. 16.3