WANS
Packet Switching

November 25, 2020

Outline

- Principles
- Interconnecting
- Virtual Circuits
- Switching Fabrics

Principles

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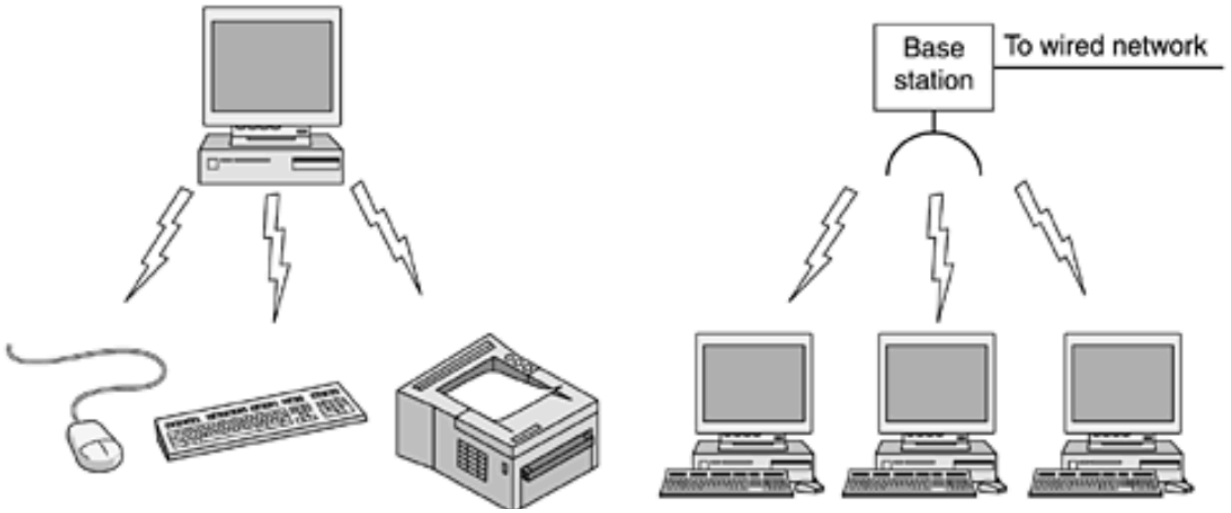
Network Size and Function

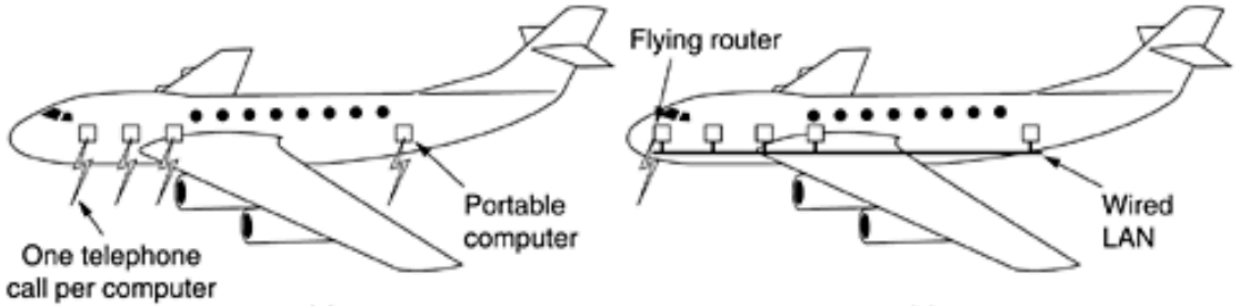
- One way to characterize networks is according to their size:
  - local area networks (LANs): extend less than 1 km.
  - metropolitan area networks (MANs): confined to a city.
  - wide area networks (WANs): can be worldwide.
- Another way is according to function:
  - storage area networks (SANs) (confined to a single room).
  - wireless sensor networks (WSNs).
  - underwater acoustic sensor networks (UWASNs)
  - delay tolerant networks (DTNs)

Local Networks

- From Bluetooth (left) or wireless (right)



- To flying LANs or Routers



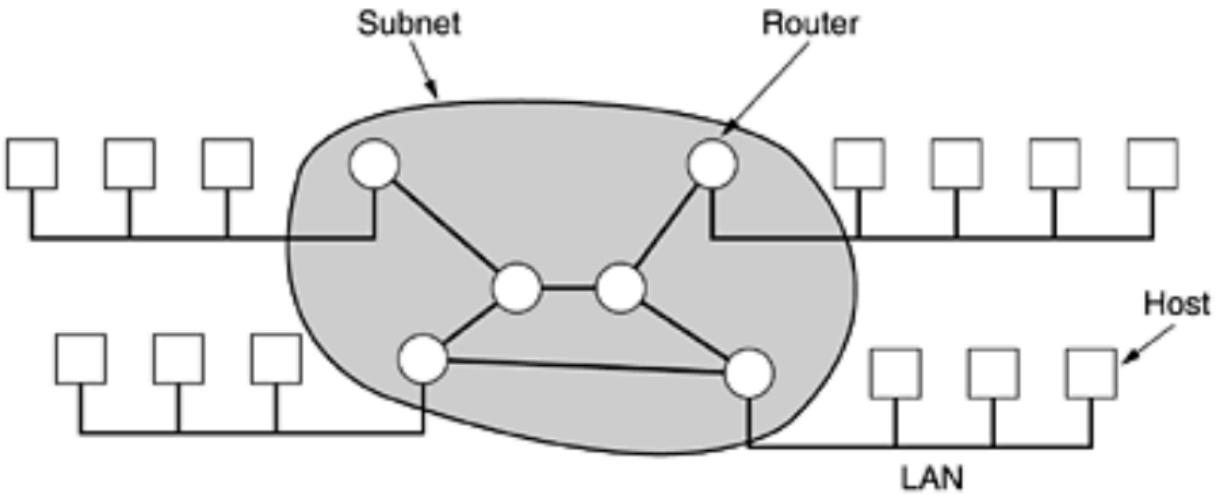
WANs

- Wide Area Network (WAN) is a computer network that covers a broad area (i.e., any network whose communications links cross metropolitan, regional, or national boundaries).

- It is a network that uses routers and public communications links and integrates smaller (local) networks.

Hosts and LANs

- Relation between hosts on LANs and the subnet.



- Each host is frequently connected to a LAN on which a router is present, although in some cases a host can be connected directly to a router.
- The collection of communication lines and routers (but not the hosts) form the subnet.

WANs

- Contrast with
  - local area networks (LANs),
  - campus area networks (CANs), or
  - metropolitan area networks (MANs) which are usually limited to a room, building, campus or specific metropolitan area (e.g., a city), respectively.
- The largest and most well-known example of a WAN is the Internet.

WANs

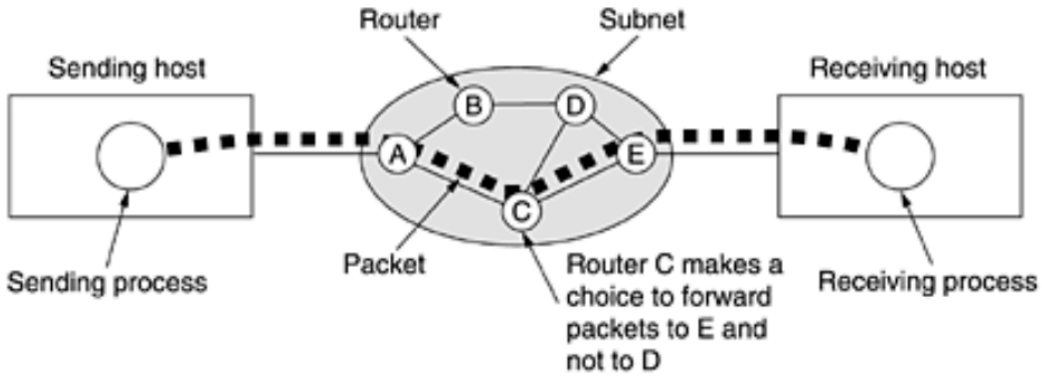
- WANs are used to connect LANs and other types of networks together, so that users and computers in one location can communicate with users and computers in other locations.
- Many WANs are built for one particular organization and are private.
- Others, built by Internet service providers (ISPs), provide connections from an organization's LAN to the Internet.
- WANs are often built using leased lines.
- At each end of the leased line, a router connects to the LAN on one side and a hub within the WAN on the other.
- A WAN may also involve satellites.

WANs

- Since leased lines can be very expensive, WANs can also be built using less costly circuit switching or packet switching methods.
- Network protocols including TCP/IP deliver transport and addressing functions.
- Protocols including Packet over SONET/SDH, MPLS, ATM and Frame relay are often used by service providers to deliver the links that are used in WANs.
- X.25 was an important early WAN protocol, and is often considered to be the "grandfather" of Frame Relay as many of the underlying protocols and functions of X.25 are still in use today (with upgrades) by Frame Relay. Now replaced by IP but still in use in legacy applications.

WANs

- In most WANs, the network contains numerous transmission lines, each one connecting a pair of routers.
- If two routers that do not share a transmission line wish to communicate, they must do this indirectly, via other routers.



- When a packet is sent from one router to another via one or more intermediate routers, the packet is received at each intermediate router in its entirety, stored there until the required output line is free, and then forwarded.

WANs and Routing

- A subnet organized according to this principle is called a store-and-forward or packet-switched subnet.
- Nearly all wide area networks (except those using satellites) have store-and-forward subnets.
- When the packets are small and all the same size, they are often called cells.
- Routing decisions are made locally.
  - When a packet arrives at router A, it is up to A to decide if this packet should be sent on the line to B or the line to C.
  - How A makes that decision is called the routing algorithm.
  - Many of them exist.

Interconnecting

Interconnecting Methods

- **Leased line** Point-to-Point connection between two computers or Local Area Networks (PPP, HDLC, SDLC, HNAS)
- **Circuit switching** A dedicated circuit path is created between end points. Best example is dialup connections (PPP, ISDN)
- **Packet switching** Devices transport packets via a shared single point-to-point or point-to-multipoint link across a carrier internetwork. Variable length packets are transmitted over Permanent Virtual Circuits (PVC) or Switched Virtual Circuits (SVC) (X.25, Frame-Relay)
- **Cell relay** Similar to packet switching, but uses fixed length cells instead of variable length packets. Data is divided into fixed-length cells and then transported across virtual circuits (ATM)

Ways to Interconnect

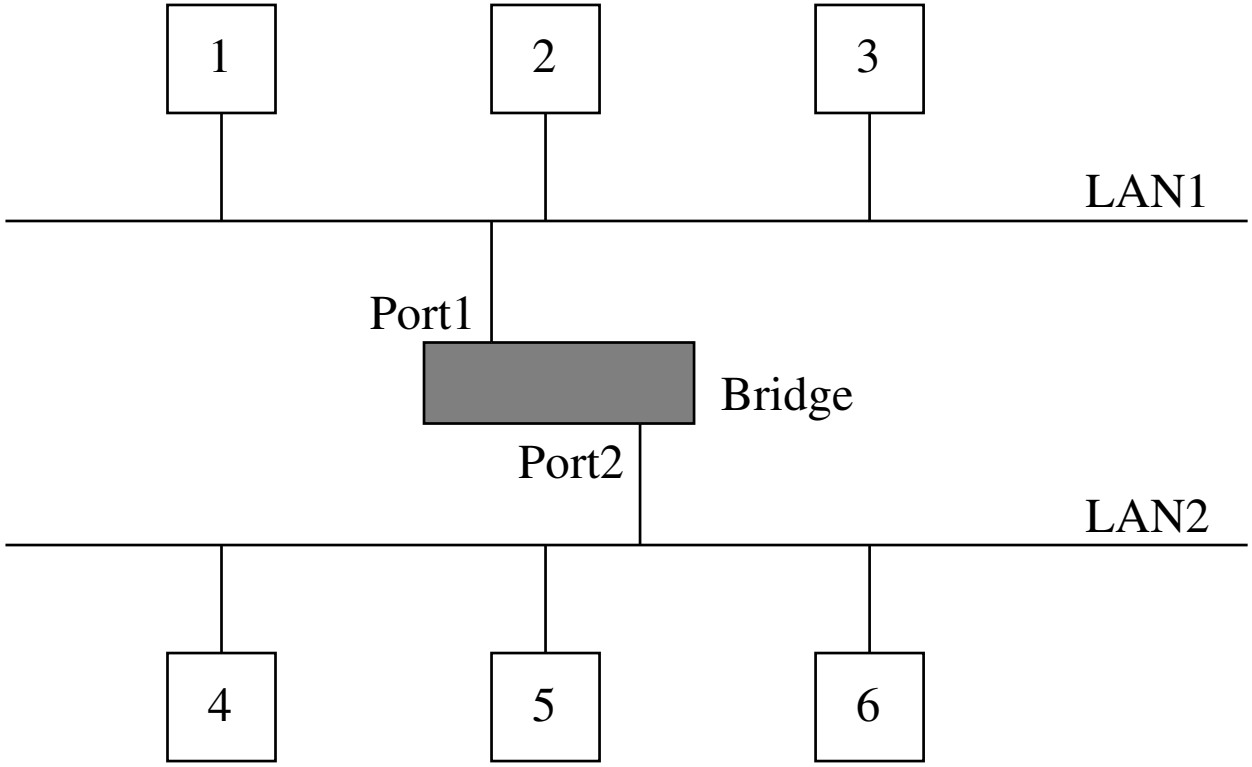
Two different networks can be interconnected at different layers.

Depending on the layer being used the devices are called:

1. **Repeaters:**
   used at the physical layer.
2. **Bridges:**
   used at the MAC or Data Link layer.
3. **Routers:**
   used at the network layer.
4. **Gateways:**
   used at a higher layer to perform protocol conversion and security functions.

Bridges

- Transparent bridges used in Ethernet LANs.



- Source routing bridges used in token ring and FDDI.

Transparent Bridges

- Defined by IEEE 802.1d Standard.
- Nodes are completely unaware of their presence in a network and it is not necessary to reconfigure the nodes.
- Bridges perform the following functions:
  1. Forwards frames from one LAN to another.
  2. Learns where nodes are attached to the LAN.
  3. Prevents loops in the network topology.
- Bridges have forwarding tables with thousands of addresses.

Src Address	From Port
...	...
...	...

Dest Address	To Port
...	...
...	...

Updating the Routing Tables

- When a frame is received the bridge compares the source address of the frame with each entry of the table.
  - If no match found, it adds source address and port number to the table.
- Then the bridge compares the destination address of the frame with each entry of the forwarding table.
  - If a match is found the bridge forwards the frame.
  - If no match is found the bridge "floods" the frame on all ports (except the one it came from).
- IEEE 802.1 specifies the use of a spanning tree algorithm: this algorithm requires that each bridge have a unique ID.

Source Routing Bridges

- Defined by IEEE 802.5 Standard.
- Used primarily to interconnect token ring networks.
- They put a burden on the end nodes: in source routing each node should determine the route to the destination.
- Hence route information is included in the header of the frame.
- It is important to be able to find good routes.

WANs

- A Wide Area Network provides long distance transmission of data, voice, image, and video information over large geographic areas that may comprise
  - a country,
  - a continent, or even
  - the whole world.
- There is a significant trend in networking for integrating diverse services such as data transmission, audio, video, etc.
- In contrast to LANs that rely on their own hardware for data transmissions, WANs may utilize public, leased, private communication equipment, or combinations thereof.

Need for WANs

- Installing point-to-point connections may be costly and not always feasible.
- Multibuses, Token rings, Ethernet, etc, may have to be ruled out because of the distances involved.
- Switching is a better solution.
  - A switched network consists of a sequence of switches that are capable of creating temporary connections between two or more hosts.

Virtual Circuits

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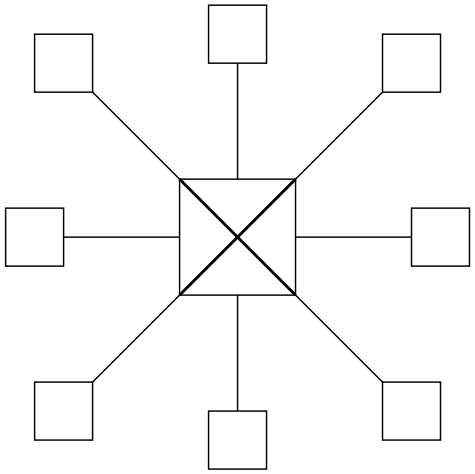
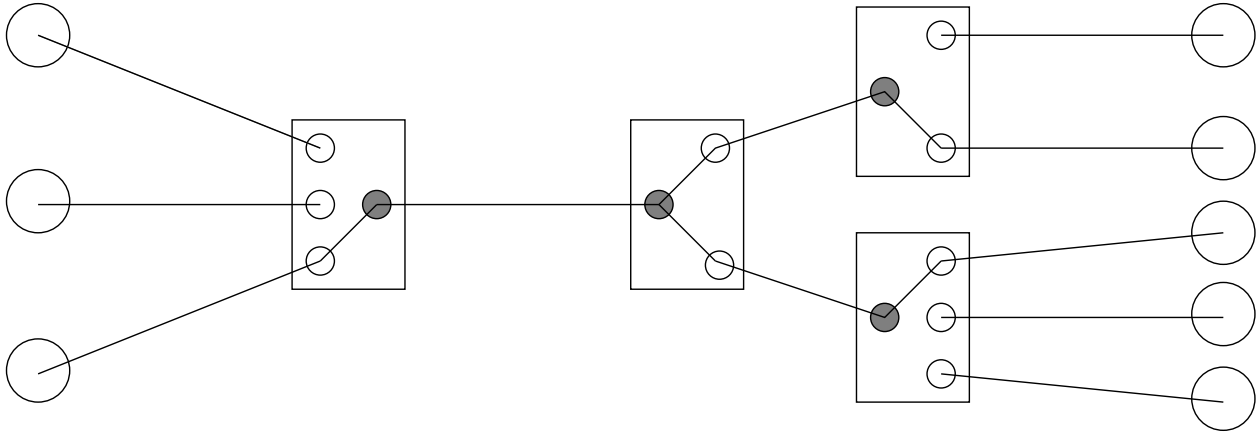
Switching

- Switch is a multi-input/multi-output mechanism having the star topology allowing us to interconnect nodes.



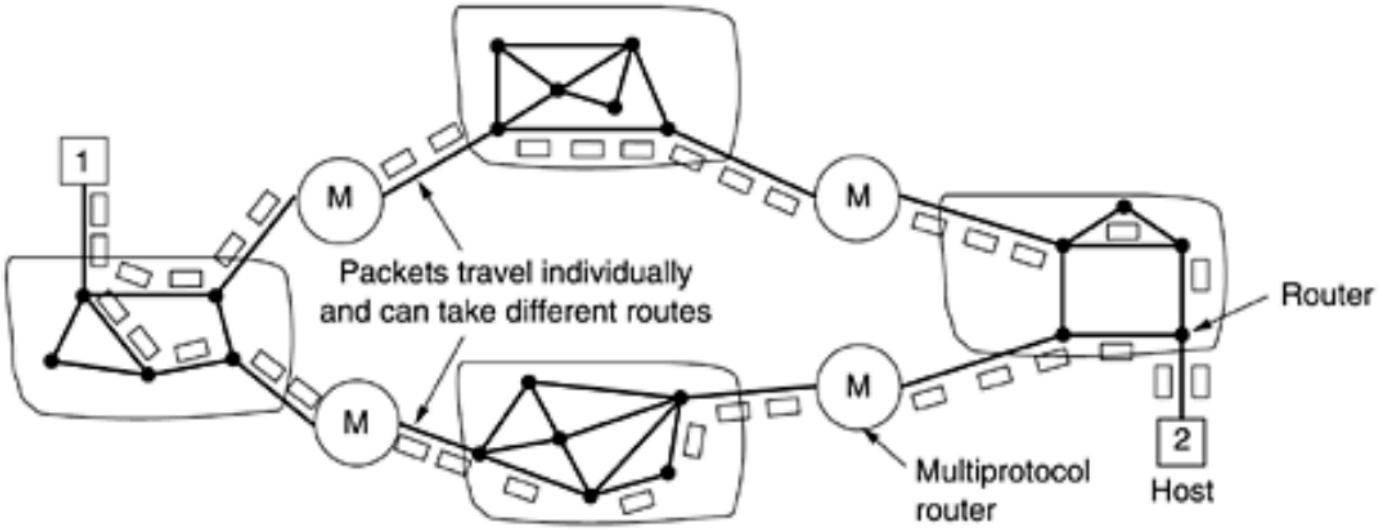
- Networks are built by interconnecting switches to each other and to hosts.
- Switches run appropriate data link protocols to communicate with a node at the other end. Their primary role is **forwarding**.

Switching



Connectionless Approach

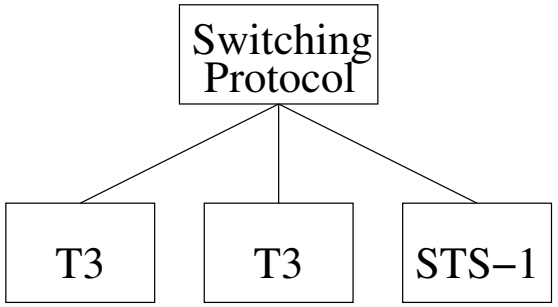
- Datagrams from host 1 to host 2 may be taking different routes through the internetwork.



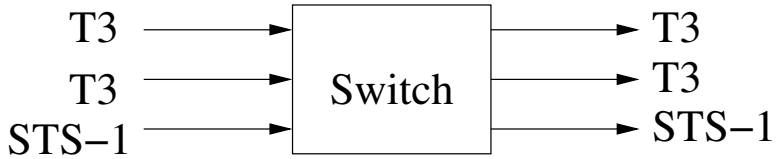
- A routing decision is made separately for each packet, possibly depending on the traffic at the moment the packet is sent.

Switching Protocols

- A switch is connected to certain links.



Protocol Graph

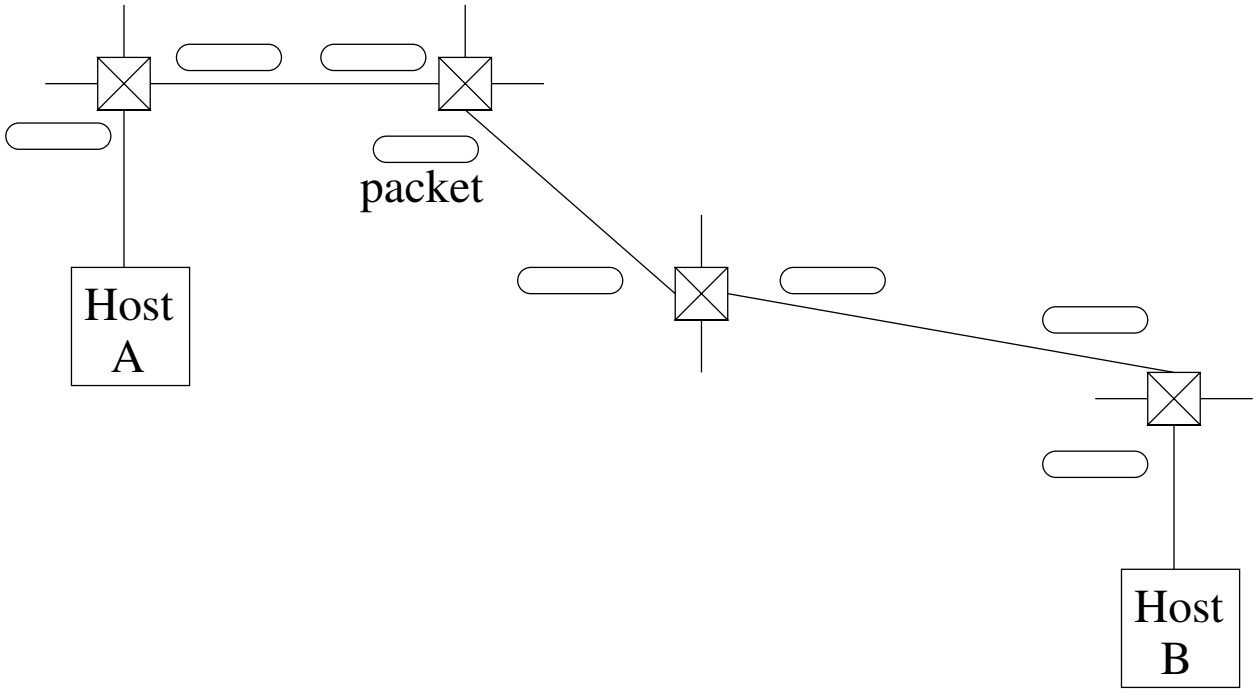


Input Ports Output Ports

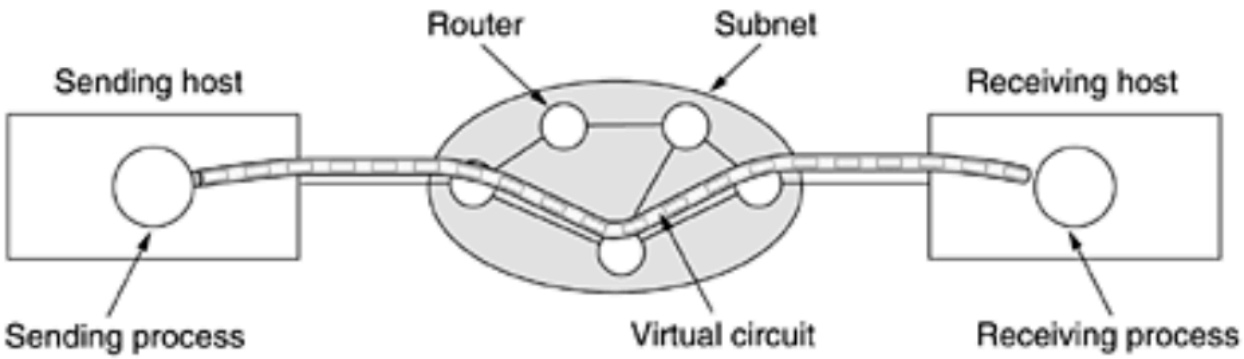
- How does a switch decide which input goes to which output?
  1. Connectionless (datagram) approach,
  2. Virtual Circuit (Connection Oriented) approach,
  3. Source Routing approach.
- We need node addresses to identify uniquely destination nodes.
- We also need identifiers for the input/output ports of the switch.

Connection Setup and Data Transfer

- Unless permanent circuits are available, some kind of signalling is necessary to establish circuits.



Virtual Circuit Switching



Virtual Circuit (VC) Switching

- Requires that a connection is setup from host to destination node: VC Switching is also known as Connection Oriented Model.
- A VC can be either long-lived: known as PVC (Permanent VC) or dynamically setup by the host: known as SVC (Switched VC).
- A PVC is setup by an administrator and includes
  1. An incoming interface on which packets for this VC arrive.
  2. A VCI (VC Identifier) that is carried in the arriving packets.
  3. An outgoing interface in which packets for the VC leave the switch.
  4. A VCI that will be used for outgoing packets.
- SVC uses routing instead to set up the VCs from a source node to a destination node.

VC Characteristics

1. Source host A will have to wait for connection request to reach destination host B. The delay is RTT.
2. Although B's address might be large (being global) the datagrams on the VC need only contain small identifiers.
3. If a link or node along the way fails the whole VC fails and a new one must be setup.
4. Buffers are allocated to each VC at initialization.
5. Sliding window protocol augmented with flow control is run between peer nodes.
6. VC rejected at request time if not enough buffers available.
7. Routing is important in setting up VCs.

Switching Fabrics

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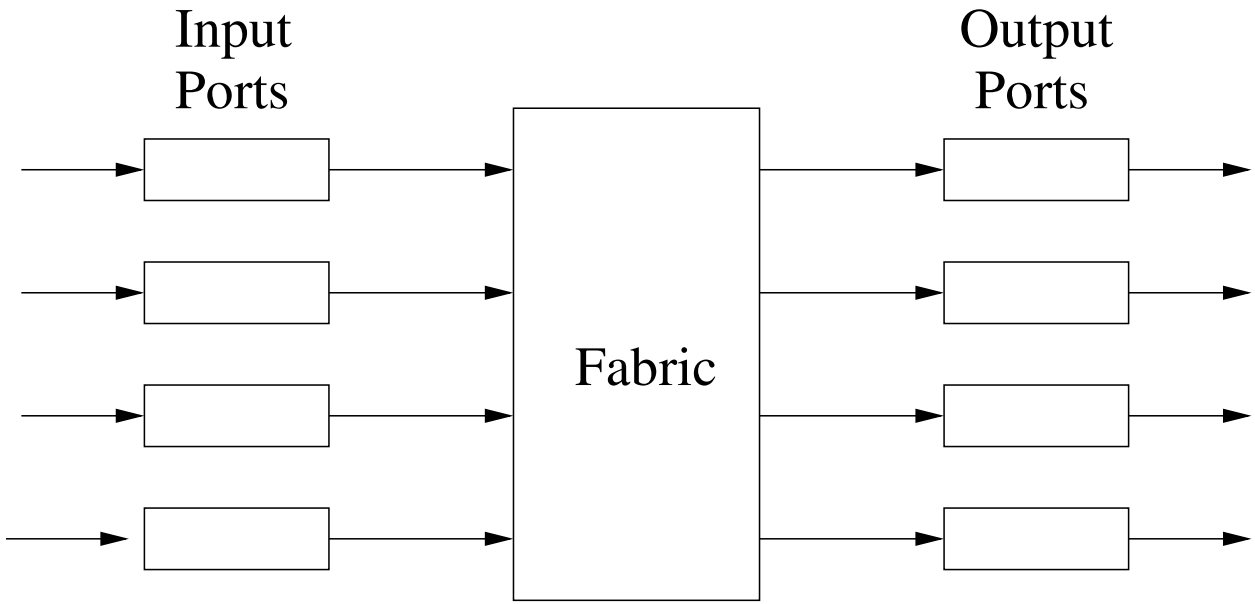
Switches: For High Performance

- A switch is a device in a computer network that electrically and logically connects together other devices.
- Multiple data cables are plugged into a switch to enable communication between different networked devices.
- Switches manage the flow of data across a network by transmitting a received network packet only to the one or more devices for which the packet is intended.
- Each networked device connected to a switch can be identified by its network address, allowing the switch to regulate the flow of traffic.
- This maximizes the security and efficiency of the network.
- Various switches exist.

Ports and Fabrics

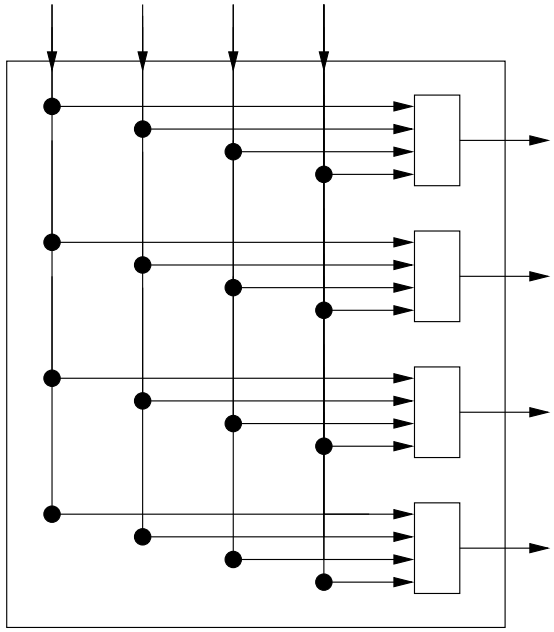


Switch Parameters

1. $m \times n$ switch has m input ports and n output ports.
2. Throughput: difficult to define accurately. Important to come up with good traffic models.
3. Size of packets entering and exiting affects performance.
4. Scalability: How much hardware needed to build a switch? How expensive?
5. Performance bottlenecks occur at ports. Where and how is buffering performed?
6. It's the queues that determine and define QoS characteristics.

Crossbar Switches

- Exhibit only output contention. Here is an example of a 4×4 crossbar switch. $n \times n$ Crossbar Switch has Complexity n^2.



- A true crossbar switch should be able to deal with the situation whereby every input had a packet to send to a given output at the same time.

Knockout Switches

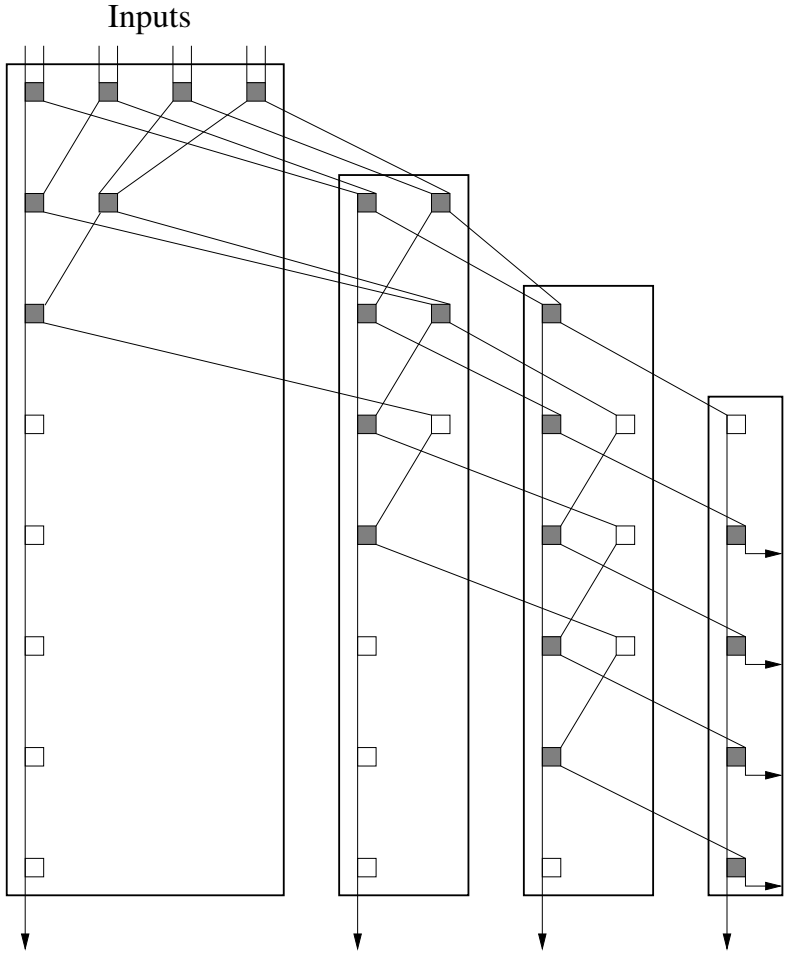
- In practice design requires that for some $l < n$, l inputs have a packet to send to a given output at the same time.
- To keep costs down l should be small. But also l should be large enough so that the probability that more than l packets arrive at the same time is small.
- The output port consists of the following.
  1. A set of packet filters that recognize packets destined for this port.
  2. The concentrator or "knockout" port: selects up to l packets from those destined for this port and discards the rest.
  3. A queue that accepts up to l packets at a time and buffers them.

Knockout Concentrators: Fabric Must be Fair!

- Fairness is achieved by playing packets against each other in a knockout tournament to select l winners from n contestants.
- Each column represents a section of the tournament.
- In leftmost column 8 players compete like in tennis quarterfinals until one wins.
- The four losers from first round of this section go to compete in second section.
- and so on.

8×4-Knockout Concentrator: $n = 8, l = 4$

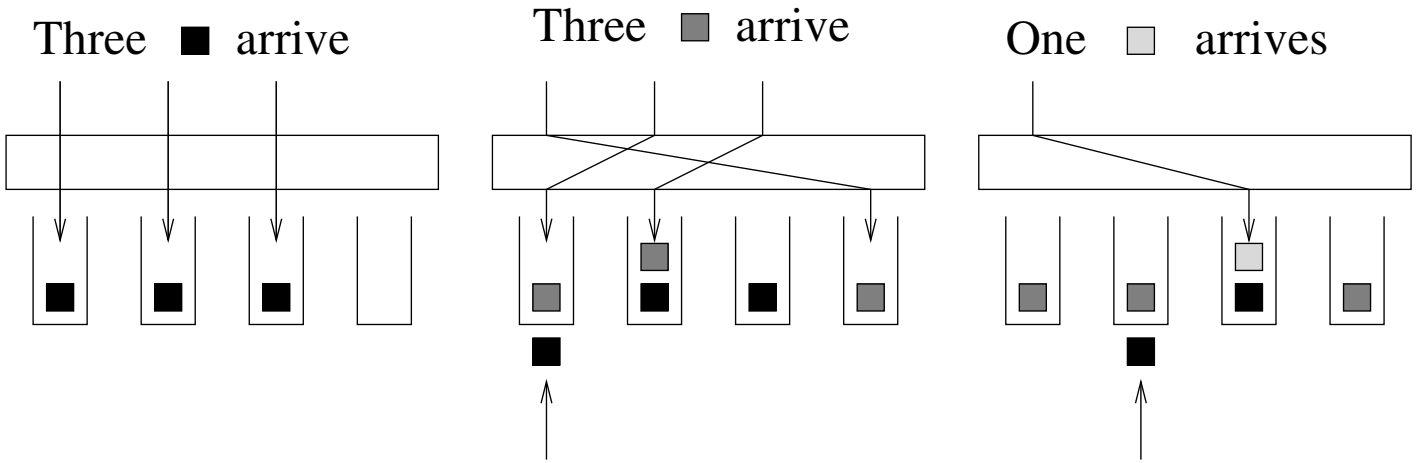
- Employs traffic merging



- We will not discuss them in detail here.

The Buffers

- Each output port has a buffer that can hold up to l packets at a time.



  A shifter moves arriving packets into different buffers to ensure they are filled in a round robin manner. At the same time packets are also read in a round robin manner.

- Drawback: it works well if traffic is uncorelated.

Some WANs

- X.25
  - X.121
  - Triple-X
  - X.3
  - X.28
  - X.29
- Frame Relay
- ATM
- SONET/SDH (Transport mechanism for Broadband services).