Chapter 5
Network Layer

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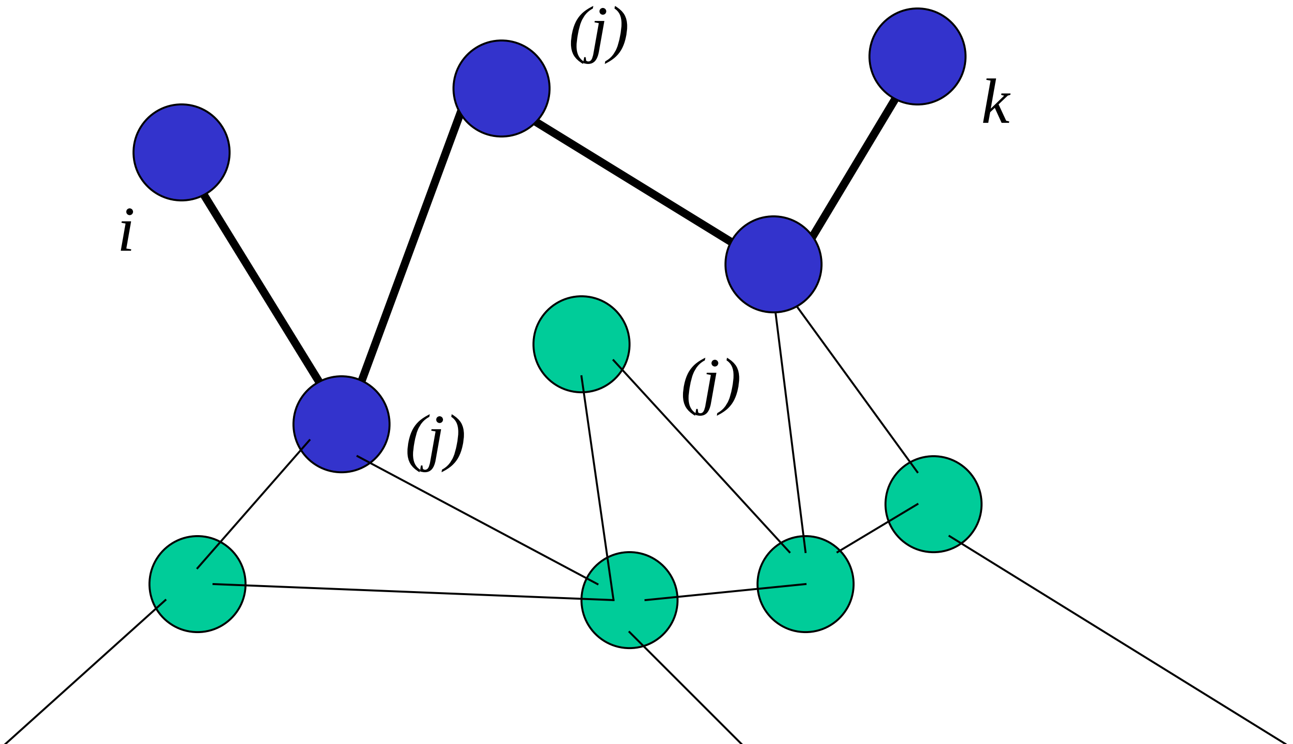
Types of Routing Algorithms

- Nonadaptive (static)
  - ✓ Do not use measurements of current conditions.
  - ✓ Static routes are downloaded at boot time.
- Adaptive Algorithms
  - ✓ Change routes dynamically
    - Gather information at runtime
      - locally
      - from adjacent routers
      - from all other routers
    - Change routes
      - Every delta T seconds
      - When load changes
      - When topology changes

Optimality principle

- 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.



Sink Trees

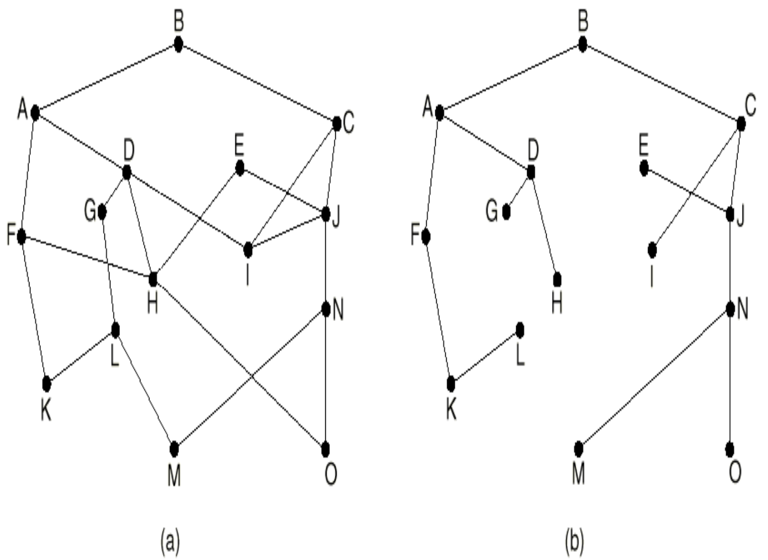


Fig. 5-5. (a) A subnet. (b) A sink tree for router *B*.

- The set of optimal routes to a particular node forms a sink tree.
- Calles as Directed Acyclic Graph (DAG).
- Sink trees are not necessarily unique.
- Goal of all routing algorithms.
  - ✓ Discover sink trees for all destinations.

Shortest Path Routing

- Given a network topology and a set of weights describing the cost to send data across each link in the network.
- Find the shortest path from a specified source to all other destinations in the network.
- Shortest path algorithm first developed by E. W. Dijkstra

Shortest Path Routing(1)

- Optimization criterion:
  - Distance,
  - Bandwidth,
  - Average Traffic,
  - Communication cost,
  - Mean Queue Length,
  - Measured Delay.
- Algorithms:
  - Dijkstra
  - Flooding
    - Selective Flooding

Shortest Path Routing(2)

- Mark the source node as permanent.
- Designate the source node as the working node.
- Set the tentative distance to all other nodes to infinity.
- While some nodes are not marked permanent

  Compute the tentative distance from the source to all nodes adjacent to the working node. If this is shorter than the current tentative distance replace the tentative distance of the destination and record the label of the working node there.

  Examine ALL tentatively labeled nodes in the graph. Select the node with the smallest value and make it the new working node. Designate the node permanent.

Shortest Path Routing(3) [Example]

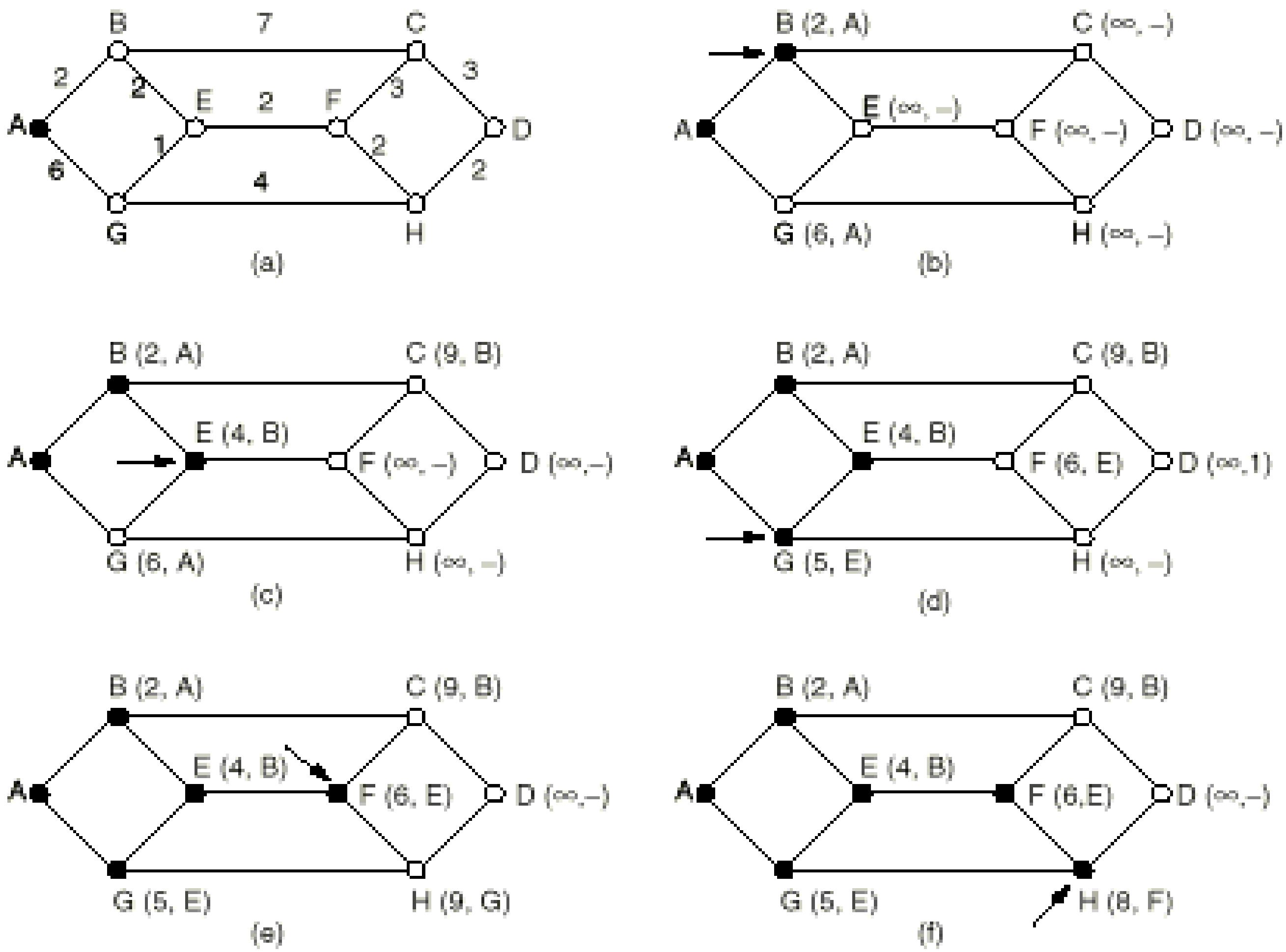


Fig. 5-6. The first five steps used in computing the shortest path from *A* to *D*. The arrows indicate the working node.

Flooding

- Brute force routing
  - Every incoming packet is sent on every outgoing line.
  - Always finds the shortest path quickly.
  - Also finds many long paths.
  - Time to live is set to size of subnet.
- Selective Flooding
  - Flood only in the direction of the destination.
- Practical in a few settings
  - Military Applications.
  - Distributed Databases.
  - Metric for comparison.

Distance Vector Routing

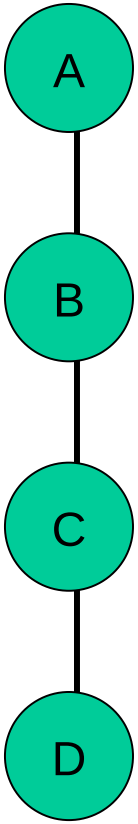
- Neighboring routers periodically exchange information from their routing tables.
- Routers replace routes in their own routing tables anytime that neighbors have found better routes.
- Information provided from neighbors
  - ✓ Outgoing line used for destination.
  - ✓ Estimate of time or distance.
    - can be number of hops, time delay, packet queue length, etc.
- **Link state routing.**

Count–to-Infinity Problem

- Slow Convergence to the correct answer.
- “Good news” Propagate fast.
- “Bad news” Propagate slowly:
  - The core of the problem is that when X tells Y that I has a path somewhere, Y has no way of knowing whether it itself is on the path.

The Split Horizon Hack

- Actual distance to a destination is not reported on the line on which packets to that destination are sent.
- Instead these distances are reported as "infinity."



C tells D the truth about its distance to A, but lies to B and says the distance is infinity.

A topology where split horizon fails

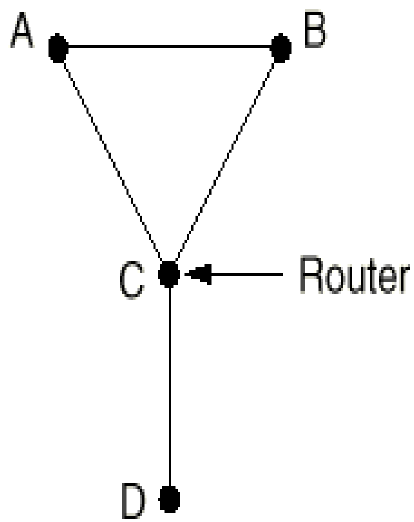


Fig. 5-12. An example where split horizon fails.

Suppose that D becomes unreachable from C.

A and B are reporting infinite distances to C, but they are reporting distances of length 2 to each other.

A and B will count to infinity.

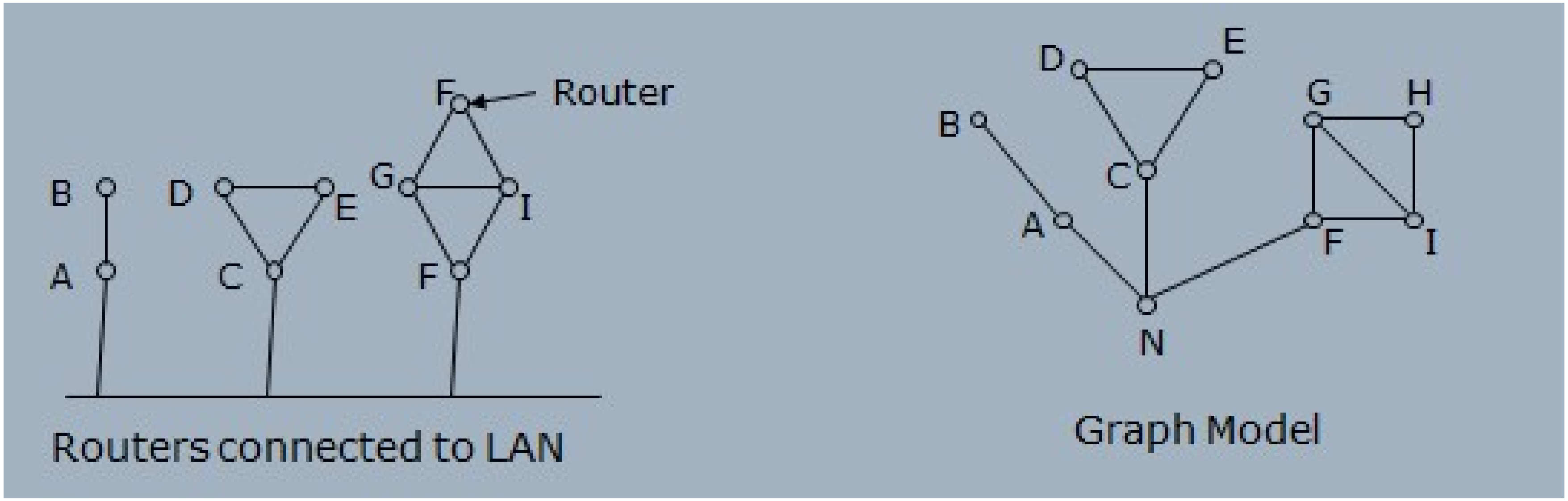
Link State Routing

Each router must do the following: **Five Steps**

1. Discover its neighbors and learn their network addresses.
2. Measure the delay or cost to each of its neighbors.
3. Construct a packet telling all it has just learned.
4. Send this packet to all other routers.
5. Compute the shortest path to every other router.

1. Discovering Your Neighbors

- “HELLO” packed send on each point-to-point line from a booted router.
- Router on the other end must reply by sending its globally unique “name”.
- Example of routers connected by a LAN.



2. Measuring Line Cost

- It is required by the Link State Routing algorithm that each router not have a reasonable estimate of the delay/cost to each of its neighbors.
  - Send “ECHO” packet (ping) that the other side is required to send back immediately.
    - Measure Round Trip time; Divide by 2 to get an estimate.
    - More accurate estimate by repeating the process several times and by averaging estimates.
    - Assumes symmetric delay.
- Channel Load Issue when Measuring Delay
  - To factor the load in: round trip timer must be started when the ECHO packed is queued.
  - To ignore the load: round trip timer must be started when ECHO packed reaches front of the queue.

2. Measuring Line Cost(2)

- Including Traffic-induced Delays:
  - ✓ If a router has a choice from 2 lines with the same bandwidth, one of which is heavily loaded all the time and one of which is not, the router will regard the route over the unloaded line as shorter path. This choice in general will result in better performance
  - ✓ Problem with Oscillations in the choice of best path.

3. Building Link State Packet

- Packet Format:
  - ✓ Identity of Sender
  - ✓ Sequence Number
  - ✓ Age
  - ✓ List of Neighbors
  - ✓ Corresponding Delay
- Packets easily built – problem with knowing when to built them.

A	
Seq.	
Age	
B	4
E	5

B	
Seq.	
Age	
A	4
C	2
F	6

C	
Seq.	
Age	
B	2
D	3
E	1

D	
Seq.	
Age	
C	3
F	4

E	
Seq.	
Age	
A	5
C	1
F	8

F	
Seq.	
Age	
B	6
D	4
E	8

4. Distributing the Link State Packets

- Distributing Link State Packets ***Reliably*** is tricky:
  - As the packets are distributed and installed, the routers getting the first ones will change their routes before other routers in the network update their routing tables.
  - Different Routers may be using different versions of the topology (inconsistencies, loops, etc.)
- Basic Algorithm: ***Flooding***
  - Sequence Number (incremented for each new packet sent) is used to keep the flood in check.
  - Routers keep track of all the source router packets they have been sent to.
  - New link state packets is checked against the track list:
    - If new/unseen (based on the sequence number) then it is broadcasted to all neighboring routers with exception of the sender.
    - If duplicate, it is disregarded.
    - If sequence number is lower than the highest one in the track list, it is rejected.

4. Distributing the Link State Packets (2)

- Problems with basic algorithm:
  1. Sequence Number wrap around.
     - Make a long precision number (e.g., 32-bit)
  2. Crash of a router: losing track of sequence number.
  3. Corruption of sequence number.
- Solution: Include Age of each packet.
  - ✓ Decrement this value once per second.
  - ✓ When zero, this state information is disregarded.
  - ✓ Normally a new packed is send every 10 sec.
    - Router information times out when:
      - Router is down, or
      - A Number of (e.g., 6) consecutive packets have been lost.

Hierarchical Routing

- Large Networks:
  - Proportionally large routing tables are required for each router
  - More CPU time is needed to scan them
  - More bandwidth is needed to send status reports.
  - At certain point network may grow so large where it is no longer feasible for every router to have an entry for every other router.
  - Solution: Routing has to be done hierarchically.

Hierarchical Routing(2)

- Routers divided in Regions (as in telephone network):
  - Each router knows how to route packets to destinations within its own region.
  - However, router does not have any information regarding the topology of the network of other regions.
- When different networks are interconnected they are regarded as a separate region in order to free the routers in one network form having to know the topological structure of the other ones.

Hierarchical Routing(3)

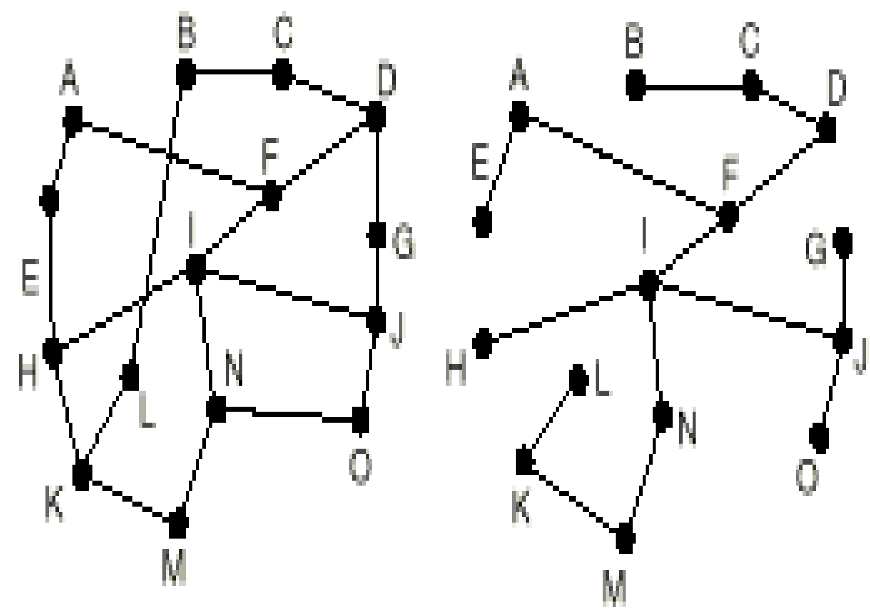
- Huge networks will require more than two-level hierarchy.
- How many hierarchical levels are optimal.
  - ✓ Kamoun and Kleinrock (1979): optimal number for an N router subnet is ln(N), requiring total of e*ln(N) entries per router.
- Example:
  Berkley, California Router to
  Malindi, Kenya.
- Berkley to Los Angeles router (out-of-state traffic)
- Los Angeles to New York router (international traffic)
- New York to Nairobi …

Broadcast Routing

- Sending a packed to all destinations simultaneously is called ***Broadcasting***.
  - Direct Method: Source sends a distinct packet to each destination routers in the subnet:
    1. Wasteful of the bandwidth.
    2. It requires source to have a list of all destinations.
  - Use spanning tree routing
    - a subset of the subnet that includes all routers but contains no loops.
  - Flooding:
    - Ordinarily ill suited for point-to-point communication:
      - Generates to many packets, and
      - Consumes to much bandwidth.

Spanning Tree Broadcasting(2)

- Uses the minimum number of packets necessary
- Routers must be able to compute spanning tree
  - ✓ Available with link state routing
  - ✓ Not available with distance vector routing



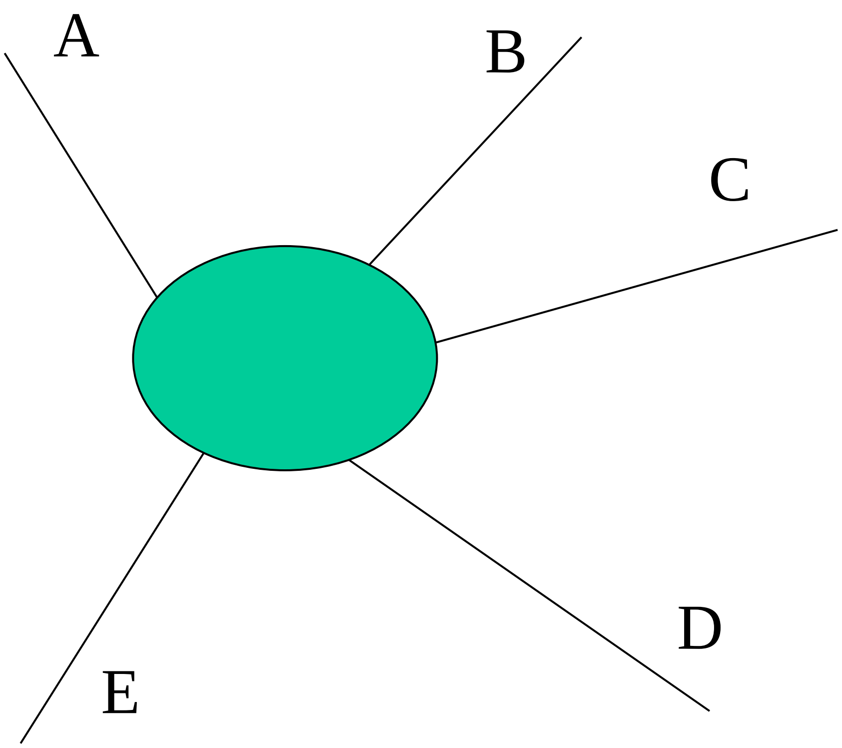
(a) (b)

Broadcast Routing(3)

- Reverse Path Forwarding:
  - Use When knowledge of a spanning tree is not available
  - Provides an approximation of spanning tree routing
  - Routers check to see if incoming packet arrives from the same line that the router uses to route outgoing packets to the broadcast source
    - If so, the router duplicates the packet on all other outgoing lines
    - Otherwise, the router discards the packet

Broadcast Routing(4) Example

- This router routes packets bound for 128.173.41.41 to via line A.
- Any broadcast from 128.173.41.41 that arrives from line A is broadcast on lines B, C, D, and E.
- Any broadcast from 128.173.41.41 that arrives from line B, C, D, or E is discarded



Multicast Routing

- A method to broadcast packets to well-defined groups.
- Hosts can join multicast groups.
  - They inform their routers.
  - Routers send group information throughout the subnet.
- Each router computes a spanning tree for each group. The spanning tree includes all the routers needed to broadcast data to the group.
- Use spanning tree protocol.