

# *Introduction to Networks and the Internet*

**CMPE 80N**

**Spring 2003**

**Week 6**



## **Announcements**

- Quiz 2: postponed!
  - **New date: 05.13.**
- Nacho's office hours:
  - 05.07 at 11am-1pm in BE 399C.
- Discussion sessions for quiz 2:
  - Friday, 05.09 during Chandra's office hours.
  - Monday, 05.12 from 1-4pm.
  - Both will be at Jack's Lounge (white boards).



## **Today**

- *Layer 3: Network layer.*



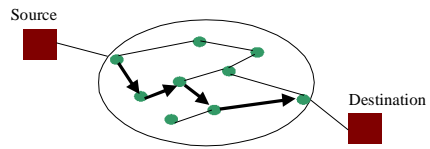
## **Network Layer**

- *Main functions: routing and forwarding.*
  - *What's routing?*
  - *What's forwarding?*



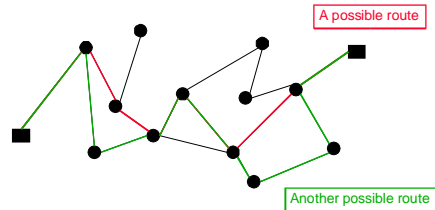
## Routing

- Find path (route) between source and destination.



## Routing (cont'd)

- **Routing** means finding a suitable path for a packet from sender to destination



## Routing (cont'd)

- A router may need to choose between two or more paths that lead to destination.
  - Choosing the "shortest" path.
- Typically, there are multiple hops to make the journey.
  - Unless hosts are on the same network.
- The **routing algorithm** is the part of a network layer software responsible for deciding which output line a packet should be transmitted on



## Forwarding

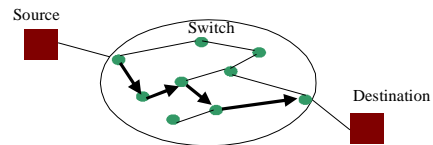
- When data is received, forward it in toward the destination.

## Who? How?

- Who performs network layer functions?
  - Switches/routers.
- How these functions are carried out?
  - Later...

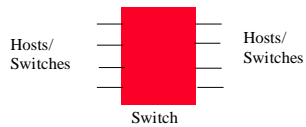
## Switches

- Switches, or routers, receive data on one side and forward it on the other side.
- Like telephone switches.



## Wide-Area Network

- One possibility: connect every host using dedicated line.
  - Problem?
- Another possibility: use interconnected switches who in turn connect to hosts.



## Switch Internals

- Early WANs used general purpose machines dedicated to the task of switching.
- Modern WAN switches use special purpose hardware optimized for the switching task.

## Store and Forward

- How switches operate.
- Shared LANs: only 1 pair of hosts can exchange a frame at a time.
- WANs: many hosts can send simultaneously.
- Switch **stores** data they receive in memory; next switch examines data, determines which interface to send it, and **forwards** data on.
- If multiple data items arrive for the same outgoing interface, they are queued waiting to be transmitted.

## Next-Hop Forwarding

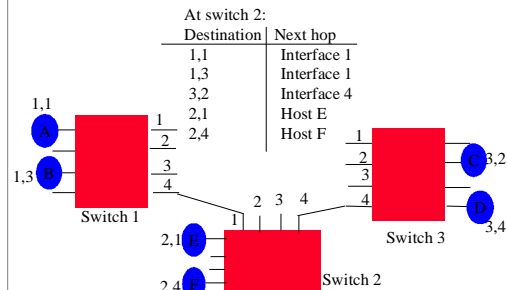
- If data not destined to directly connected host, switch forwards it to the **next hop** toward destination.
  - Airline travel analogy.
  - SF-> Miami: SF->Dallas->Atlanta->Miami.
- Next hop does not depend on source, not on the path traveled so far.
- Only needs destination address!
- Advantage: switch does not need to keep complete information about how to reach all possible destinations.

## Routing Table

- Table containing destination and associated next-hop information.

Switch 2

## Routing Table: Example



## More Routing Table

- Each router stores information about forwarding in a **routing table**.
  - Initialized at system initialization.
  - Must be updated as network topology changes.
- Routing table contains a list of destination and next **hop** for each destination.

## Routing and Hierarchical Addresses

- Hierarchical addresses allow routing tables to be smaller and more concise.

At switch 2:

Destination	Next hop	Destination	Next Hop
1,1	Interface 1	1, any	Interface 1
1,3	Interface 1		
3,2	Interface 4	3, any	Interface 4
2,1	Host E	2, any	Local
2,4	Host F		

## Today

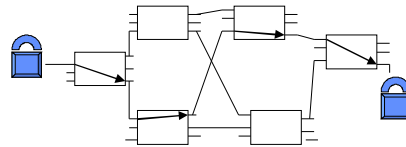
- Network layer (cont'd).
- Internetworking.

## Network Layer: Implementation and Services

## Circuit- versus Packet-Switching

- **Circuit Switching**
  - Physical circuit (physical connection) is established between source and destination throughout the network (involving switches and links).
  - This happens before any data can be sent.

## Circuit Switching



## Packet Switching

- No physical path establishment ahead of time.
- As data moves from source to destination, route is formed one hop at a time: store-and-forward.
- On-demand resource acquisition as opposed to circuit switching where resources reserved statically beforehand.

## The Internet

- Example of packet switching network!

## ***Datagram and Virtual Circuit***

- *Services provided to transport layer.*



## ***Virtual Circuit***

- *Analogy to physical circuits used by telephone networks.*
- *At connection establishment time, path from source to destination is selected and used throughout connection lifetime.*
- *When connection is over, virtual circuit terminated.*



## ***Datagram***

- *No logical connection.*
- *Each packet (datagram) routed independently; successive packets may follow different routes.*
- *More work at intermediate routers, but more robust and adaptive to failures and congestion.*



## ***The Internet***

- *Datagram network!*
- *Datagrams are formed by **header** and **payload**.*
- *IP Datagrams can have different sizes*
  - *Header is fixed (20 bytes)*
  - *Data area can contain between 1 byte and 65 KB*



## Forwarding Datagrams

- Header contains all information needed to deliver datagrams to **destination**.
  - Destination address.
  - Source address.
- Router examines header of each datagram and forwards it along path to destination.

## Routers

- For VCs, routers keep a table with (VC number, outgoing interface) entries.
  - Packets only need to carry VC number.
- For datagrams, routing table.
  - (destination, outgoing interface) entries.
  - Each packet must carry destination address.

## Routing Algorithms

- Routing algorithm: decides which route a packet should take from source to destination.
  - For router: which interface a packet should be forwarded.

## Routing Algorithms (cont'd)

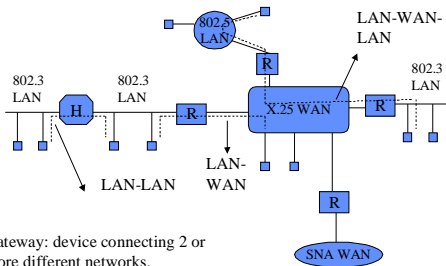
- If datagram network, decision is made for every packet.
- If VC, decision is made only once when VC is setup.

## Internetworking

## Internetworking

- *Interconnection of 2 or more networks forming an internetwork, or internet.*
  - LANs, MANs, and WANs.
- *Different networks mean different protocols.*
  - TCP/IP, IBM's SNA, DEC's DECnet, ATM, Novell and AppleTalk.

## Example Internetwork



Gateway: device connecting 2 or more different networks.

## Gateways

- *Repeaters/hubs: operate at physical layer (bits); amplify/regenerate signal.*
- *Routers: operate at network layer.*
- *Gateways: interconnect (different) networks.*

## How do networks differ?

- Service offered: connection-oriented versus connection-less.
- Protocols: IP, IPX, AppleTalk, DECnet.
- Addressing: flat (802) versus hierarchical (IP).
- Maximum transmission unit.
- Etc...

## Connectionless Internetworking

- Datagram model.
  - Different packets may take different routes.
  - Separate routing decision for each packet.
  - No ordered delivery guarantees.

## Datagram versus VC Internets

- VC:
  - Plus's: resources reserved in advance, ordered delivery, short headers.
  - Minus's: vulnerability to failures, less adaptive, hard if involving datagram subnet.
- Datagram:
  - Plus's: more robust and adaptive, can be used over datagram subnets (many LANs, mobile networks).
  - Minus's: Longer headers, unordered delivery.

## Internetwork Routing

- 2-level hierarchy:
  - Routing within each network: interior gateway protocol.
  - Routing between networks: exterior gateway protocol.
- Within each network, different routing algorithms can be used.
- Each network is autonomously managed and independent of others: autonomous system (AS).

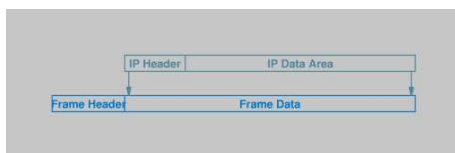
## Internetwork Routing (cont'd)

- Typically, packet starts in its LAN. Gateway receives it (broadcast on LAN to "unknown" destination).
- Gateway sends packet to gateway on the destination network using its routing table.

## Encapsulation Revisited

- Each datagram is **encapsulated** within a data link layer frame
  - The whole datagram is placed in the **data area** of the frame.
  - The data link layer addresses for source and destination included in the frame header.

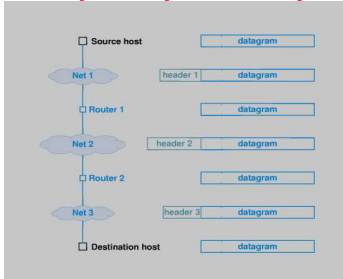
## Encapsulation - Example



## Encapsulation Across Multiple Hops

- Each router in the path from source to destination:
  - **Decapsulates** datagram from incoming frame.
  - **Forwards** datagram - determines next hop.
  - **Encapsulate** datagram in outgoing frame.

## Encapsulation Across Multiple Hops - Example

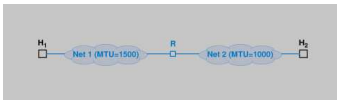


## Maximum Transfer Unit

- Each data link layer technology specifies the maximum size of a frame.
  - Called the Maximum Transfer Unit (MTU).
    - Ethernet: 1,500 bytes.
    - Token Ring: 2048 or 4096 bytes.
- What happens when large packet wants to travel through network with smaller MTU?
  - Maximum payloads (data portion of datagram) range from 48 bytes (ATM cells) to 64Kbytes (IP packets).

## MTU (cont'd)

- A possible solution:
  - The sender may limit the size of the datagrams to the MTU of the network
  - What if there are other networks in the path to destination with smaller MTU?



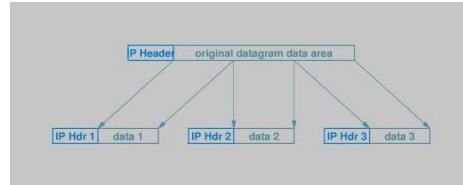
## Fragmentation

- Another solution (used by IP): **fragmentation**.
- Gateways break packets into fragments to fit the network's MTU; each sent as separate datagram.
- Gateway on the other side have to **reassemble** fragments into original datagram.

## Keeping Track of Fragments

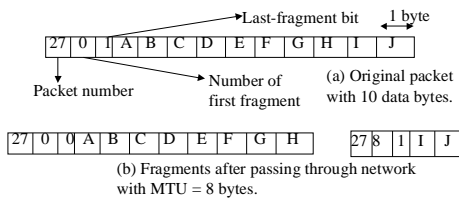
- Fragments must be numbered so that original data stream can be reconstructed.
- Define elementary fragment size that can pass through every network.
- When packet fragmented, all pieces equal to elementary fragment size, except last one (may be smaller).
- Datagram may contain several fragments.

## Fragmentation - Example



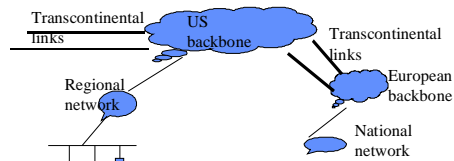
## Fragmentation – Example (cont'd)

- Header contains packet number, number of first fragment in packet, and last-fragment bit.



## The Internet's Network Layer

- The Internet as a collection on networks or autonomous systems (ASs).
- Hierarchical structure.



## The Internet Protocol: IP

- Glues Internet together.
- Common network-layer protocol spoken by all Internet participating networks.
- Best effort datagram service:
  - No reliability guarantees.
  - No ordering guarantees.

## IP (cont'd)

- **IP** is responsible for datagram routing.
- **Important:** each datagram is routed independently!
  - Two different datagrams from same source to same destination can take different routes!
  - Why?
  - Implications?

## IP (cont'd)

- IP provides a **best effort** delivery mechanism
  - Does not guarantee to prevent duplicate datagrams, delayed and out-of-order delivery, corruption of data or datagram loss
- **Reliable delivery** is provided by the **transport layer**, not the **network layer (IP)**
- Network layer (IP) can **detect** and **report** errors without actually **fixing** them

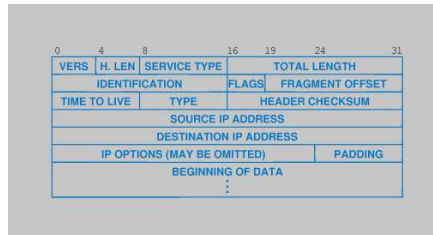
## IP

- Transport layer breaks data streams into datagrams which are transmitted over Internet, possibly being fragmented.
- When all datagram fragments arrive at destination, reassembled by network layer and delivered to transport layer at destination host.

## IP Datagram Format

- IP datagram consists of header and data (or payload).
- Header:
  - 20-byte fixed (mandatory) part.
  - Variable length optional part.

## Datagram Header Format



## IP Versions

- IPv4: IP version 4.
  - Current, predominant version.
  - 32-bit long addresses.
- IPv6: IP version 6.
  - Evolution of IPv4.
  - Longer addresses (16-byte long).