The Network Layer Forwarding Tables and Switching ‘Fabric’

Key Network-Layer Functions

1. **routing**: determine route taken by packets from source to destination
   - *Network-wide routing algorithms*

2. **forwarding**: move packets from router’s input link to appropriate output link
   - *Internal to a single router*

Network Layer Overview

- **Network layer services**
  - Desired services and tasks
  - Actual services and tasks

- **Forwarding versus routing**
  - Routing algorithms path selection
  - Routing algorithms creation of forwarding table

- **Inside a router: switching ‘fabric’**

- **Three Network Layer protocols**
  - IP – for addressing and forwarding
  - Routing protocols – determining the best path
  - ICMP – messaging protocol

Router Architecture Overview

Two key router functions:

- 1. **run routing algorithms/protocol**
- 2. **forward datagrams from incoming to outgoing link**
Four sources of packet delay

Find an analogy for each category below in the caravan example.

- Propagation
- Transmission
- Nodal processing
- Queueing

Three types of switching fabrics

Input Port Functions

Decentralized switching:
- given datagram destination, lookup output port using forwarding table in input port memory (note: application vs. router 'port')
- goal: complete input port processing at 'line speed'
- queuing: if datagrams arrive faster than forwarding rate into switch circuitry

Queuing in Routers

- Where can queuing occur?
- Why does it occur?
Input Port Queuing

- Circuitry slower than input ports combined -> queueing may occur at input queues
- Head-of-the-Line (HOL) blocking: queued datagram at front of queue prevents others in queue from moving forward
- Queuing delay and loss due to input buffer overflow

Output Ports

- Buffering required when datagrams arrive from circuitry faster than the transmission rate
- Scheduling discipline chooses among queued datagrams for transmission

Output Port Queuing

- Packet scheduler at the output port
  - Select one queued packet for transmission
    - FCFS = “________________”? 
    - Weighted-fair-queuing - share the outgoing link “fairly” among connections

Interplay between routing and forwarding

- Create versus use the forwarding table
IP Addressing: Overview

- **IP address**: 32-bit identifier for each interface on a host or router.
  - Dotted-decimal notation

- **Interface**: connection between host/router and physical link
  - Routers typically have multiple interfaces
  - Hosts typically have one interface
  - IP addresses associated with each interface

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Forwarding table

<table>
<thead>
<tr>
<th>Destination Address Range</th>
<th>Link Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111</td>
<td>0</td>
</tr>
<tr>
<td>11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111</td>
<td>1</td>
</tr>
<tr>
<td>11001000 00010111 00010110 00000000 through 11001000 00010111 00010111 11111111</td>
<td>2</td>
</tr>
<tr>
<td>otherwise</td>
<td>3</td>
</tr>
</tbody>
</table>

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Subnets

- **A subnet contains**: devices that can physically reach each other without an intervening router

- **IP address**: subnet portion (high order bits) host portion (low order bits)

- **Subnet mask notation**: differentiates the network versus host part of the address
  - e.g., the leftmost 24 bits are for the network...
    - 223.3.0/24

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Longest prefix matching

<table>
<thead>
<tr>
<th>Prefix Match</th>
<th>Link Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>11001000 00010111 00010010</td>
<td>0</td>
</tr>
<tr>
<td>11001000 00010111 00010100</td>
<td>1</td>
</tr>
<tr>
<td>11001000 00010111 00011010</td>
<td>2</td>
</tr>
<tr>
<td>otherwise</td>
<td>3</td>
</tr>
</tbody>
</table>

Examples

- **DA**: 11001000 00010111 00010110 10101010 Which interface?
- **DA**: 11001000 00010111 00011000 00101010 Which interface?
Subnets

How many subnets are in this figure?

Recall: Forwarding table

<table>
<thead>
<tr>
<th>Destination Address Range</th>
<th>Link Interface</th>
</tr>
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<tbody>
<tr>
<td>11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111</td>
<td>0</td>
</tr>
<tr>
<td>11001000 00010111 00011000 00000000 through 11001000 00010111 00011111 11111111</td>
<td>1</td>
</tr>
<tr>
<td>11001000 00010111 00011001 0001000000 through 11001000 00010111 00011111 11111111</td>
<td>2</td>
</tr>
<tr>
<td>otherwise</td>
<td>3</td>
</tr>
</tbody>
</table>

IP addressing: CIDR

CIDR: Classless InterDomain Routing
- subnet portion of address of arbitrary length
- address format: a.b.c.d/x, where x is # bits in subnet (left-most) portion of address
- Addresses of all hosts in the same subnet have the same left most 'x' bits
- The 'x' most significant bits are the 'prefix'

<table>
<thead>
<tr>
<th>subnet part</th>
<th>host part</th>
</tr>
</thead>
<tbody>
<tr>
<td>11001000 00010111 00010000 00000000</td>
<td>00010000 00000000</td>
</tr>
<tr>
<td>200.23.16.0/23</td>
<td></td>
</tr>
</tbody>
</table>

Forwarding Table “Ranges”

- What are the assumptions and implications of having large ranges of IP addresses forwarded to the same outgoing link?
- Why is CIDRized (‘classless’) addressing an improvement over ‘classful’ addressing, that restricted the network prefix to complete bytes?
  - (see page 344)
IP datagram format

<table>
<thead>
<tr>
<th>Field</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>IP protocol version</td>
<td>32 bits</td>
</tr>
<tr>
<td>header length (bytes)</td>
<td>16-bit identifier, flags, fragment offset</td>
</tr>
<tr>
<td>max number remaining hops</td>
<td>(decremented at each router)</td>
</tr>
<tr>
<td>upper layer protocol</td>
<td>32 bit source IP address</td>
</tr>
<tr>
<td>to deliver payload to</td>
<td>32 bit destination IP address</td>
</tr>
<tr>
<td>Options (if any)</td>
<td>Options (if any)</td>
</tr>
</tbody>
</table>

Summary

- There are many possible network layer services → IP provides none
- Forwarding vs. Routing
  - Forwarding tables
- Inside a router
  - The internet in miniature
  - Switching ‘fabric’ (circuity)
- The network IP datagram
- IP addressing structure