Addressing

Topics

- IP addresses
  - Dotted-quad notation
  - IP prefixes for aggregation
- Address allocation
  - Classful addresses
  - Classless InterDomain Routing (CIDR)
  - Growth in the number of prefixes over time
- Packet forwarding
  - Forwarding tables
  - Longest-prefix match forwarding
  - Where forwarding tables come from
IP Address (IPv4)

- A unique 32-bit number (i.e., 4B addresses)
- Identifies an interface (on a host, on a router, …)
- Represented in dotted-quad notation

```
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 1
  host  host  host
  router  router  router
LAN 2
```

LAN = Local Area Network
WAN = Wide Area Network

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

```
1.2.3.4  5.6.7.8  2.4.6.8  1.2.3.5  5.6.7.9  2.4.6.9
```

```
LAN 1
  host  host
  router  router
LAN 2
```

forwarding table
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

```
Network (24 bits) Host (8 bits)
```

IP Address and a 24-bit Subnet Mask

Address

```
00001100 00100010 10011110 00000101
12 34 158 5
```

Mask

```
11111111 11111111 11111111 00000000
255 255 255 0
```

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

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

IP Address: 12.4.0.0  IP Mask: 255.254.0.0

<table>
<thead>
<tr>
<th>Address</th>
<th>Mask</th>
</tr>
</thead>
<tbody>
<tr>
<td>00001100 00001000 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 ~300,000-400,000 prefixes

```
12.0.0.0/16
12.1.0.0/16
12.2.0.0/16
12.3.0.0/16
12.3.0.0/24
12.3.254.0/24
```

Scalability: Address Aggregation

Provider is given 201.10.0.0/21

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

201.10.0.0/21

Provider 1

Provider 2

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

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 Inter Domain 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!)


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

• 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