Interconnecting Networks (1/4)

- Networks of networks
  - Why the LAN (i.e., *single hop*) environment is insufficient:
    - Networks must span large geographical areas
    - Networks must accommodate large number of users
    - In other words, networks must be *scalability*
  - Inter-network (i.e., *multi-hop*) environments:
    - Extended LAN: Interconnection of multiple LANs (each typically having the same MAC layer) via bridges
    - Heterogeneous networks: Interconnection of multiple LANs with potentially different MAC layers via routers

Interconnecting Networks (2/4)

- In the single hop (i.e., LAN) environment, knowledge of the destination’s layer 2 address (i.e., data link control or MAC address) is sufficient
  - Members of the same LAN (or, equivalently, endpoints of a common serial link) are one-hop neighbors of one another
  - LAN members announce their layer 2 address (e.g., MAC address) to other members
  - Packet delivery is achieved through direct transmission and addressing to the destination via a layer 2 address

Interconnecting Networks (3/4)

- In the multi-hop environment, a single hop path between hosts may not be available
  ⇒ Require a routing or forwarding protocol
- In the heterogeneous multi-hop environment, layer 2 addresses may be incompatible:
  - E.g., source host connected to the network via an Ethernet interface while the destination host is connected to the network via token ring interface or serial link, etc.
  ⇒ Require layer 3 addressing

Interconnecting Networks (4/4)

Example: Extended LAN

Example: Heterogeneous Network

Extended LANs

- Interconnections through bridges
- Implemented via layer 3 networking protocols know as bridging protocols
- Classification of bridge technologies
  - Transparent bridges
    - Source MAC layer not aware whether the destination is connected locally via the same LAN or remotely via the extended LAN
  - Source routing bridges
    - Source MAC specifies a hop-by-hop bridge path to the destination
Transparent Bridges (1/8)

- If source (s) and destination (d) hosts are connected to the same LAN, the packet is received directly by the destination upon successful transmission on the link.
- If s and d do not belong to the same LAN one or more intermediate bridges are needed to deliver the frame to the destination LAN.

Transparent Bridges (2/8)

- One implementation option is to employ flooding:
  - Each bridge forwards a received frame on all outgoing links except for the one on which it was received.
  - However, it is not possible to control the flooding because the MAC header likely lacks a packet ID or hop limit field to prevent unlimited looping and forwarding of the packet.

Transparent Bridges (3/8)

- On the other hand, a practical option would be a tree configuration algorithm:
  - Forwarding over the extended LAN topology is restricted to a bridge-interconnected spanning tree.
  - Since the restricted bridging topology is a tree, there is no looping of packets.
  - A bridge forwards a packet over an outgoing link only if that link belongs to the spanning tree (and is not the link on which the packet was received) → Packet is transmitted only once to each LAN.

Transparent Bridges (4/8)

- Root Bridge: Bridge with the lowest ID.
- Root Port: Port in the direction of the shortest path to the root.
- Designated Port: Port in the direction of the shortest path from a LAN to the root.
- Blocked Port: Port that is neither a root or designated port.

Transparent Bridges (5/8)

- A bridge protocol data unit (BPDU) is transmitted by a bridge if:
  - Bridge believes it is the root → Transmit BPDU at regular intervals on all ports.
  - Bridge knows it is not the root → Forward (after processing) BPDU received from its root port on to all designated ports.
- BPDU content:
  - Transmitting bridge ID
  - ID that the transmitting bridge believes to be the root ID
  - Cost in hops of reaching the root from the transmitting bridge.

Transparent Bridges (6/8)

- Initially, each bridge believes it is the root.
- Upon receiving a BPDU, the received message is used if:
  - It identifies a smaller root ID or
  - It identifies a root with equal ID and shorter distance or
  - Root ID and cost are equal but the sending bridge has a smaller ID.
Transparent Bridges (7/8)

- Building a forwarding database (FDB) to hosts
  - Initially all bridging tables for forwarding to hosts are empty.
  - When a frame is received on an attached LAN (that is not blocked) the bridge records the port number and the frame source in its FDB.
  - Each entry has a timer that is reset whenever the entry is updated or used.

- Forwarding frames
  - If a frame is received on a blocked port → discard.
  - If a frame is received on a non-blocked port:
    - If entry exists for the destination exists, forward on to appropriate output port.
    - If FDB lacks an entry for the destination, the frame is forwarded on all non-blocked ports (except on the port from which the frame was received).

Source Routing Bridges (1/5)

- Hop-by-hop path from source to destination is specified in the frame header, e.g., (Source ID, Bridge ID1,...,Bridge IDn, Dest ID).
- On-demand flood-search path discovery procedure (e.g., Section 5.4.2) is applied to learn an end-to-end path:
  - E.g., all routes broadcast from source.
    - ID of each forwarding bridge is appended to the path list.
    - If recipient bridge finds its own ID in the path, the path discovery is discarded.
    - Destination will receive multiple copies of the of path discovery packet (one for each path) and sends a reply to source along the reverse of the preferred path.

Source Routing Bridges (2/5)

- Flood-search path discovery (continued)
  - Alternatively, a single-route broadcast.
    - Each bridge maintains a spanning tree (but no FDB).
    - Path discovery packet is disseminated along branches of spanning tree to all hosts, including destination.
    - Destination packet then sends an all-routes broadcast to the source (as described in the previous implementation).
    - Source then receives multiple copies of the all-routes broadcast packet and inspects the recorded paths.
    - Best path to destination is then selected.

Example of single-route broadcast:

Extended LAN:

Spanning Tree:

Example of single-route broadcast (host 1 to host 3):

Source Routing Bridges (3/5)

Source Routing Bridges (4/5)

- Note: Spanning tree yields a sub-optimal FDB, in general.
  - E.g., path from host 8 to host 12 would be (8,B4,B1,B2,B3,12).

FDB at Bridge 3

<table>
<thead>
<tr>
<th>Port Number</th>
<th>Destination</th>
<th>Port Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>3</td>
</tr>
</tbody>
</table>
Ch. 9 Homework Overview (1/3)

- P9.2: Apply the tree configuration algorithm of Section 9.2.1.2 to Fig. 9.17
  - Label each port of resulting tree as a root (R), designated (D) or blocked (B) port
  - See also example in notes

Ch. 9 Homework Overview (2/3)

- P9.3: Given the following received BPDUs, derive the resulting BPDUs to be transmitted:

<table>
<thead>
<tr>
<th>Port Number</th>
<th>Believed Root</th>
<th>Cost</th>
<th>Transmitting Bridge ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22</td>
<td>45</td>
<td>28</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>39</td>
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<tr>
<td>3</td>
<td>9</td>
<td>54</td>
<td>51</td>
</tr>
<tr>
<td>4</td>
<td>9</td>
<td>46</td>
<td>36</td>
</tr>
<tr>
<td>5</td>
<td>48</td>
<td>0</td>
<td>48</td>
</tr>
</tbody>
</table>

  - Solve for cases where receiving bridge ID is 14 and 4
  - Identify root, designated and blocked ports of the bridge
  - Outputted BPDU includes believed root, cost and ID of the transmitting bridge

Ch. 9 Homework Overview (3/3)

- P9.4: Given the extended LAN of Fig. 9.18, source S1 and destination S6, show the forwarding path trees for messages exchanged in the single-route and all-route broadcast procedures when a spanning tree is maintained
  - Refer to Fig. 9.12 and lecture notes for examples

- P9.5: Repeat P9.4 for the case where no spanning tree is maintained (i.e., all-route broadcast from source)