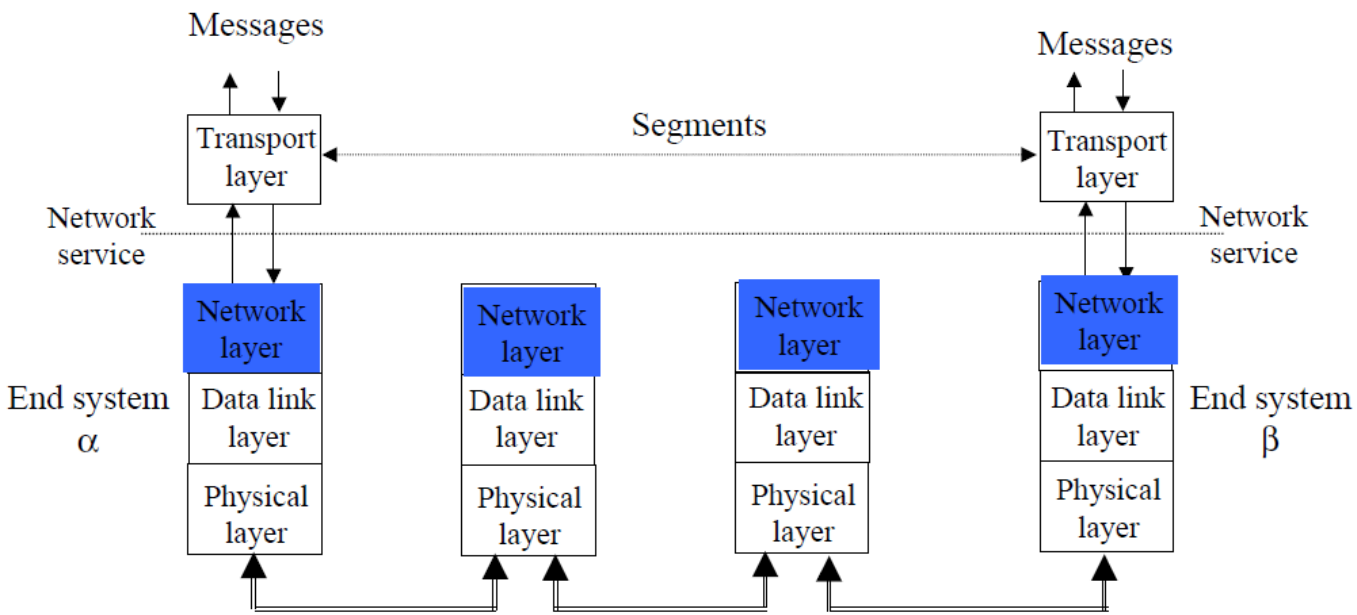
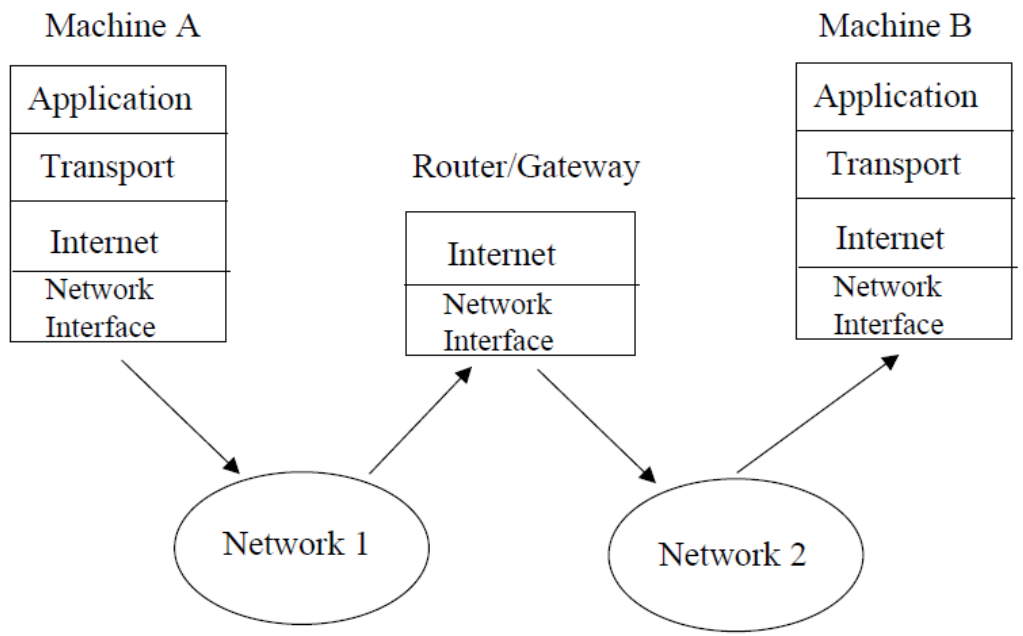
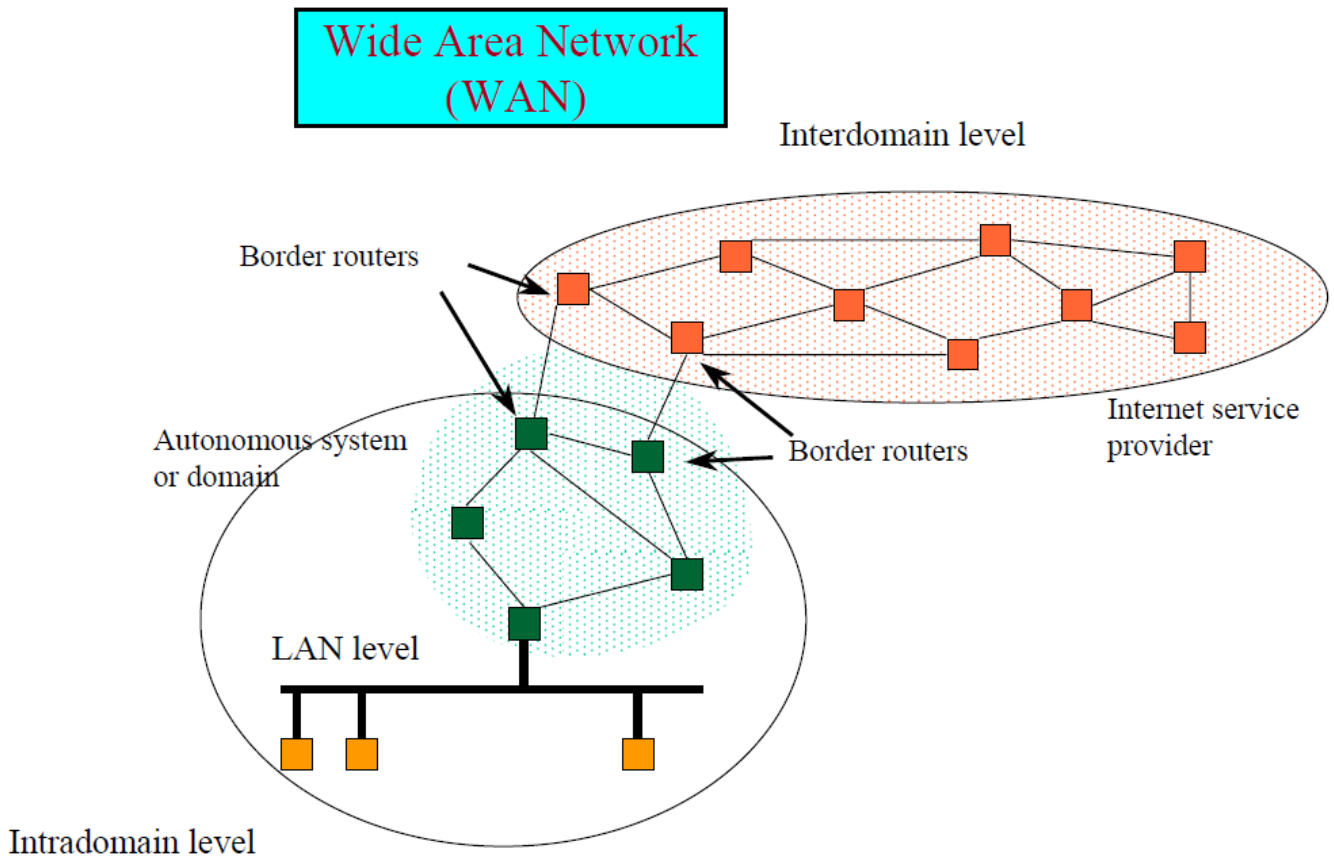
Network Layer

- This layer is concerned with getting packets from the source all the way to the destination.
- Getting to the destination may require making many hops at intermediate routers along the way.
- Thus, the network layer is the lowest layer that deals with end-to-end transmission.


Messages
Messages
Transport layer
Segments
Transport layer
Network service
Network service
Network layer
Network layer
Network layer
Network layer
End system α
Data link layer
Data link layer
Data link layer
Data link layer
End system β
Physical layer
Physical layer
Physical layer
Physical layer


Machine A
Application
Transport
Internet
Network Interface
Router/Gateway
Internet
Network Interface
Machine B
Application
Transport
Internet
Network Interface
Network 1
Network 2


Wide Area Network
(WAN)
Interdomain level
Border routers
Internet service
provider
Border routers
Autonomous system
or domain
LAN level
Intradomain level

Functions of Network layer

- Routing
  - The process of transferring packets received from the Data Link Layer of the source network to the Data Link Layer of the correct destination network is called routing.
  - Involves decision making at each intermediate node on where to send the packet next so that it eventually reaches its destination.
  - The node which makes this choice is called a router. For routing we require some mode of addressing which is recognized by the Network Layer. This addressing is different from the MAC layer addressing.

- Inter-networking
- The network layer is the same across all physical networks (such as Token-Ring and Ethernet).
- Thus, if two physically different networks have to communicate, the packets that arrive at the Data Link Layer of the node which connects these two physically different networks, would be stripped of their headers and passed to the Network Layer.
- The network layer would then pass this data to the Data Link Layer of the other physical network.

- Congestion Control : If the incoming rate of the packets arriving at any router is more than the outgoing rate, then congestion is said to occur.
- Congestion may be caused by many factors.
  - If suddenly, packets begin arriving on many input lines and all need the same output line, then a queue will build up. If there is insufficient memory to hold all of them, packets will be lost.
  - But even if routers have an infinite amount of memory, congestion gets worse, because by the time packets reach to the front of the queue, they have already timed out (repeatedly), and duplicates have been sent. All these packets are dutifully forwarded to the next router, increasing the load all the way to the destination.
  - Another reason for congestion are slow processors. If the router's CPUs are slow at performing the bookkeeping tasks required of them, queues can build up, even though there is excess line capacity. Similarly, low-bandwidth lines can also cause congestion.

Network layer functions

- transport packet from sending to receiving hosts
- network layer protocols in *every* host, router

three important functions:

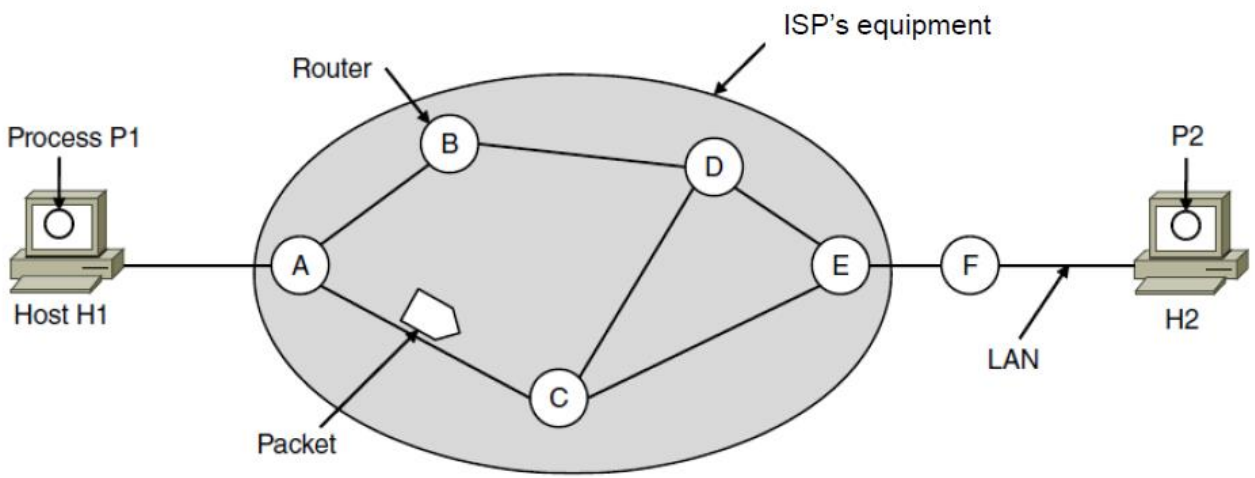
- *path determination:* route taken by packets from source to dest. *Routing algorithms*
- *switching:* move packets from router's input to appropriate router output
- *call setup:* some network architectures require router call setup along path before data flows

Network Layer Design Issues

- Store-and-Forward Packet Switching
- Services Provided to the Transport Layer
- Implementation of Connectionless Service
- Implementation of Connection-Oriented Service
- Comparison of Virtual-Circuit and Datagram Subnets

Store-and-Forward Packet Switching

- A host with a packet to send transmits it to the nearest router, either on its own LAN or over a point-to-point link to the carrier.
- The packet is stored there until it has fully arrived so the checksum can be verified.
- Then it is forwarded to the next router along the path until it reaches the destination host, where it is delivered.
- This mechanism is store-and-forward packet switching


ISP's equipment
Router
Process P1
B
D
P2
A
E
F
Host H1
H2
LAN
C
Packet

Packet Switching

- Data is divided into small parts (packets)
- Packets are transmitted from node to node, processed and forwarded
- Also known as store-and-forward switching

Two connection types

- Connectionless: datagram
- Connection-oriented: virtual circuit

Services Provided to the Transport Layer

- The network layer provides services to the transport layer at the network layer/transport layer interface.
- The network layer services have been designed with the following goals in mind.
- The services should be independent of the router technology.
- The transport layer should be shielded from the number, type, and topology of the routers present.
- The network addresses made available to the transport layer should use a uniform numbering plan, even across LANs and WANs.

- The discussion centers on whether the network layer should provide connection oriented service or connectionless service.

Internet community's opinion:

- The routers' job is moving packets around and nothing else.
- The subnet is inherently unreliable. Therefore, the hosts should accept the fact that the network is unreliable and do error control and flow control themselves.
- This viewpoint leads quickly to the conclusion that the network service should be connectionless, with primitives SEND PACKET and RECEIVE PACKET.
- Furthermore, each packet must carry the full destination address, because each packet sent is carried independently of its predecessors, if any.

Telephone companies' opinion:

- The subnet should provide a reliable, connection oriented service.
- In this view, quality of service is the dominant factor, and without connections in the subnet, quality of service is very difficult to achieve, especially for real-time traffic such as voice and video.

Network service model

service abstraction

Q: What *service model* for "channel" transporting packets from sender to receiver?

- guaranteed bandwidth?
- preservation of inter-packet timing (no jitter)?
- loss-free delivery?
- in-order delivery?
- congestion feedback to sender?

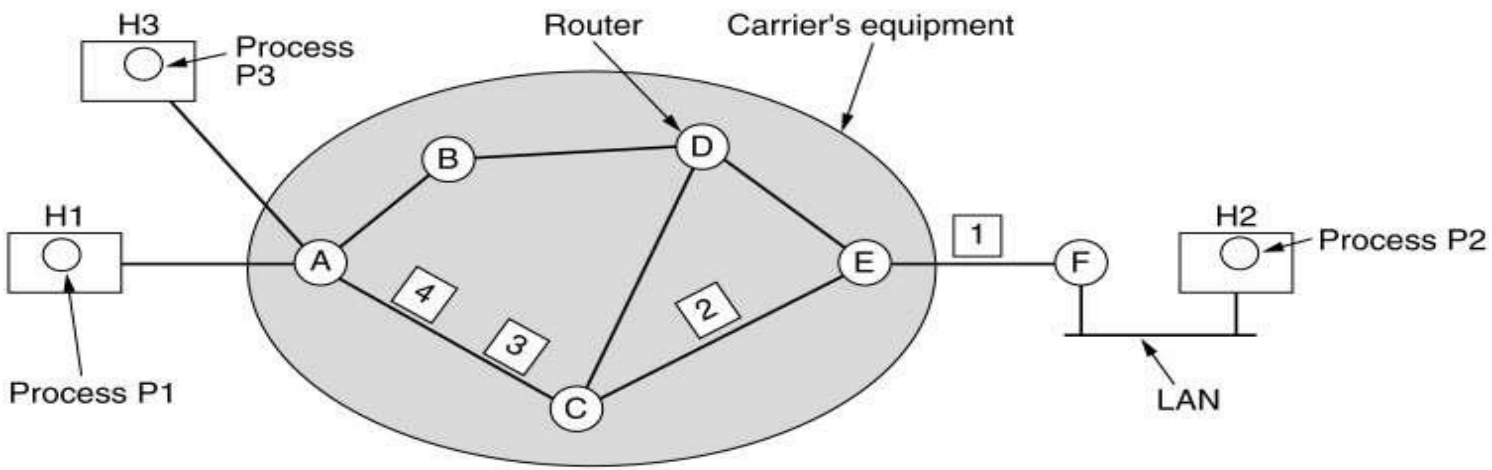
The most important abstraction provided by network layer:

virtual circuit
or datagram?

Implementation of Connection-Oriented Service

- If connection-oriented service is used, a path from the source router to the destination router must be established before any data packets can be sent.
- This connection is called a VC (virtual circuit), in analogy with the physical circuits set up by the telephone system, and the subnet is called a virtual-circuit subnet.
- When a connection is established, a route from the source machine to the destination machine is chosen as part of the connection setup and stored in tables inside the routers.
- When the connection is released, the virtual circuit is also terminated.
- With connection-oriented service, each packet carries an identifier telling which virtual circuit it belongs to.

Routing within Virtual Circuit subnet



A's table

In		Out	
H1	1	C	1
H3	1	C	2

C's table

A	1	E	1
A	2	E	2

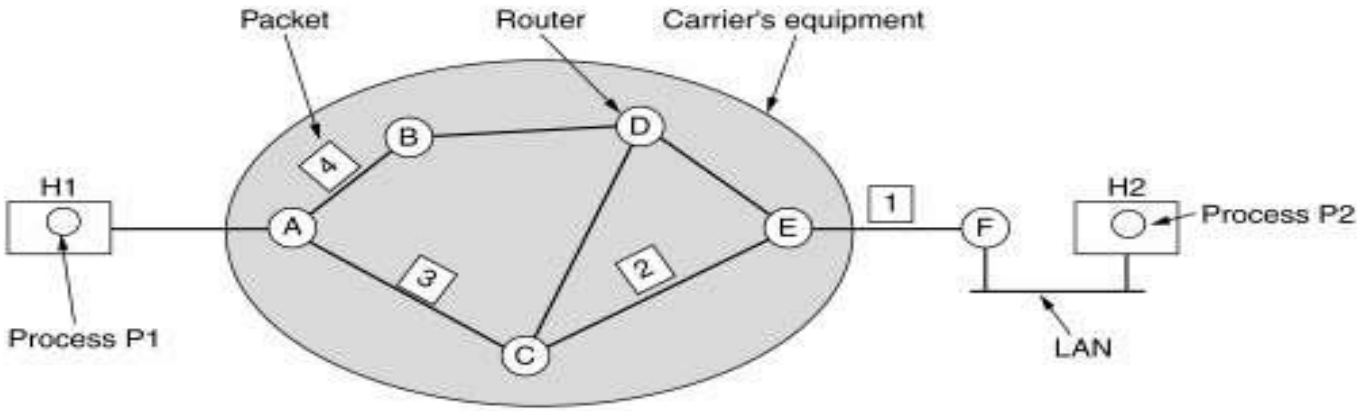
E's table

C	1	F	1
C	2	F	2

Implementation of Connectionless Service

- No connection setup
- Message is broken into packets
- Each packet is individually routed
- Routers decides line based on routing table
- Packets may follow different paths
- Not guaranteed to arrive in order
- If connectionless service is offered, packets are injected into the subnet individually and routed independently of each other.
- In this context, the packets are frequently called datagrams and the subnet is called a datagram subnet.

Routing within a datagram subnet



A's table

Dest.	initially	later
A	–	–
B	B	B
C	C	C
D	B	B
E	C	B
F	C	B

C's table

Dest.	Line
A	A
B	A
C	–
D	D
E	E
F	E

E's table

Dest.	Line
A	C
B	D
C	C
D	D
E	–
F	F

Routers

- When a packet comes into a router, the frame header and trailer are stripped off and the packet located in the frame's payload field is passed to the routing software. This software uses the packet header to choose an output line.
- Each router has an internal table telling it where to send packets for each possible destination.
- The algorithm that manages the tables and makes the routing decisions is called the routing algorithm.

Comparison of Virtual-Circuit and Datagram Subnets

- One trade-off is between router memory space and bandwidth. VC allow packets to contain circuit numbers instead of full destination addresses.
- If the packets tend to be fairly short, a full destination address in every packet may represent a significant amount of overhead and hence, wasted bandwidth.
- Another trade-off is setup time versus address parsing time.
- Using VC requires a setup phase, which takes time and consumes resources.
- VC have some advantages in guaranteeing quality of service and avoiding congestion within the subnet because resources can be reserved in advance, when the connection is established.

Issue	Datagram subnet	Virtual-circuit subnet
Circuit setup	Not needed	Required
Addressing	Each packet contains the full source and destination address	Each packet contains a short VC number
State information	Routers do not hold state information about connections	Each VC requires router table space per connection
Routing	Each packet is routed independently	Route chosen when VC is set up; all packets follow it
Effect of router failures	None, except for packets lost during the crash	All VCs that passed through the failed router are terminated
Quality of service	Difficult	Easy if enough resources can be allocated in advance for each VC
Congestion control	Difficult	Easy if enough resources can be allocated in advance for each VC