The Network Layer: Router Design, Forwarding

CS 352, Lecture 13, Spring 2020
http://www.cs.rutgers.edu/~sn624/352

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Course announcements

• Project 1 grades available
  • 24/7 grading policy: re-grading considered until 10 PM Sunday 29th
  • TAs have provided feedback on Sakai. Contact TAs for more details

• Lecture and recitation logistics:
  • You will have received WebEx training invitations on Piazza
  • Use a wired connection if possible
  • You can hear me better in a quiet environment
  • Use the chat or Q&A box to ask questions any time
  • Use raise hand feature during time allotted for verbal questions
  • Answer WebEx polls throughout the lecture!
Where we are: The network layer

The network layer exists on every endpoint and router.
Review of concepts

• Forwarding and routing
• Data plane and control plane
  • Control plane can be distributed (this course) or centralized (won’t discuss)
• Network-layer addresses (IP addresses)
  • Primary function: identifiers for routing
Poll #1

• An IP address corresponds to:
  • (1) the endpoint
  • (2) the application
  • (3) the point of attachment of the endpoint to the network
  • (4) all of the above

• Please use the WebEx poll feature to answer
Review of concepts

• Forwarding and routing
• Data plane and control plane
  • Control plane can be distributed (this course) or centralized (won’t discuss)
• Network-layer addresses (IP addresses): identifiers for routing
• Classful addressing: classes A, B, C, multicast, reserved
  • Distinguished by first few bits
  • Different # bits allotted to network address and host address
• Classless addressing (CIDR):
  • Freely change size of network (host) address
  • Allocate a subset of available addresses using a subnet
• Internet routing scales through hierarchy
  • IP subnetworks are the zip codes of the Internet
Poll #2

• Given the IP address and subnet below, what is the value of X?
  • (1) 11
  • (2) 23
  • (3) 32
  • (4) none of the above

200.23.16.0/X
Poll #3

• How many hosts can this subnetwork support?
  • (1) $2^9$
  • (2) $2^{23}$
  • (3) $2^{32}$
  • (4) none of the above

```
11001000 00010111 00010000 00000000
```

200.23.16.0/X
What’s inside a router?
What do routers look like?

Access routers

Core router

Data center top-of-rack switch
Routing Algorithm

Traditionally:
Individual routing algorithm components in each and every router interact in the control plane (Distributed control plane).

Basic components: Control & Data Planes

Control plane
per route-change processing (~ a few seconds)

Data plane
per-packet processing (~ tens of nanoseconds)

Values in arriving packet's header

Routing Algorithm

<table>
<thead>
<tr>
<th>header</th>
<th>output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0100</td>
<td>3</td>
</tr>
<tr>
<td>0110</td>
<td>2</td>
</tr>
<tr>
<td>0111</td>
<td>2</td>
</tr>
<tr>
<td>1001</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 4.2
Routing algorithms determine values in forward tables

Contr

Control plane
Data plane
per route-change processing (~ a few seconds)

Data plane
per-packet processing (~ tens of nanoseconds)

Tables. In this example, a routing algorithm runs in each and every router and both forwarding and routing functions are contained within a router. As we'll see in Sections 5.3 and 5.4, the routing algorithm function in one router communicates with the routing algorithm function in other routers to compute the values for its forwarding table. How is this communication performed? By exchanging routing messages containing routing information according to a routing protocol! We'll cover routing algorithms and protocols in Sections 5.2 through 5.4.

The distinct and different purposes of the forwarding and routing functions can be further illustrated by considering the hypothetical (and unrealistic, but technically feasible) case of a network in which all forwarding tables are configured directly by human network operators physically present at the routers. In this case, no routing protocols would be required! Of course, the human operators would need to interact with each other to ensure that the forwarding tables were configured in such a way that packets reached their intended destinations. It's also likely that human configuration would be more error-prone and much slower to respond to changes in the network topology than a routing protocol. We're thus fortunate that all networks have both a forwarding and a routing function!
Router architecture overview

- **Control plane**
- **Data plane**

- **router input ports**
- **high-speed switching fabric**
- **router output ports**

- **route processor**
Input port functions

Switching:

- using header field values, lookup output port using forwarding table in input port memory
- goal: complete input port processing at line speed (i.e., speed of the interface, say 100 Mbit/s)
- queueing: if datagrams arrive faster than they can be sent via the switch fabric to the output port
Destination-based Forwarding in the Internet

Packet

payload

header

Router

Destination Address

Routing Lookup Data Structure

Outgoing Port

Forwarding Table

<table>
<thead>
<tr>
<th>Dest-network</th>
<th>Port</th>
</tr>
</thead>
<tbody>
<tr>
<td>65.0.0.0/8</td>
<td>3</td>
</tr>
<tr>
<td>128.9.0.0/16</td>
<td>1</td>
</tr>
<tr>
<td>149.12.0.0/19</td>
<td>7</td>
</tr>
</tbody>
</table>
Forwarding in the Internet is based on the destination IP address on packet.

There are exceptions. But Internet forwarding is mostly:
- independent of the source, e.g., legitimate vs. malicious source
- independent of the type of traffic, e.g., Netflix vs. web
Three types of switching fabrics

memory

bus

crossbar
Output Ports

- **Buffering** when datagrams arrive from fabric faster than the output port rate
  - If buffers filled up, packets are dropped!
  - **Buffer management policy** decides which pkts to keep and drop

- **Scheduling discipline** chooses among queued datagrams for transmission
  - Who gets priority is chosen by the scheduler
Poll #4

• Suppose two packets arrive at a router input port. Packet 1 has (src, dst) IP address == (X, Y). Packet 2 has (src, dst) IP address == (Z, Y). Then:
  • (1) The two packets are unlikely to be forwarded out of the same output port
  • (2) The two packets are highly likely to be forwarded out of the same port
  • (3) Not sure
Poll #5

• A packet is waiting to be transmitted at a buffer on the router output port. Who decides when the packet will be transmitted?
  • (1) buffer manager
  • (2) Packet scheduler
  • (3) Forwarding table
  • (4) Line termination
Prefixes and IP lookup
## Example Forwarding Table

<table>
<thead>
<tr>
<th>Destination IP Prefix</th>
<th>Outgoing Port</th>
</tr>
</thead>
<tbody>
<tr>
<td>65.0.0.0/8</td>
<td>3</td>
</tr>
<tr>
<td>128.9.0.0/16</td>
<td>1</td>
</tr>
<tr>
<td>65.0.0.128/25</td>
<td>4</td>
</tr>
<tr>
<td>142.12.0.0/19</td>
<td>7</td>
</tr>
</tbody>
</table>

### Longest prefix match

- IP prefix: 0-32 bits
- Longest prefix match

![Diagram showing longest prefix match]
Prefixes can Overlap

Routing lookup: Find the longest matching prefix (the most specific route) among all prefixes that match the destination address.
Reducing Routing Table Size

Without CIDR:

200.71.0.0
200.71.1.0
200.71.2.0
......
200.71.255.0

With CIDR:

200.71.0.0
200.71.1.0
200.71.2.0
......
200.71.255.0

200.71.0.0/16
Hierarchical addressing: Route aggregation

Efficient advertisement of routing information!

Organization 0
- 200.23.16.0/23

Organization 1
- 200.23.18.0/23

Organization 2
- 200.23.20.0/23

Organization 7
- 200.23.30.0/23

Fly-By-Night-ISP

ISPs-R-Us

“Send me anything with addresses beginning 200.23.16.0/20”

“Send me anything with addresses beginning 199.31.0.0/16”

Internet
LPM: Announcing more specific routes

ISPs-R-Us has a more specific route to Organization 1
Longest prefix match will be used to route IP packets

Organization 0
200.23.16.0/23

Organization 2
200.23.20.0/23

Organization 7
200.23.30.0/23

Organization 1
200.23.18.0/23

Fly-By-Night-ISP

"Send me anything with addresses beginning 200.23.16.0/20"

ISPs-R-Us

"Send me anything with addresses beginning 199.31.0.0/16 or 200.23.18.0/23"

Internet
Poll #6

• If the destination IP address of a packet matches three forwarding rules 128.0.0.0/16, 128.0.0.0/20, 128.0.0.0/24, which rule will the router use?
  • (1) 128.0.0.0/16
  • (2) 128.0.0.0/20
  • (3) 128.0.0.0/24
  • (4) None of the above

(1) 128.0.0.0/16
Poll #7

• If an ISP owns two prefixes 128.0.0.0/16 and 128.1.0.0/16, what prefix can it legitimately advertise to the rest of the Internet?
  • (1) 128.0.0.0/8
  • (2) 128.0.0.0/15
  • (3) 128.0.0.0/14
  • (4) None of the above