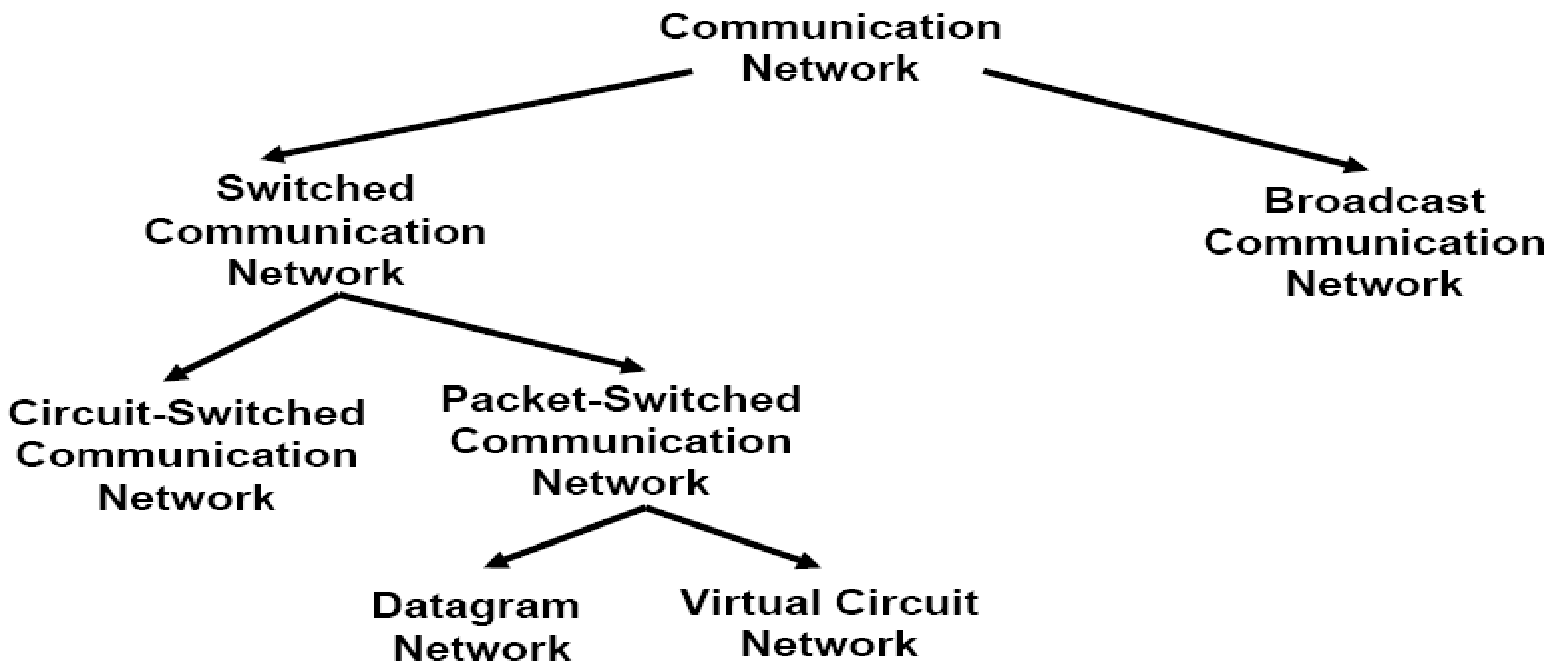
Chapter Four

Wide Area Network (WAN) Technology

A Taxonomy of

- Communication networks can be classified based on the way in which the nodes exchange information.



Introduction to WAN

- utilize protocols at levels 1-3 of the OSI reference model that are optimized, both physically and logically, for extended travel
- when you select a WAN technology, you will be faced with many confusing options:
  - the amount of data they can deliver,
  - the speed at which they operate,
  - their initial and recurring costs,
  - their management requirements, and
  - their flexibility to include new locations or new technologies such as voice or video

Switching

- involves moving something through a series of intermediate steps, or segments, rather than moving it directly from start point to end point
- serves the same purpose as the direct connection, but it uses transmission resources more efficiently
- WAN uses switching
- There are different kinds of switching:
  - Circuit switching
  - Packet switching
  - Message switching
- WANs rely primarily on packet switching, but they also make use of circuit switching, message switching,
  - the relatively recent, high-speed packet-switching technology known as ***cell relay***

1. Circuit Switching

- involves creating a direct physical connection between sender and receiver
- a connection lasts as long as the two parties need to communicate
- allows for a fixed (and rapid) rate of transmission
- switching is done at the physical layer
- The primary drawback is
  - any unused bandwidth remains exactly unused
- The most common form of circuit switching - the telephone system
- but circuit switching is also used in some networks

- **Advantages**:
  - fixed delays
  - guaranteed continuous delivery
- **Disadvantages**
  - the long connection delay (between the end of dialing and the start of ringing)
  - circuits are not used when session is idle
  - inefficient for bursty traffic
  - usually done using a fixed rate stream (e.g., 64 Kbps) - difficult to support variable data rates

2. Message Switching

- does not involve a direct physical connection
- When a network relies on message switching, the sender can fire off a transmission—after addressing it appropriately—whenever it wants
- when the sender has a block of data to be sent,
  - it is stored in the first switching office (i.e., router) and then forwarded later;
  - each block is received in its entirety, inspected for errors, and then transmitted - a store-and-forward network

- the intermediaries aren't required to forward messages immediately.
  - Instead, they can hold messages before sending them on to their next destination
- no limit on block size; routers need disk buffers
- a single block may tie up the line
- not in use anymore

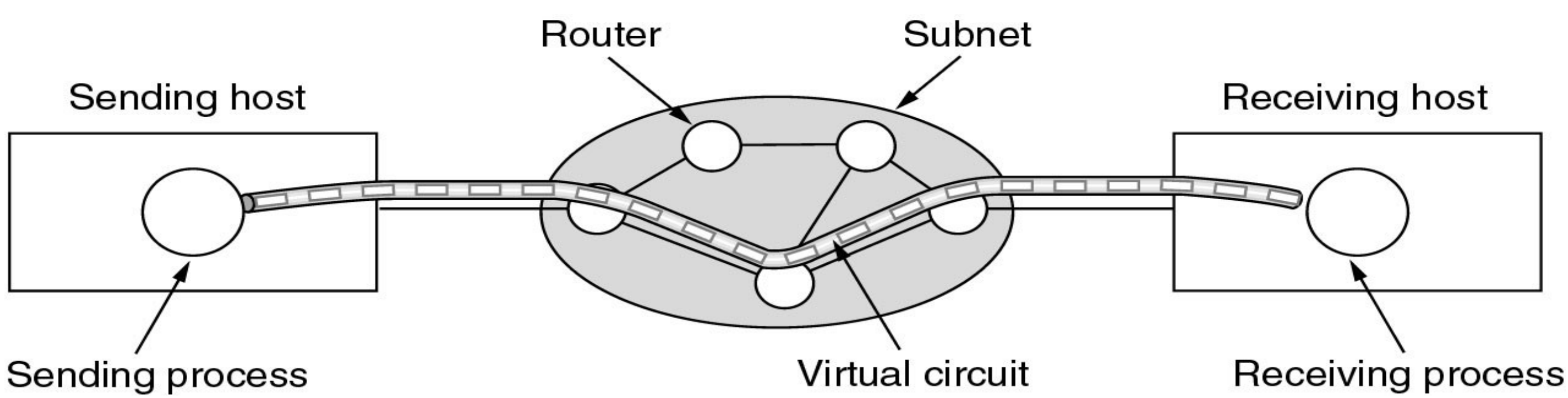
3. Packet Switching

- similar to message switching,
  - but with a tighter limit on block size so that packets can be buffered in memory rather than on disk
- suitable for interactive traffic; no monopoly
- all transmissions are broken into units called **packets**,
- each of which contains addressing information that identifies both the source and destination nodes
- These packets are then routed through various intermediaries, known as ***Packet Switching Exchanges*** (***PSE*s**) Router
- packet-switched networks transfer data over variable routes
- At each node the entire packet is received, stored, and then forwarded (**Store-and-Forward Networks**)

- There has to be some kind of connection — either ***connectionless*** or ***connection-oriented*** services, depending on the type of packet-switching network involved
- In establishing the link between sender and recipient, a connection-oriented service can make use of
  - either ***Switched Virtual Circuits*** (***SVC***s)
  - or ***Permanent Virtual Circuits*** (***PVC***s)
- Using a ***switched virtual circuit*** is comparable to calling someone on the telephone
- Using a ***permanent virtual circuit***, on the other hand, is more like relying on a leased line

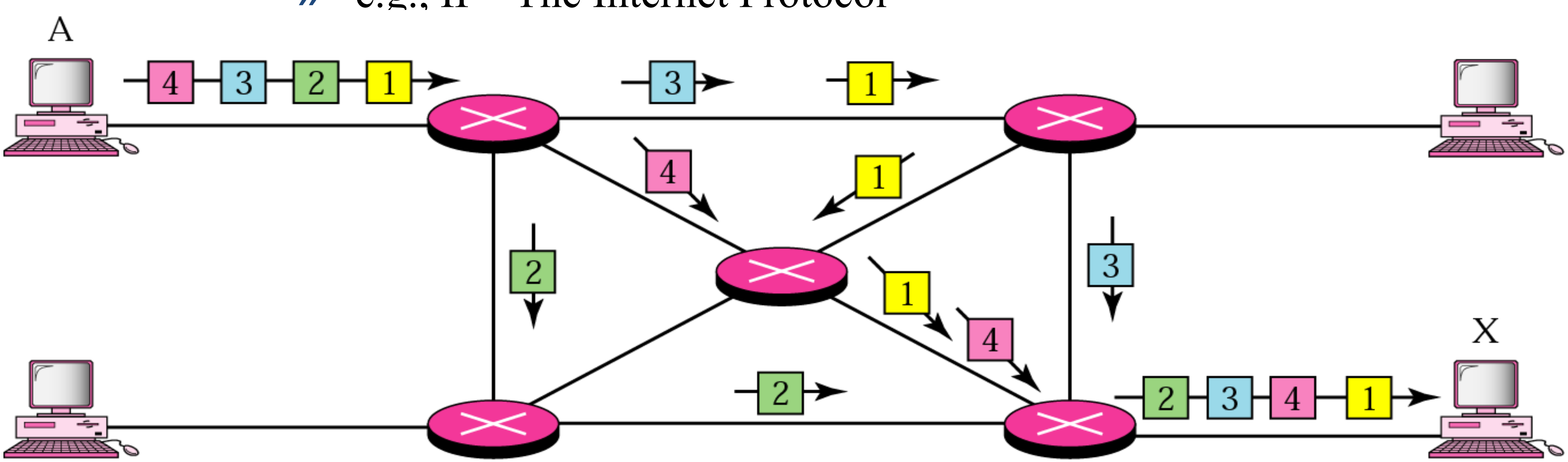
- A packet-switching network might be, for example,
  - a frame relay network
  - an ATM (Asynchronous Transfer Mode) network
  - Etc.
- **Advantage**
  - Line efficiency
    - Single node to node link can be shared by many packets over time
    - Packets queued and transmitted as fast as possible
  - Data rate conversion
    - Each station connects to the local node at its own speed
    - Nodes buffer data if required to equalize rates
  - Packets are accepted even when network is busy
    - Delivery may slow down
  - Priorities can be used

- two popular approaches to packet switching: ***the Datagram Approach and the Virtual Circuit approach***
  - ***A. Virtual Circuit approach*** - a data link layer technology
    - Hybrid of circuit switching and packet switching
    - a single route is established between sender and receiver at the beginning of the session by sending a set-up packet
    - as the packet travels all the way, the routers on the path record an entry in their internal tables and make reservation of resources at the beginning
    - a call teardown deletes
    - no routing decision is made by every switch for every packet; it is made only once and the virtual circuit
    - used for connection-oriented services
  - e.g., ATM (Asynchronous Transfer Mode)



B. **Datagram Approach** - mostly used in the network layer

- each packet is treated independently of all others
- packet in this approach is referred to as **datagram**
- used for connectionless services
- route chosen on packet-by-packet basis
- different packets may follow different routes
- packets may arrive out of order at the destination
- Up to receiver to re-order packets and recover from missing packets
  - » e.g., IP - The Internet Protocol



Item	Circuit switched	Packet switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
Time of possible congestion	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Transparency	Yes	No
Charging	Per minute	Per packet

Frame Relay

- Often referred to as a ***fast packet switching*** technology
- transfers ***variable-length*** packets
  - up to 4 KB in size at 56 Kbps or T1 (1.544 or 2 Mbps) speeds over permanent virtual circuits
- Operating only at the data link layer
- was designed to take advantage of newer digital transmission capabilities, such as fiber optic cable and ISDN
- These offer reliability and lowered error rates
- include a means of detecting corrupted transmissions through a cyclic redundancy check, or CRC
- does not include any facilities for error correction
- the sender does not overwhelm the recipient with too much data

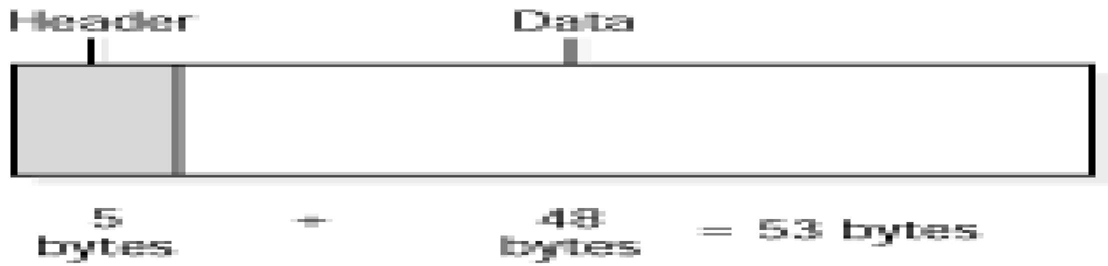
- because it operates over permanent virtual circuits (PVCs)
  - transmissions follow a known path
  - and there is no need for the transmitting devices to figure out which route is best to use at a particular time
- It provides end-to-end service over a known — and fast — digital communications route
- It is based on multiplexing a number of (virtual) circuits on a single communications line

- response to congestion
  - First, to request the sending application to slow down a little its transmission speed
  - Second, involves discarding frames flagged as lower-priority deliveries
- Frame relay networks connecting LANs to a WAN rely on routers and switching equipment capable of providing appropriate frame-relay interfaces

ATM (Asynchronous Transfer Mode)

- is a transport method
- capable of delivering not only data but also voice and video simultaneously and over the same communications lines
- is a connection-oriented networking technology
- closely tied to the ITU's recommendation on *broadband ISDN* (*BISDN*)
- is good for high-speed LAN and WAN networking over a range of media types
  - from the traditional coaxial cable, twisted pair, and fiber optic to communications services of the future, including FDDI, and SONET

- like frame relay, it is based on packet switching
  - however, it relies on cell relay, a high-speed transmission method
- based on fixed-size units (tiny ones only 53 bytes long) that are known as ***cells*** and that are multiplexed onto the carrier.



ATM cell

- It is so fast as uniformly sized cells travel faster and can be routed faster
- Transmission speeds are commonly 56 Kbps to 1.544 Mbps,
  - but the ITU has also defined ATM speeds as high as 622 Mbps (over fiber optic cable)

- It is a wonderful means of transmitting all kinds of information at high speed.
- It is reliable, flexible, scalable, and fast because it relies on higher-level protocols for error checking and correction
- It can interface with both narrowband and broadband networks,
- It is especially suitable for use in a network backbone

- **Downside**
  - ATM networks must be made up of ATM-compatible devices
  - they are both expensive and not yet widely available
  - there is a chicken-or-egg dilemma facing serious ATM deployment:
    - businesses are not likely to incur the expense of investing in ATM-capable equipment if ATM services are not readily available through communications carriers over a wide area, yet carriers are reluctant to invest in ATM networking solutions if there is not enough demand for the service

BISDN

- is next-generation ISDN,
- Is a technology that can deliver all kinds of information over the network
- information is divided into two basic categories, ***interactive services*** and ***distributed*** *(or* ***distribution)*** ***services***.
  - ***Interactive services*** include **you-*and*-me** types of transactions, such as videoconferencing, messaging, and information retrieval
  - ***Distributed services*** include **you-*to*-me** types of information that are either delivered or broadcast to the recipient
  - These services are further divided into
    - those that the recipient controls (for example, e-mail, video telephony, and telex) and
    - those that the recipient cannot control other than by refusing to "tune in" (for example, audio and television broadcasts)

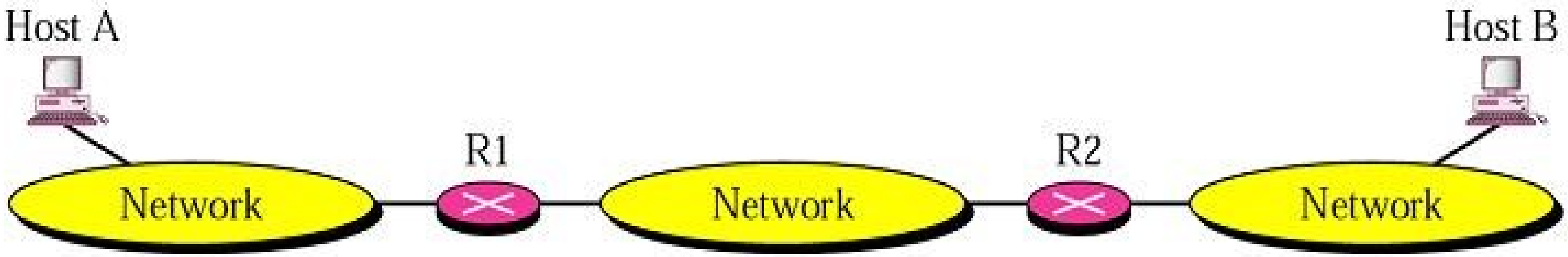
- The difference between narrowband ISDN and BSDN is the method of delivery
- Narrowband ISDN transmissions are based on time division multiplexing (TDM),
  - which uses timing as the key to interleaving multiple transmissions onto a single signal
- BISDN uses ATM, with its packet switching and its little 53-byte cells
- BISDN is comparable to a catalog shopping service that delivers everything from food to clothing, and ATM is like the boxes in which those products are packaged and delivered

Routing and Routing Protocols

- making a decision and choosing one route whenever there are multiple routes based on some criteria
- it is the job of the network layer routing protocol
- at the heart of such protocol is the routing algorithm that determines the path for a packet
- The routing algorithm is responsible for deciding which output line an incoming packet should be transmitted on.
- Routing involves two basic activities:
  - determining optimal routing paths and
  - transporting information groups (typically called packets) through an internetwork.

- If the subnet uses datagram internally this decision must be made anew for every arriving packet.
- On the other hand if the subnet uses Virtual Circuits (VCs), this decision is made only when a new virtual circuit is set up.
- Desirable properties of a routing algorithm:
  - correctness,
  - simplicity,
  - robustness,
  - stability,
  - fairness, and
  - Optimality

- routing requires a host or a router to have a routing table which is constructed by the routing algorithm



Routing table for host A

Destination	Route
Host B	R1, R2, Host B

Routing table for R1

Destination	Route
Host B	R2, Host B

Routing table for R2

Destination	Route
Host B	Host B

- given big internetworks such as the Internet, the number of entries in the routing table becomes large and table look ups become inefficient;

- methods for reducing its size required
  - **Next-Hop Routing**
    - the routing table holds only the information that leads to the next hop

Routing table for host A

Destination	Next Hop
Host B	R1

Routing table for R1

Destination	Next Hop
Host B	R2

Routing table for R2

Destination	Next Hop
Host B	—

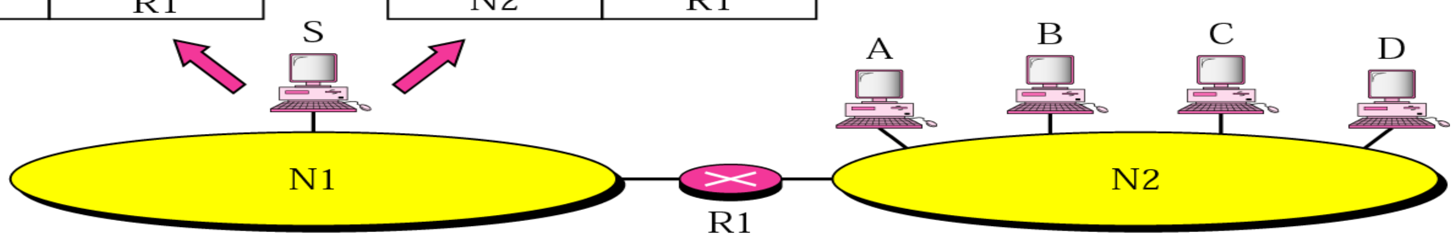
- **Network Specific Routing**
  - instead of having an entry for every host connected to the same physical network, there is only one entry to define the address of the network itself

Routing table for host S based on host-specific routing

Destination	Next Hop
A	R1
B	R1
C	R1
D	R1

Routing table for host S based on network-specific routing

Destination	Next Hop
N2	R1



- **Routing Vs Forwarding**
  - **Forwarding** deals with getting a packet in one line and putting it in an outgoing line.
    - As a function it is the force that gets packets moving in a network.
  - **Routing** deals with choosing the correct outgoing line to place a packet for transmission.
- routing algorithms must converge rapidly.
  - ***Convergence*** is the process of agreement, by all routers, on *optimal* routes
- Routing algorithms that converge slowly can cause routing loops or network outages

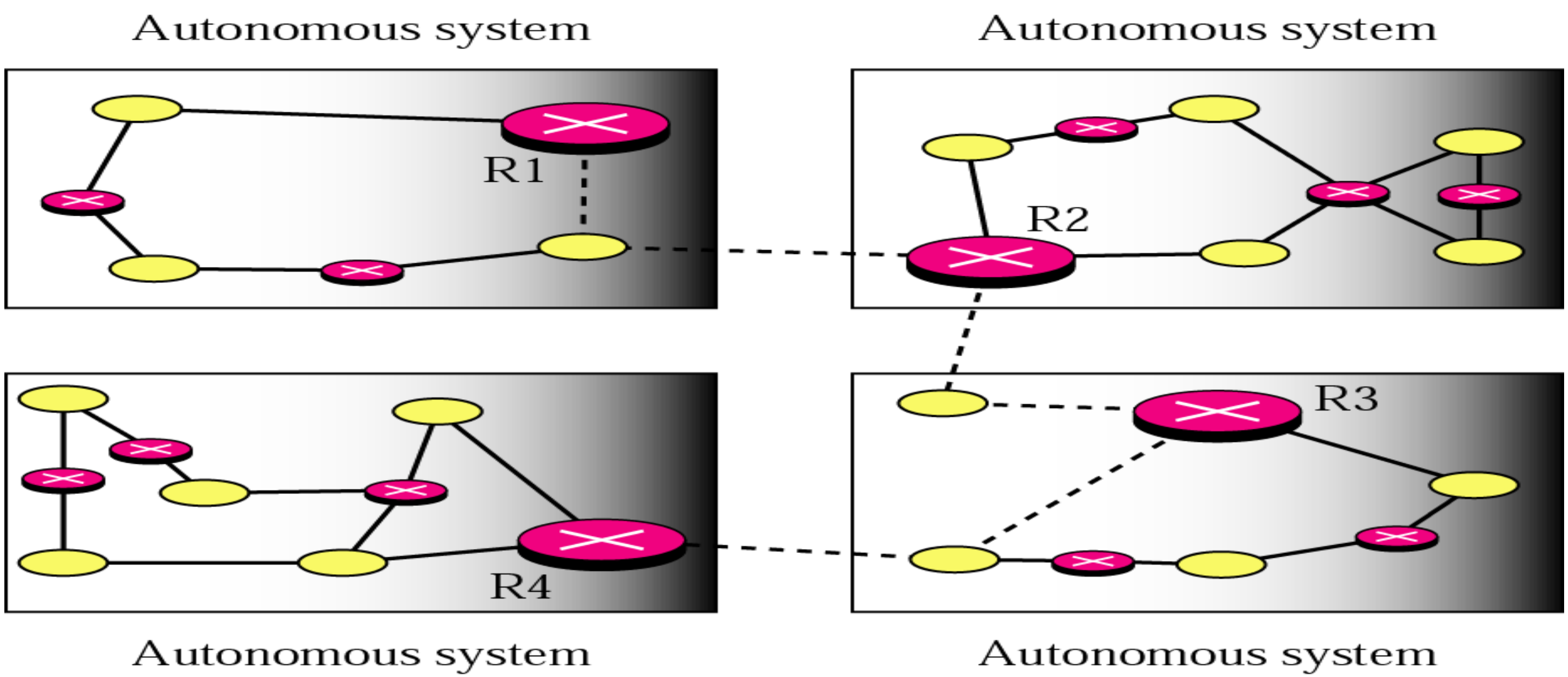
- Types of Routing Algorithms (routing tables):
  - non-adaptive (static)
  - adaptive (dynamic)
- **Nonadaptive (Static)**
  - routing decisions are not based on measurements or estimates of the current topology or traffic
  - the choice of a route is computed in advance, off-line, and downloaded to the routers when the network is booted or
  - an administrator enters the route for each destination into the table;
  - not automatically updated when there is a change;
  - may be used in a small internet, but not for big internet like the Internet

- **Adaptive (Dynamic)**
  - routing decisions are made periodically (every δ sec) to reflect
    - » changes in the topology,
    - » changes in traffic,
    - » a shutdown of a router,
    - » a break in the link,
    - » a better route has been created, ...

- **Routing Protocols**
  - use metrics to evaluate what path will be the best for a packet to travel
  - a metric is a cost assigned for passing through a network
  - the cost could be
    - the level of congestion of a link (mean queue length, transmission delay, average traffic),
    - bandwidth,
    - the geographic distance traversed by the link,
    - number of hops,
    - estimated transit time,
    - communication cost, ...

- cost may change with time
- which cost to choose depends on the application
- the total metric of a particular route is equal to the sum of the metrics of networks that comprise the route
- a router chooses the route with the shortest (smallest) metric
- **Interior and Exterior Routing (protocols)**
  - since an internet can be large, one routing protocol cannot handle the task of updating the routing tables of all routers
  - hence, an internet is divided into **Autonomous Systems**
  - an ***Autonomous System (AS)*** is a group of networks and routers under the authority of a single administration
  - routing inside an autonomous system is referred to as **Interior Routing**;

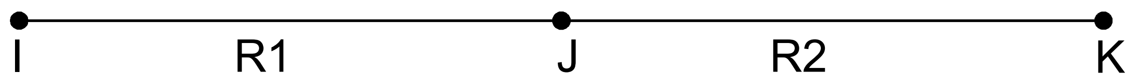
- each AS can choose its own routing protocol
- routing between autonomous systems is referred to as **Exterior Routing**;
- one protocol is usually chosen to handle routing between autonomous systems;
- usually used for routing in the Internet



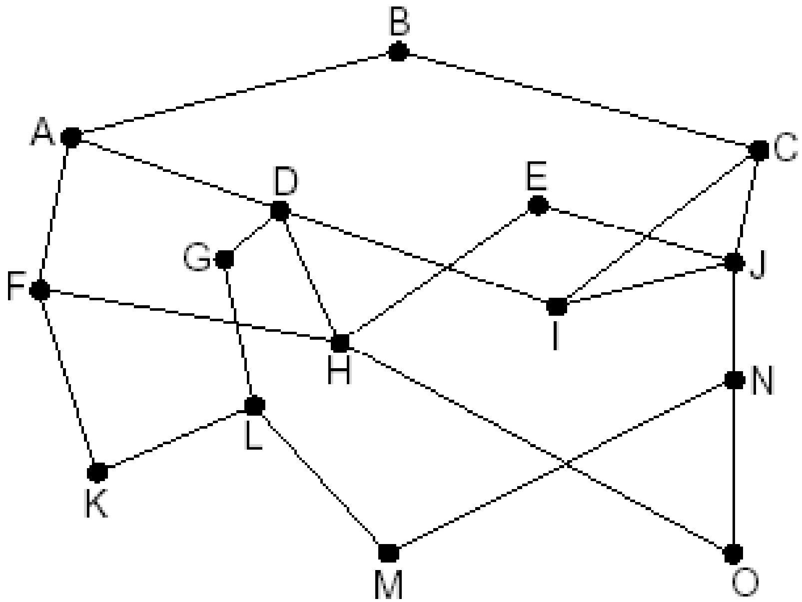
- R1, R2, R3, and R4 use both interior and exterior routing protocols
- the rest use only interior routing protocols
- **solid lines** - communication between routers
- **broken lines** - communication between the routers that use an exterior routing protocol
- why an exterior routing protocol apart from size of an internet? - politics
  - **political** - I hate country X hence I will not handle its traffic
  - **security** - my information is confidential and should not pass through a hostile country

- **economic**
  - it should not pass through a competitor's network
  - I am not paid for it and hence don't want to carry a transit packet
- such policies are typically manually configured into each router and are not part of the protocol itself

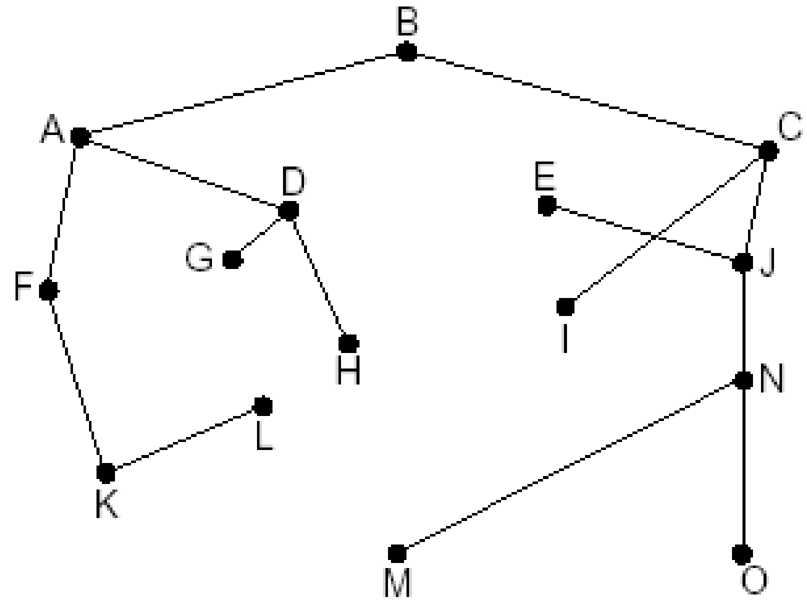
- ***The Optimality Principle:*** the optimal route
  - if router **J** is on the optimal path from **I** to **K**, then the optimal path from **J** to **K** also falls along the same route
  - why?
    - if a route better than **R2** existed from **J** to **K**, then the route from **I** to **K** could be improved by concatenating it with **R1**



  - the consequence of the optimality principle is that
    - “the set of optimal routes from all sources to a given destination form a tree rooted at the destination”
  - such a tree is called a **Sink Tree**



a subnet

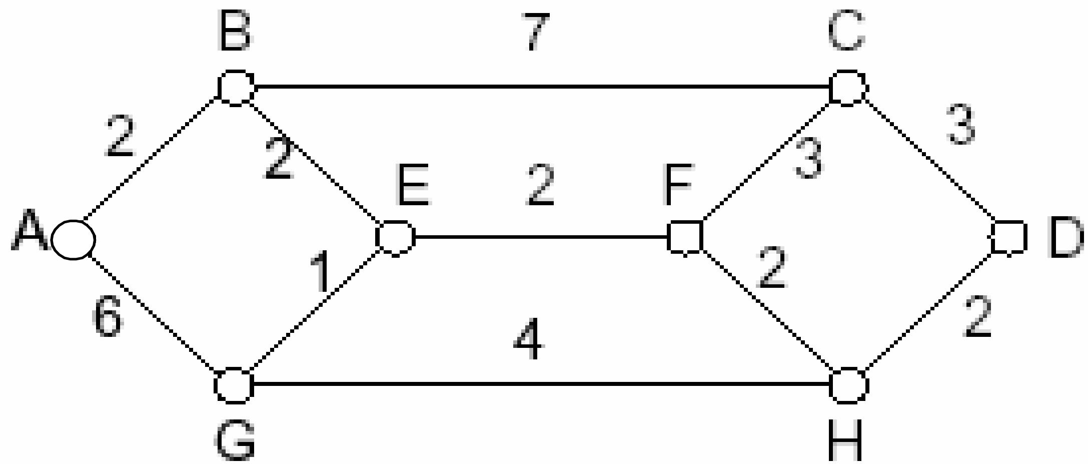


sink tree for router B

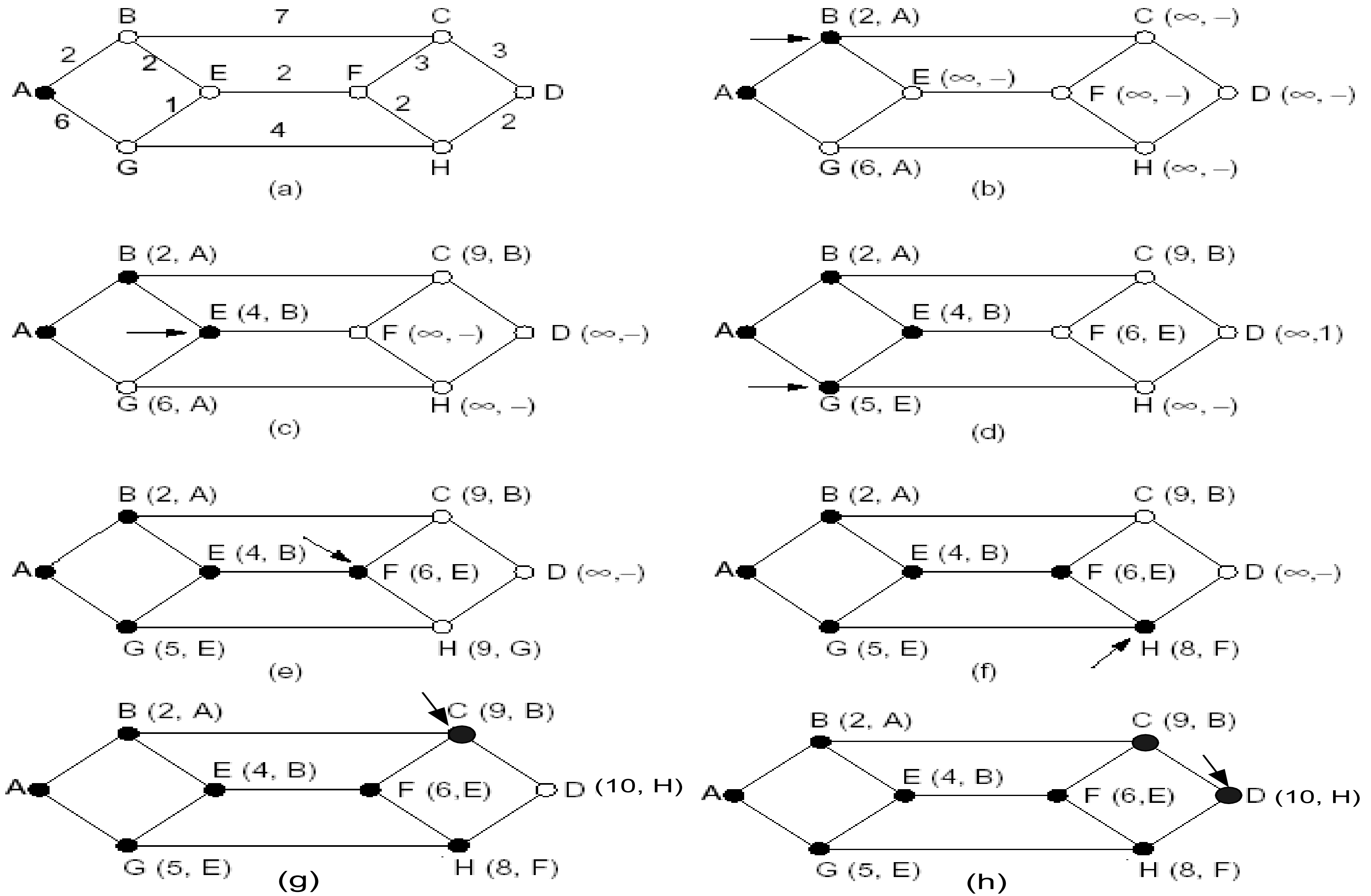
- **(distance metric is the number of hops)**
  - the sink tree is not necessarily unique;
  - as a tree it does not contain any loops;
  - each packet will be delivered within a finite and bounded number of hops; at least in theory

- the goal of a routing algorithm is to discover the sink trees for all routers
- the optimality principle and the sink tree serve as benchmarks to measure routing algorithms

- **Shortest Path Routing (static)** for unicast routing (by Dijkstra)
  - **aim**:
    - build a graph of the subnet - each node of the graph representing a router and each arc representing a link;
    - the arcs are labeled as a function of any one of the metrics discussed (distance, hop count, ...)
  - to select a route between two routers, the algorithm finds the "shortest" path between them on the graph



- how does the algorithm work to find the shortest path?
  - each node is labeled with its distance from the source;
  - initially labeled ∞ since no path is known
  - a label may be tentative or permanent (when the shortest possible path is found - **filled-in circle**)



– we want to find the path from A to D

– the shortest path is **ABEFHD**

→ working node