Hierarchical Routing

Our routing study thus far - idealization
- all routers identical
- network “flat”
... not true in practice

scale: with 50 million destinations:
- can’t store all dest’s in routing tables!
- routing table exchange would swamp links!

administrative autonomy
- internet = network of networks
- each network admin may want to control routing in its own network

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Route to networks, not hosts
- aggregate routers into regions, “autonomous systems” (AS)
- routers in same AS run same routing protocol
  - “intra-AS” routing protocol
  - routers in different AS can run different intra-AS routing protocol

Gateway routers
- special routers in AS
- run intra-AS routing protocol with all other routers in AS
- also responsible for routing to destinations outside AS
  - run inter-AS routing protocol with other gateway routers

Intra-AS and Inter-AS routing

Gateways:
- perform inter-AS routing amongst themselves
- perform intra-AS routers with other routers in their AS

We’ll examine specific inter-AS and intra-AS Internet routing protocols shortly
### IP Addressing: introduction

- **IP address**: 32-bit identifier for host, router interface
- **Interface**: connection between host, router and physical link
  - Router's typically have multiple interfaces
  - Host may have multiple interfaces
  - IP addresses associated with interface, not host, router

![Diagram of IP addresses]

#### IP Addressing

- **IP address**:
  - Network part (high order bits)
  - Host part (low order bits)
- **What's a network?**
  (from IP address perspective)
  - Device interfaces with same network part of IP address
  - Can physically reach each other without intervening router

![Diagram of network connections]

- **IP Addresses**
  - Given notion of "network", let's re-examine IP addresses:
  - "class-full" addressing:

  ![Diagram of IP addresses and classes]

  - **A**: 0.0.0.0 to 127.255.255.255
  - **B**: 128.0.0.0 to 191.255.255.255
  - **C**: 192.0.0.0 to 223.255.255.255
  - **D**: 224.0.0.0 to 239.255.255.255
**IP addressing: CIDR**

- **classful addressing:**
  - inefficient use of address space, address space exhaustion
  - e.g., class B net allocated enough addresses for 65K hosts, even if only 2K hosts in that network
- **CIDR: Classless InterDomain Routing**
  - network portion of address of arbitrary length
  - address format: \(a.b.c.d/x\), where \(x\) is \# bits in network portion of address

```
11001000  00010111  0001000  00000000  200.23.16.0/23
```

**IP addresses: how to get one?**

- **Hosts (host portion):**
  - hard-coded by system admin in a file
- **DHCP: Dynamic Host Configuration Protocol:**
  - dynamically get address: "plug-and-play"
  - host broadcasts "DHCP discover" msg
  - DHCP server responds with "DHCP offer" msg
  - host requests IP address: "DHCP request" msg
  - DHCP server sends address: "DHCP ack" msg

**Network (network portion):**
- get allocated portion of ISP’s address space:
  - ISP’s block 11001000 00010111 00010000 00000000 200.23.16.0/20
  - Organization 0 11001000 00010111 00010000 00000000 200.23.16.0/23
  - Organization 1 11001000 00010111 00010010 00000000 200.23.18.0/23
  - Organization 2 11001000 00010111 00010100 00000000 200.23.20.0/23
  - ...  ..... .... ....
  - Organization 7 11001000 00010111 00011110 00000000 200.23.30.0/23

**Hierarchical addressing: route aggregation**

Hierarchical addressing allows efficient advertisement of routing information:

```
Internet
  ▼
  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"
```
Hierarchical addressing: more specific routes

ISPs-R-Us has a more specific route to Organization 1

- 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

Send me anything with addresses beginning 200.23.16.0/20

IP addressing: the last word...

Q: How does an ISP get block of addresses?

A: ICANN: Internet Corporation for Assigned Names and Numbers
  - allocates addresses
  - manages DNS
  - assigns domain names, resolves disputes

Getting a datagram from source to dest.

Routing table in A

<table>
<thead>
<tr>
<th>Dest. Net.</th>
<th>next router</th>
<th>Nhops</th>
</tr>
</thead>
<tbody>
<tr>
<td>223.1.1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>223.1.2</td>
<td>223.1.1.4</td>
<td>2</td>
</tr>
<tr>
<td>223.1.3</td>
<td>223.1.1.4</td>
<td>2</td>
</tr>
</tbody>
</table>

IP datagram:

- Misc fields
- Source IP addr
- Dest IP addr
- Data

- Datagram remains unchanged, as it travels source to destination
- Addr fields of interest here

Getting a datagram from source to dest.

Starting at A, given IP datagram addressed to B:

- Look up net. address of B
- Find B is on same net. as A
- Link layer will send datagram directly to B inside link-layer frame
  - B and A are directly connected

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**Getting a datagram from source to dest.**

Starting at A, dest. E:
- look up network address of E
- E on *different* network
  - A, E not directly attached
- routing table: next hop router to E is 223.1.1.4
- link layer sends datagram to router 223.1.1.4 inside link-layer frame
- datagram arrives at 223.1.1.4
- continued.....

Arriving at 223.1.4, destined for 223.1.2.2
- look up network address of E
- E on *same* network as router's interface 223.1.2.9
  - router, E directly attached
- link layer sends datagram to 223.1.2.2 inside link-layer frame via interface 223.1.2.9
- datagram arrives at 223.1.2.2!!! (hooray!)