Internet Addresses
Reading: Chapter 4
Internet Addresses

Outline/Goals

IP addresses  RFC 950, STD 05
– Dotted-quad notation
– IP prefixes for aggregation

• Address allocation
  – Classful addresses
  – Classless InterDomain Routing (CIDR) - RFC 4632, BDP 122, RFC 1817
  – Growth in the number of prefixes over time

• Packet forwarding
  – Forwarding tables
  – Longest-prefix match forwarding
  – Where forwarding tables come from

• Chapter 4!!!!
Internet Addresses

- Hide Physical Network
- Make Internet appear as a single, uniform entity
- Help in routing
- Universal Communications Service
  - Allow any host to communicate with any other host, don’t care about actual location.
Host Identifiers

- Name - what an object is
- Address - where it is—logically vs physical (MAC)
- Route - how to get there
IP Address (IPv4)

- A unique 32-bit number
- Identifies an interface (on a host, on a router, …)
- Represented in dotted-quad notation

```
12  34  158  5

00001100 00100010 10011110 00000101
```
Grouping Related Hosts

- The Internet is an “inter-network”
  - Used to connect *networks* together, not *hosts*
  - Needs a way to address a network (i.e., group of hosts)

LAN = Local Area Network – interconnected hosts
WAN = Wide Area Network – interconnected networks
Scalability Challenge

• Suppose hosts had arbitrary addresses
  – Then every router would need a lot of information
  – …to know how to direct packets toward the host
Internet Address (Global) Structure

- **Properties**
  - globally unique
  - hierarchical: network + host

- **Dot Notation**
  - 10.3.2.4
  - 128.96.33.81
  - 192.12.69.77
Complete Internet Address Allocations

Figure 4.1 The five forms of Internet (IP) addresses. The three primary forms, Classes A, B and C, can be distinguished by the first two bits.
Hierarchical Addressing: IP Prefixes

- Divided into network & host portions (left and right)
- 12.34.158.0/24 is a 24-bit prefix with $2^8$ addresses

```
  12  34  158  5

00001100  00100010  10011110  00000101
```

Network (24 bits)                      Host (8 bits)
Internet Address Range

- Class A: 0.0.0.0 - 127.255.255.255
- Class B: 128.0.0.0 - 191.255.255.255
- Class C: 192.0.0.0 - 223.255.255.255
- Class D: 224.0.0.0 - 239.255.255.255
- Class E: 240.0.0.0 - 247.255.255.255
IP Address and a 24-bit Subnet Mask

Address

<table>
<thead>
<tr>
<th></th>
<th>12</th>
<th>34</th>
<th>158</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>00001100</td>
<td>00100010</td>
<td>10011110</td>
<td>00000101</td>
</tr>
</tbody>
</table>

Mask

<table>
<thead>
<tr>
<th></th>
<th>255</th>
<th>255</th>
<th>255</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11111111</td>
<td>11111111</td>
<td>11111111</td>
<td>00000000</td>
</tr>
</tbody>
</table>
Scalability Improved

- Number related hosts from a common subnet
  - 1.2.3.0/24 on the left LAN
  - 5.6.7.0/24 on the right LAN
Easy to Add New Hosts

- No need to update the routers
  - E.g., adding a new host 5.6.7.213 on the right
  - Doesn’t require adding a new forwarding entry
Weaknesses in IP Addressing

- When host moves, its IP address must change
- Change in network size, e.g., class C moves to class B
- Routing is based on Network Address, multiple interfaces have multiple unrelated addresses
- Not enough addresses
Address Allocation
Classful Addressing

• In the olden days, only fixed allocation sizes
  – Class A: 0*
    • Very large /8 blocks (e.g., MIT has 18.0.0.0/8)
  – Class B: 10*
    • Large /16 blocks (e.g., Princeton has 128.112.0.0/16)
  – Class C: 110*
    • Small /24 blocks (e.g., AT&T Labs has 192.20.225.0/24)
  – Class D: 1110*
    • Multicast groups
  – Class E: 11110*
    • Reserved for future use
• This is why folks use dotted-quad notation!
Classless Inter-Domain Routing (CIDR)

Use two 32-bit numbers to represent a network. Network number = IP address + Mask

<table>
<thead>
<tr>
<th>Address</th>
<th>Mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>00001100 00000100 00000000 00000000</td>
<td>11111111 11111110 00000000 00000000</td>
</tr>
</tbody>
</table>

Network Prefix for hosts

Written as 12.4.0.0/15
CIDR: Hierarchical Address Allocation

- Prefixes are key to Internet scalability
  - Address allocated in contiguous chunks (prefixes)
  - Routing protocols and packet forwarding based on prefixes
  - Today, routing tables contain ~150,000-200,000 prefixes
Scalability: Address Aggregation

Provider is given 201.10.0.0/21

Provider

201.10.0.0/22
201.10.4.0/24
201.10.5.0/24
201.10.6.0/23

Routers in the rest of the Internet just need to know how to reach 201.10.0.0/21. The provider can direct the IP packets to the appropriate customer.
But, Aggregation Not Always Possible

Multi-homed customer with 201.10.6.0/23 has two providers. Other parts of the Internet need to know how to reach these destinations through both providers.
Scalability Through Hierarchy

- Hierarchical addressing
  - Critical for scalable system
  - Don’t require everyone to know everyone else
  - Reduces amount of updating when something changes
- Non-uniform hierarchy
  - Useful for heterogeneous networks of different sizes
  - Initial class-based addressing was far too coarse
  - Classless InterDomain Routing (CIDR) helps
- Next few slides
  - History of the number of globally-visible prefixes
  - Plots are # of prefixes vs. time

Growth faster than improvements in equipment capability
CIDR Deployed (1994-1996): Much Flatter

Efforts to aggregate (even decreases after IETF meetings!)

2/11/14

CS125-myaddressing

Good use of aggregation, and peer pressure in CIDR report

Internet boom and increased multi-homing
Long-Term View (1989-2005): Post-Boom
Obtaining a Block of Addresses Now

- **Separation of control**
  - Prefix: assigned *to* an institution
  - Addresses: assigned *by* the institution to their nodes

- **Who assigns prefixes?**
  - Internet Corporation for Assigned Names and Numbers
    - Allocates large address blocks to Regional Internet Registries
  - Regional Internet Registries (RIRs)
    - E.g., ARIN (American Registry for Internet Numbers)
    - Allocates address blocks within their regions
    - Allocated to Internet Service Providers and large institutions
  - Internet Service Providers (ISPs)
    - Allocate address blocks to their customers
    - Who may, in turn, allocate to their customers…
Figuring Out Who Owns an Address

• Address registries
  – Public record of address allocations
  – Internet Service Providers (ISPs) should update when giving addresses to customers
  – However, records are notoriously out-of-date

• Ways to query
  – UNIX: “whois –h whois.arin.net 128.112.136.35”
  – http://www.arin.net/whois/
  – …
Example Output for 128.112.136.35

OrgName: Princeton University
OrgID: PRNU
Address: Office of Information Technology
Address: 87 Prospect Avenue
City: Princeton
StateProv: NJ
PostalCode: 08544-2007
Country: US
NetRange: 128.112.0.0 - 128.112.255.255
CIDR: 128.112.0.0/16
NetName: PRINCETON
NetHandle: NET-128-112-0-0-1
Parent: NET-128-0-0-0-0
NetType: Direct Allocation
RegDate: 1986-02-24
Are 32-bit Addresses Enough?

• Not all that many unique addresses
  – \(2^{32} = 4,294,967,296\) (just over four billion)
  – Plus, some are reserved for special purposes
  – And, addresses are allocated in larger blocks

• And, many devices need IP addresses
  – Computers, PDAs, routers, tanks, toasters, …

• Long-term solution: a larger address space
  – IPv6 has 128-bit addresses \((2^{128} = 3.403 \times 10^{38})\)

• Short-term solutions: limping along with IPv4
  – Private addresses
  – Network address translation (NAT)
  – Dynamically-assigned addresses (DHCP)
Hard Policy Questions

- How much address space per geographic region?
  - Equal amount per country?
  - Proportional to the population?
  - What about addresses already allocated?

- Address space portability?
  - Keep your address block when you change providers?
  - Pro: avoid having to renumber your equipment
  - Con: reduces the effectiveness of address aggregation

- Keeping the address registries up to date?
  - What about mergers and acquisitions?
  - Delegation of address blocks to customers?
  - As a result, the registries are horribly out of date
Conclusions

• IP address
  – A 32-bit number
  – Allocated in prefixes
  – Non-uniform hierarchy for scalability and flexibility
  – Too small....