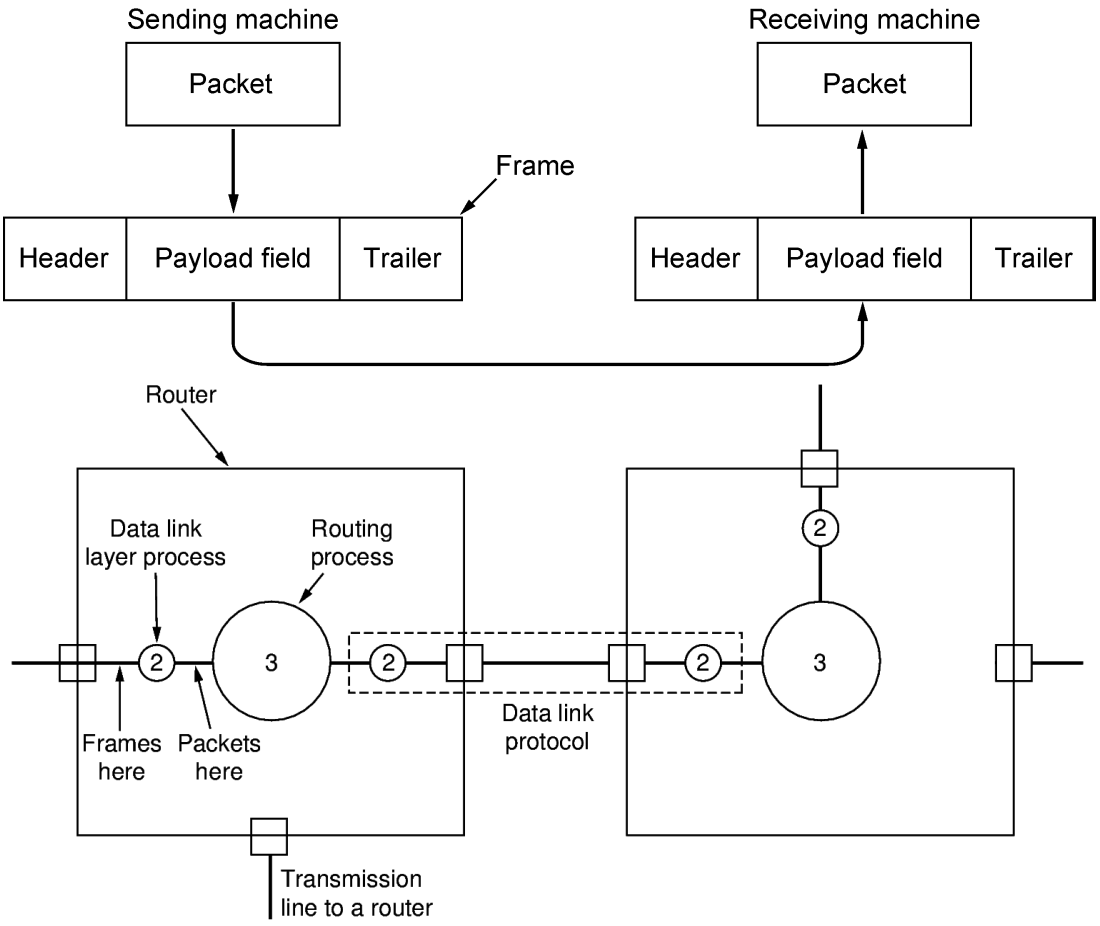
Lecture 16
Plan: Start network layer and introduction to routing

1. Basic Concepts:
Objective: provide a packet delivery system for transport layer, using the point-to-point links of the data link layer

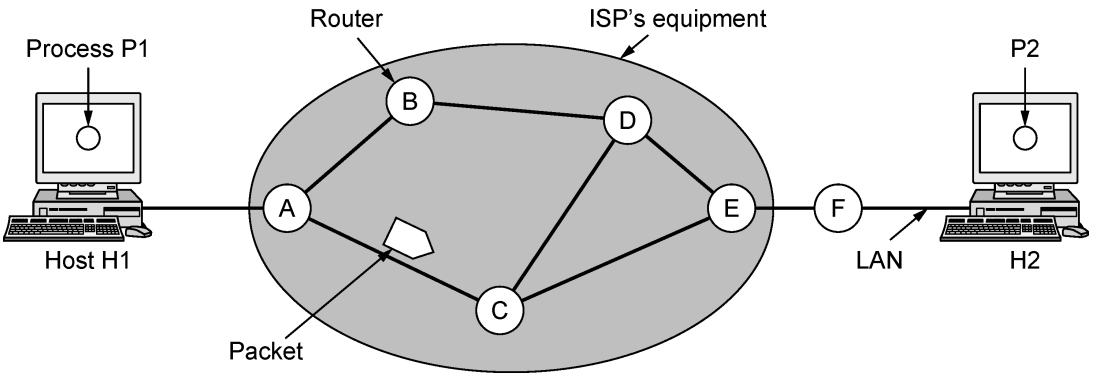
Q:/ What is a packet?
A:/ a small segment of the data passed from the transport layer (the so-called data in data link frames)



Data link layer concerns more on the delivery of frames in the local LAN while the network layer is more concerned with the routing of packets from one network to another network.

Q:/ Why do we need this delivery system?
A:/
Fantasy: every node (a host, or a LAN) is directly connected together.
Reality: nodes are connected indirectly through a subnet of routers

Q:/ How are packets sent in the subnet?
A:/ store-and-forward packet switching



- Data is split into shorter packets
- Packets are sent from source to destination and reassembled at the destination

Q:/ Why do we need to queue the packets in the router on the input port and the output port

A:/ Input: packets may arrive faster than the switching network can process them

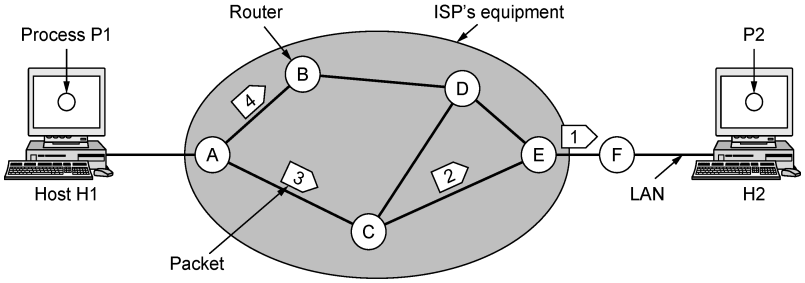
Output: Several inputs arrive at the same time addressing to the same receiver

Note:

- forwarding: For each packet read on an input port, determine which output port should be written (local)
- routing: Determine the end-to-end path along which to send a packet from host A to host B (global)

2. Design Issues

1. Class of service: Connectionless or connection-oriented
    - Datagram (connectionless)



A's table (initially)

Dest.	Line
A	–
B	B
C	C
D	B
E	C
F	C

A's table (later)

A	–
B	B
C	C
D	B
E	B
F	B

C's table

A	A
B	A
C	–
D	E
E	E
F	E

E's table

A	C
B	D
C	C
D	D
E	–
F	F

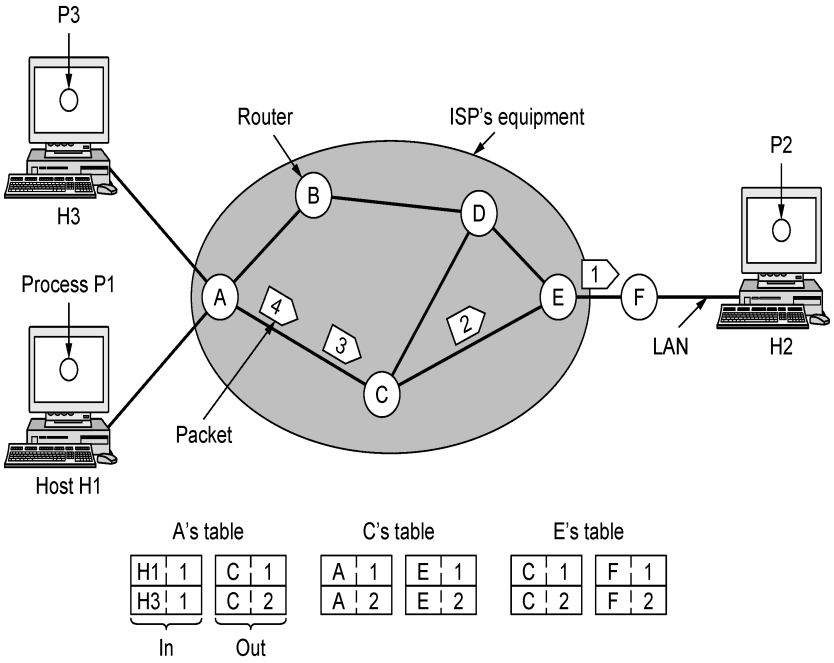
    - each packet is routed independent of all others.
    - each router has a routing table, mapping addresses to output ports

P1's transport layer passed a message to its network layer to be sent to p2 on H2. The message is too big so it is divided into 4 packets. The format of the routing table in the routers are (destination, outgoing line). Routing tables may change and will affect the subsequent routing moves. For example, the routing table of A is changed.

  - Example: Internet Protocol
  - Pro: more adaptable to failures, no initial setup overhead
  - Con: Routing is done for each packet
- Virtual Circuit (connection-oriented)
  - Connection is setup between the sender and the receiver
  - the connection is essentially a path/route with an identifier

  Q:/ How to assign unique identifiers?

  A:/ The VC can have a different id on different legs of the route – label switching. In the example below, A intentionally changed the id of packets from H3 to 2 before forward it to C.



  - Example: X.25, ATM
  - Pro: Once established, no need to do routing. Every packet follow the same route. In order delivery; better quality
  - Con: VC requires setup time and all routers on the path have to communicate. Not good if router crashes or topology changed

So to compare the two approaches, here is a summary of features

Issue	Datagram network	Virtual-circuit network
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

Note

- TCP/IP: a connection-oriented transport protocol on top of a connectionless network layer(ftp, http)
- UDP/IP: a connectionless transport protocol on top of a connectionless network layer (multi-media, email)
- datalink layer can also provide connection or connectionless communications. But it is not as critical as it is shown in the network layer
- Network layer protocol in Internet (IP) is best effort protocol (no guarantee on bandwidth, lost packets, in-order delivery)

Q:/ Why do we use IP on internet?
A:/ inherently, the network is unstable; thus it is not necessary to use a more stable protocol.

2. Routing Algorithms

- data gram: applied to every packet
- VC: applied when the visual circuit is set up (session routing)

Issues:

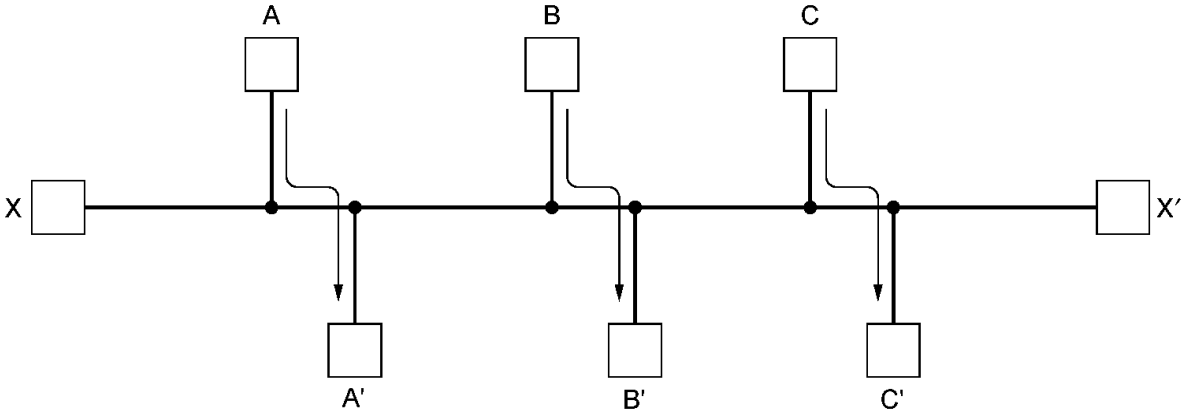
- Q:/ What is (are) the performance objective(s)?

A:/

- Maximize throughput
- Minimize delay or some other cost measures
  - average delay
  - maximum delay
- Fairness
- Robustness
- Correctness

Note: These factors may conflict with each other.

- Q:/ Should we give routers global information or just local information?
- Q:/ Should we use dynamic or static routing?

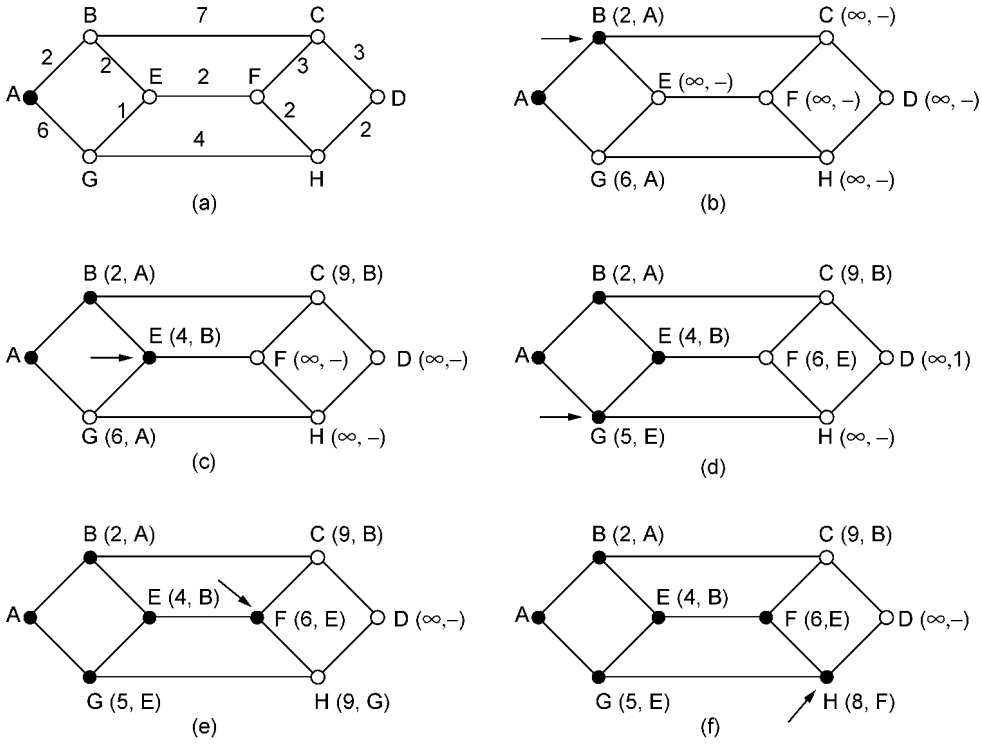


3. Static Global shortest path

- Represent the subnet as a graph
- Assign to each link a cost function, such as
  - distance
  - delay time
  - 1 (=# of hops)

Note: In practice, is a weighted sum of many factors

- Use Dijkstra's algorithm to determine the shortest path between any two nodes



In the end, we have a tree structure that is optimal

- Information stored in a routing table at each router maps the destination address to next hop
- When a packet arrives, examine the destination address
    - If it is this router, send packet to host (on its LAN)
    - If not, loop it up on the routing table and get the next hop. Forward the packet to the next hop
- No difference between data gram and VC
- Problem: Static(not work if a node/link fails, added or changed)