Router Architecture Overview

Two key router functions:
- run routing algorithms/protocol (RIP, OSPF, BGP)
- forwarding datagrams from incoming to outgoing link
Today: Focus on Forwarding Datagrams

- Input Ports
- Output Ports
- Interconnection Fabric
- Forwarding Process
  - Datagrams: Lookups
  - (Virtual Circuit next lecture)
- Examples of Routers

Input Port Functions

Decentralized switching:
- given datagram dest., lookup output port using forwarding table in input port memory
- goal: complete input port processing at 'line speed'
- queuing: if datagrams arrive faster than forwarding rate into switch fabric

Physical layer: bit-level reception
Data link layer: e.g., Ethernet

- line termination
- data link processing (protocol, decapsulation)
- lookup, forwarding
- queueing
- fabric
Output Ports

Queuing Functions

- **Buffer management**: decide when and which packet to drop
- **Scheduler**: decide when and which packet to transmit
Output Queued Router

- Only output interfaces store packets
- Advantage
  - Easy to design algorithms: only one congestion point

Output Queued Routers

Output Port Contention at Time t

One Packet Time Later
Output Queued Router

- Only output interfaces store packets

**Advantage**
- Easy to design algorithms: only one congestion point

**Disadvantage**
- Requires a speedup of a factor of $N$, where $N$ is the number of interfaces $\rightarrow$ not feasible for large $N$

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Input Queues

- Only input interfaces store packets

**Advantages**
- Easy to build
- Simple algorithms
**Input Queues: Head-of-line Blocking**

- The packet at the head of an input queue cannot be transferred, thus blocking the following packets.

```
Input 1  Output 1
Input 2  Output 2
Input 3  Output 3
```

Cannot be transferred because of HOL blocking

Cannot be transferred because of output contention

Wastes router capacity

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**Input Queues**

- Only input interfaces store packets
- **Advantages**
  - Easy to build
  - Simple algorithms
- **Disadvantages**
  - HOL Blocking
- Need a speedup that eliminates HOL but does not create output queues...
  - About 2 suffices...

```
input interface  output interface
```

Fabric
Advanced Queuing Functions

- **Packet classification**: map each packet to a predefined class
  - use to implement more sophisticated services (e.g., QoS)
- **Flow**: a subset of packets between any two endpoints in the network

![Diagram of packet classification and flow](image)

Three types of switching fabrics

- **Memory**: A, B, C, X, Y, Z
- **Bus**: A, B, C, X, Y, Z
- **Crossbar**: A, B, C, X, Y, Z

![Diagram of three types of switching fabrics](image)
Shared Bus Fabrics

- Typically < 5Gb/s aggregate capacity
- Limited by shared bus
- 1 Gbps bus, Cisco 1900: sufficient speed for access and enterprise routers (not regional or backbone)

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Shared Memory Based Fabrics

Typically < 0.5Gbps aggregate capacity
Limited by rate of shared memory

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Switched Fabrics

- Typically < 50Gbps aggregate capacity

Switched Backplane

- Overcome bus bandwidth limitations
- Banyan networks, other interconnection nets initially developed to connect processors in multiprocessor
- Advanced design: fragmenting datagram into fixed length cells, switch cells through the fabric.
- Cisco 12000: switches Gbps through the interconnection network

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Example: Crossbar Switches

- **Basic Idea**
  - $N^2$ switching points
    - not scalable

- **Engineering Idea**
  - It is very unlikely that more than $L$ packets will want to go to the same output port simultaneously
  - How many switching points can we save for fixed $L$?

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The Knockout Concentrator

- **Goal**: If there are greater than $L$ packets that want to go to the same destination, pick $L$ in a fair manner.
- **Organize the switching elements as if they are implementing a multi-round tournament**
  - A game consists of two players and the winner is selected at random (at a switching element)
  - The winner moves on to the next round, while the loser plays a “consolation” rank
  - The top $L$ players are selected.
Knockout Switch Concentrator

What is the complexity?
How many 2X2 elements for fixed L?

Why have multiple rounds?

- Example: N=8, L=4
- After one round, there are four winners and four losers
- Why not just pick the winners and drop the losers?
Example

Stopping after the first round would mean that two packets are dropped even though all four should be delivered.

The Forwarding Decision Process

- Datagram Routing: Each packet is independently forwarded at each router
  - Must look up IP address ranges
- Virtual Circuit Routing:
  - call setup, teardown for each call before data can flow
  - each packet carries VC identifier (not destination host address)
  - every router on source-dest path maintains “state” for each passing connection
  - link, router resources (bandwidth, buffers) may be allocated to VC (dedicated resources = predictable service)
Datagram Route Lookup

- Longest Prefix Match
  - Not easy to do at line speeds!
- It is useful to think of the search process as a traversal of a special kind of labeled tree called a Trie

Trees and Tries

Binary Search Tree

Binary Search Trie

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Simple Tries and LPM

- The routing table entry is a variable length prefix
  - E.g. 01111111 00001111 0000100100 for 128.23.9.0/26
  - A balanced tree won’t work
  - Variable number of steps required

LPM in IP Routers

*Binary tries*

Example Prefixes

- a) 00001
- b) 00010
- c) 00011
- d) 001
- e) 0101
- f) 011
- g) 100
- h) 1010
- i) 1100
- j) 11110000

Nick McKeown
LPM in IP Routers

"Patricia" trie

Example Prefixes

a) 00001
b) 00010
c) 00011
d) 001
e) 0101
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Router Performance

- **Goal**: To work at line speed
  - Depends on interfaces
- Throughput is difficult to quantify
  - Depends on traffic flow
  - Traffic flow is hard to model
- Packets per second hard to quantify
  - IP packets are of variable size
- Routers at different parts of the network have different characteristics
Why we Need Faster Routers

1: To prevent routers from being the bottleneck

Packet processing Power

<table>
<thead>
<tr>
<th>Year</th>
<th>SPEC95Int CPU results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>0.1</td>
</tr>
<tr>
<td>1990</td>
<td>1</td>
</tr>
<tr>
<td>1995</td>
<td>10</td>
</tr>
<tr>
<td>2000</td>
<td>100</td>
</tr>
</tbody>
</table>

Link Speed

<table>
<thead>
<tr>
<th>Year</th>
<th>Fiber Capacity (Gbit/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985</td>
<td>0.1</td>
</tr>
<tr>
<td>1990</td>
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<td>2000</td>
<td>100</td>
</tr>
</tbody>
</table>

2x / 18 months

2x / 7 months

TDM

DWDM

Source: SPEC95Int & David Miller, Stanford.

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Why we Need Faster Routers

2: To reduce cost, power & complexity of Data Centers

POP with large routers

Pop with smaller routers

- Ports: Price >$100k, Power > 400W.
- It is common for 50-60% of ports to be for interconnection.

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Example: Wide Area Routers

**Cisco GSR 12416**
- 19"
- 6ft
- 2ft
- Capacity: 160Gb/s
- Power: 4.2kW
- Both Have Crossbar Fabrics

**Juniper M160**
- 19"
- 3ft
- 2.5ft
- Capacity: 80Gb/s
- Power: 2.6kW

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Examples: Cisco 7600

- MAN-WAN Router
- Up to 128 Gbps with Crossbar Fabric
- 10Mbps – 10Gbps LAN Interfaces
- Various WAN Interfaces
- Many QoS features and interfaces
Examples: Cisco cat 6500

- From LAN to Access
- 48 to 576 10/100 Ethernet Interfaces
- 10 GigEth, OC-3, OC-12, OC-48, ATM
- QoS, Security
- Load Balancing; VPN
- Up to 128Gbps (with crossbar)
- L4-7 Switching
- IP Telephony (E1, T1, inline-power Ethernet)
- SNMP, RMON

OC-n: Optical carrier
\[ n = 51.84 \text{Mbs} \]