EE 122: IP Addressing

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http://inst.eecs.berkeley.edu/~ee122/
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Goals of Today’s Lecture

- IP addresses
  - Dotted-quad notation
  - IP prefixes for aggregation
  - Classful addresses
  - Classless InterDomain Routing (CIDR)
  - Special-purpose address blocks
- Address allocation
  - Hierarchy by which address blocks are given out
  - Finding information about an allocation
Designing IP’s Addresses

- Question #1: what should an address be associated with?
  - E.g., a telephone number is associated not with a person but with a handset
- Question #2: what structure should addresses have? What are the implications of different types of structure?
- Question #3: who determines the particular addresses used in the global Internet? What are the implications of how this is done?

IP Addresses (IPv4)

- A unique 32-bit number
- Identifies an interface (on a host, on a router, …)
- Represented in dotted-quad notation. E.g., 12.34.158.5:

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


Hierarchical Addressing in U.S. Mail

- Addressing in the U.S. mail
  - Zip code: 15232
  - Street: Forbes Avenue
  - Building on street: 5000
  - Apartment: 61B
  - Name of occupant: Ion Stoica

- Forwarding the U.S. mail
  - Deliver letter to the post office in the zip code
  - Assign letter to mailman covering the street
  - Drop letter into mailbox for the building/room
  - Give letter to the appropriate person

Hierarchical Addressing: IP Prefixes

- Divided into network (left) & host portions (right)
- 12.34.158.0/24 is a 24-bit prefix with $2^9$ addresses
  - Terminology: "Slash 24"
IP Address and a 24-bit Subnet Mask

Address

12  34  158  5

00001100 00100010 10011110 00000101

11111111 11111111 11111111 00000000

255  255  255  0

Mask

Addressing Hosts in the Internet

- 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
WAN = Wide Area Network
Routers

- Router consists of:
  - Set of input interfaces where packets arrive
  - Set of output interfaces from which packets depart
  - Some form of interconnect connecting inputs to outputs

- Router implements:
  - Forward packet to corresponding output interface
  - Manage bandwidth and buffer space resources

Forwarding Table

- Store a mapping between IP addresses and output interfaces:
  - Forward an incoming packet based on its destination address
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

LAN 1
- 1.2.3.4
- 5.6.7.8
- 2.4.6.8

LAN 2
- 1.2.3.5
- 5.6.7.9
- 2.4.6.9

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

LAN 1
- 1.2.3.4
- 1.2.3.7
- 1.2.3.156

LAN 2
- 5.6.7.8
- 5.6.7.9
- 5.6.7.212

forwarding table
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

LAN 1: 1.2.3.4 1.2.3.7 1.2.3.156
LAN 2: 5.6.7.8 5.6.7.9 5.6.7.212

Classful Addressing

- Class A: if first byte in [0..127], assume /8 (top bit = 0)
  - Very large blocks (e.g., MIT has 18.0.0.0/8)

- Class B: first byte in [128..191] ⇒ assume /16 (top bits = 10)
  - Large blocks (e.g., UCB has 128.32.0.0/16)

- Class C: [192..223] ⇒ assume /24 (top bits = 110)
  - Small blocks (e.g., ICIR has 192.150.187.0/24)
  - The "swamp" (many European networks, due to history)
Classful Addressing (cont’d)

- Class D: [224..239] (top bits 1110)
- Multicast groups
- Class E: [240..255] (top bits 11110)
  - Reserved for future use

What problems can classful addressing lead to?
- Only comes in 3 sizes
- Routers can end up knowing about a lot of class C's

Classless Inter-Domain Routing (CIDR)

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

IP Address : 12.4.0.0      IP Mask: 255.254.0.0

Address

Mask

Network Prefix for hosts

Written as 12.4.0.0/15 or 12.4/15
**CIDR: Hierarchal Address Allocation**

- Prefixes are key to Internet scalability
  - Addresses allocated in contiguous chunks (prefixes)
  - Routing protocols and packet forwarding based on prefixes

![CIDR Diagram]

**Scalability: Address Aggregation**

Provider is given 201.10.0.0/21 (201.10.0.x .. 201.10.7.x)

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. ⇒ /23 route must be globally visible


- Initial growth: super-linear; no aggregation
- Dot-com implosion; Internet bubble bursts
- Advent of CIDR allows aggregation: linear growth
- Internet boom: multihoming drives superlinear growth
- Back in business
Special-Purpose Address Blocks

- **Private addresses**
  - By agreement, not routed in the public Internet
  - For networks not meant for general Internet connectivity
  - Blocks: 10.0.0.0/8, 172.16.0.0/12, 192.168.0.0/16

- **Link-local**
  - By agreement, not forwarded by any router
  - Used for single-link communication only
  - Intent: autoconfiguration (especially when DHCP fails)
  - Block: 169.254.0.0/16

- **Loopback**
  - Address blocks that refer to the local machine
  - Block: 127.0.0.0/8
  - Usually only 127.0.0.1/32 is used

- **Limited broadcast**
  - Sent to every host attached to the local network
  - Block: 255.255.255.255/32

Scalability Through Non-Uniform Hierarchy

**Summary:**

- **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) gains much more flexibility
5 Minute Break

Questions Before We Proceed?

Address Allocation
Obtaining a Block of Addresses

- 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
  - ICANN is politically charged
  - 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 (could be recursive)
      - Often w/o charge

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 169.229.60.27”
  - http://www.arin.net/whois/
  - …
Example Output for 169.229.60.27

University of California, Office of the President UCNET-BLK (NET-169-229-0-0-1)
169.229.0.0 - 169.233.255.255

University of California at Berkeley ISTDATA
(NET-169-229-0-0-2)
169.229.0.0 - 169.229.255.255

- ISTDATA – Information Services and Technology (IST) - Data Communication and Network Services

Are 32-bit Addresses Enough?

- Not all that many unique addresses
  - $2^{32} = 4,294,967,296$ (just over four billion)
  - Plus, some (many) 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 (perhaps): 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)
Network Address Translation (NAT)

- Before NAT...
  - Every machine connected to the Internet had a unique IP address
Network Address Translation (cont’d)

- Independently assign addresses to machines behind same NAT
  - Usually in address block 192.168.0/16
- Use port numbers to multiplex demultiplex internal addresses
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![Diagram of NAT and IP addresses]

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![Diagram showing NAT configuration]

192.2.3.4

192.2.3.5

Clients

5.6.7.8

192.2.3.4

192.2.3.5

Clients

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**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 often out of date

**Summary of IP Addressing**

- 32-bit numbers identify **interfaces**
- Allocated in prefixes
- **Non-uniform hierarchy** for scalability and flexibility
  - Routing is based on **CIDR**
- A number of special-purpose blocks reserved
- Address allocation:
  - ICANN ⇒ RIR ⇒ ISP ⇒ customer network ⇒ host
- Issues to be covered later
  - How hosts get their addresses (**DHCP**)
  - How to map from an IP address to a link address (**ARP**)
Next Lecture

- IP Forwarding; Transport protocols
- Read K&R: 3-3.4 (pp 195-240)