EE 122: Switching and Forwarding

Kevin Lai
September 23, 2002

Direct Link Network Review

- Data link layer presents a single media (e.g., single wire) network model
- Problem and solutions
  - Framing
    - character stuffing, byte counting, bit stuffing, clocked framing
  - Error detection
    - parity, checksum, CRC
  - Reliability
    - stop and go, sliding window
- solutions also apply to similar problems in higher layers
  - problems can not be completely solved at data link layer
  - only implemented in data link layer as optimization

Limitations of Direct Link Networks

- distance
  - distance increases propagation delay
  - large propagation delay causes large coordination delay
    - e.g., Ethernet collision detection requires 2*prop_delay
- number of hosts
  - More hosts increases the probability of collisions
  - collisions decrease efficiency of link
- bandwidth
  - bandwidth of link is shared among all connected nodes
- single media type
  - different media (e.g., fiber, Ethernet, wireless) have different tradeoffs for performance, cost, etc.

Direct Link Networks v.s. Switching

Direct Link Network Switched Network

Single link n links

Switch

Emulates clique

Definitions

- switch (aka bridge)
  - does switching
  - operates at data link layer
  - router also does switching, but at network layer
- switching consists of
  - forwarding
    - read data from input links,
    - decide which output link to forward on, and
    - examine packet header or incoming circuit, and
    - look up in forwarding table
    - transmit it on one of the output links (unicast)
  - routing
    - how the switch/router builds up its forwarding table

Properties

- spans larger physical area than direct link network (DLN)
  - can connect multiple switches together
- supports more hosts than DLN
  - hosts on separate links can transmit at same time
- higher aggregate bandwidth than DLN
  - approaches (n/2)*b instead of b, n = number of
  - switched links, b = bandwidth of one link
- supports more than one media type
  - more expensive for bridge than router
**Bridge/Router Comparison**

- Router interconnects different link layer protocols more easily
- Basic:
  - Ethernet
  - 802.11b
  - ATM
  - SONET
- O(n^2) converters
  - n = different link types

**Forwarding Techniques**

- packet switching:
  - aka [packet|datagram|connectionless] [switching|forwarding]
  - source routing
  - virtual circuit switching:
    - aka virtual circuit forwarding
    - circuit switching
    - despite names, all ways for switch to decide which output port to forward data

**Packet Switching**

- Data is separated into packets
- Each packet is forwarded independently of previous packets
  - packets between two hosts can follow different paths
- On link failure, adjoining switches select new route and continue forwarding packets
- Statistical multiplexing:
  - any one host may use 100% of a link’s bandwidth

**Statistical Multiplexing v.s. Resource Reservations**

- Reserve explicit amount of resources (e.g., bandwidth)
  - get exactly that amount
- Statistical multiplexing: get whatever is available
  - low utilization
  - congestion, packet loss

**Packet Switching Operation**

- Each switch maintains a forwarding table
  - forwarding entry: (address, output port)
- Upon packet arrival
  - input port forwards the packet to the output port whose address matches packet’s destination address
    - exact match
    - longest prefix match
      - forwarding entry: (address prefix, output port)
      - forward packet to the output port whose address matches packet’s destination address in the longest number of bits

**Packet Switching Properties**

- Expensive forwarding
  - forwarding table size depends on number of different destinations
    - must lookup in forwarding table for every packet
- Robust
  - link and router failure may be transparent for end-hosts
- High bandwidth utilization
  - statistical multiplexing
- No service guarantees
  - Network allows hosts to send more packets than available bandwidth → congestion → dropped packets
Source Routing

- Each packet specifies the sequence of routers, or alternatively the sequence of output ports, from source to destination

Source Routing (cont’d)

- Gives the source control of the path
- Not scalable
  - Packet overhead proportional to the number of routers
  - Typically, require variable header length which is harder to implement
- Hard for source to have complete information
- Loose source routing → sender specifies only a subset of routers along the path

Virtual Circuit (VC) Switching

- Packets not switched independently
- Establish virtual circuit before sending data
- Forwarding table entry
  - (input port, input VCI, output port, output VCI)
- VCI – Virtual Circuit Identifier
- Each packet carries a VCI in its header
- Upon a packet arrival at interface i
  - Input port uses i and the packet’s VCI v to find the routing entry (i, v, i’, v’)
  - Replaces v with v’ in the packet header
  - Forwards packet to output port i’

VC Forwarding: Example

VC Forwarding (cont’d)

- A signaling protocol is required to set up the state for each VC in the routing table
  - A source needs to wait for one RTT (round trip time) before sending the first data packet
- Can provide per-VC QoS
  - When we set the VC, we can also reserve bandwidth and buffer resources along the path

Virtual Circuit Switching Properties

- Less expensive forwarding
  - Forwarding table size depends on number of different circuits
  - Must lookup in forwarding table for every packet
- Much higher delay for short flows
  - 1 RTT delay for connection setup
- Less robust
  - End host must spend 1 RTT to establish new connection after link and router failure
- Flexible service guarantees
  - Either statistical multiplexing or resource reservations
Circuit Switching

- Packets not switched independently
- Establish circuit before sending data
- Circuit is a dedicated path from source to destination
  - E.g., old style telephone switchboard, where establishing circuit means connecting wires in all switches along path
  - E.g., modern dense wave division multiplexing (DWDM) form of optical networking, where establishing circuit means reserving an optical wavelength in all switches along path
- No forwarding table

Circuit Switching Properties

- Cheap forwarding
  - No table lookup
- Much higher delay for short flows
  - 1 RTT delay for connection setup
- Less robust
  - End host must spend 1 RTT to establish new connection after link and router failure
- Must use resource reservations

Forwarding Comparison

<table>
<thead>
<tr>
<th></th>
<th>Pure Packet Switching</th>
<th>Initial Circuit Switching</th>
<th>Circuit Switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forwarding Cost</td>
<td>High</td>
<td>Low</td>
<td>None</td>
</tr>
<tr>
<td>Bandwidth Utilization</td>
<td>High</td>
<td>Flexible</td>
<td>Low</td>
</tr>
<tr>
<td>Resource Reservations</td>
<td>None</td>
<td>Flexible</td>
<td>Low</td>
</tr>
<tr>
<td>Robustness</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Routing

- Update forwarding/routing tables
- Manual configuration
  - Simple, error prone, work for administrator
- Learning bridges
  - All that is needed for single bridge
- Spanning Tree
  - Necessary for multiple bridges
- Described in internetworking section
  - Distance Vector
  - Link State

Learning Bridges

Learning Bridge Problem
Spanning Tree

Summary

- Switching
  - overcome limitations of direct link networks
- Forwarding techniques
  - packet switching
  - source routing
  - virtual circuit switching
  - circuit switching
- Routing techniques