IPv6 Overview

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What's the Problem?

- Older network protocol: IP version 4
  - Limited addresses
    - 32-bit addresses only allow 4 billion possibilities
    - It sounds like a lot, but they are wastefully allocated
      - Large ranges are allocated but underutilized.
      - Example: VTSU has 64K addresses, but maybe only 20,000 are used.
    - Also, many devices are coming online.
      - India, China, Brazil
      - Many handheld devices, etc. (cell phones, PDAs)
  - Poor routing structure

Routing Table Explosion

- Originally, there was no correlation between IP address and physical location.
- Routing tables expanded linearly with network size

155.42.0.0/16

It would make more sense for all the 155.*.*.* networks to be over here.

Routing table must have separate entries for each possible network.

167.87.0.0/16

155.43.0.0/16

Network Collapse

- Growth toward destruction...
  - Network growth was exponential in the number of connected (sub)networks
  - Thus, routing table growth was exponential
  - Processor speed increased more slowly
  - Thus, routers spent more time searching routing tables.
  - Eventually...
    - Routers wouldn't be able to keep up.
    - Packet loss would skyrocket.
    - The Internet would fail.
  - This was expected to happen by 2000.

CIDR

- Classless Interdomain Routing.
  - The idea...
    - Allocate IP addresses according to network topology.
    - Similar addresses can be treated in one routing table entry ("route summarization").
  - Addresses with a common prefix all in the same "direction."
    - 155.42.0.0/16
      - The trailing "16" means that the first 16 bits are the prefix.

CIDR In Action

- The top-level router uses the prefix to specify routes for many networks.
  - Reduces routing table size dramatically.
  - Tables now grow logarithmically with network size.

155.42.0.0/15

155.42.0.0/16

167.0.0.0/8

Networks with the
same prefix accessed
using the same
high level route.

155.43.0.0/16

167.114.0.0/16

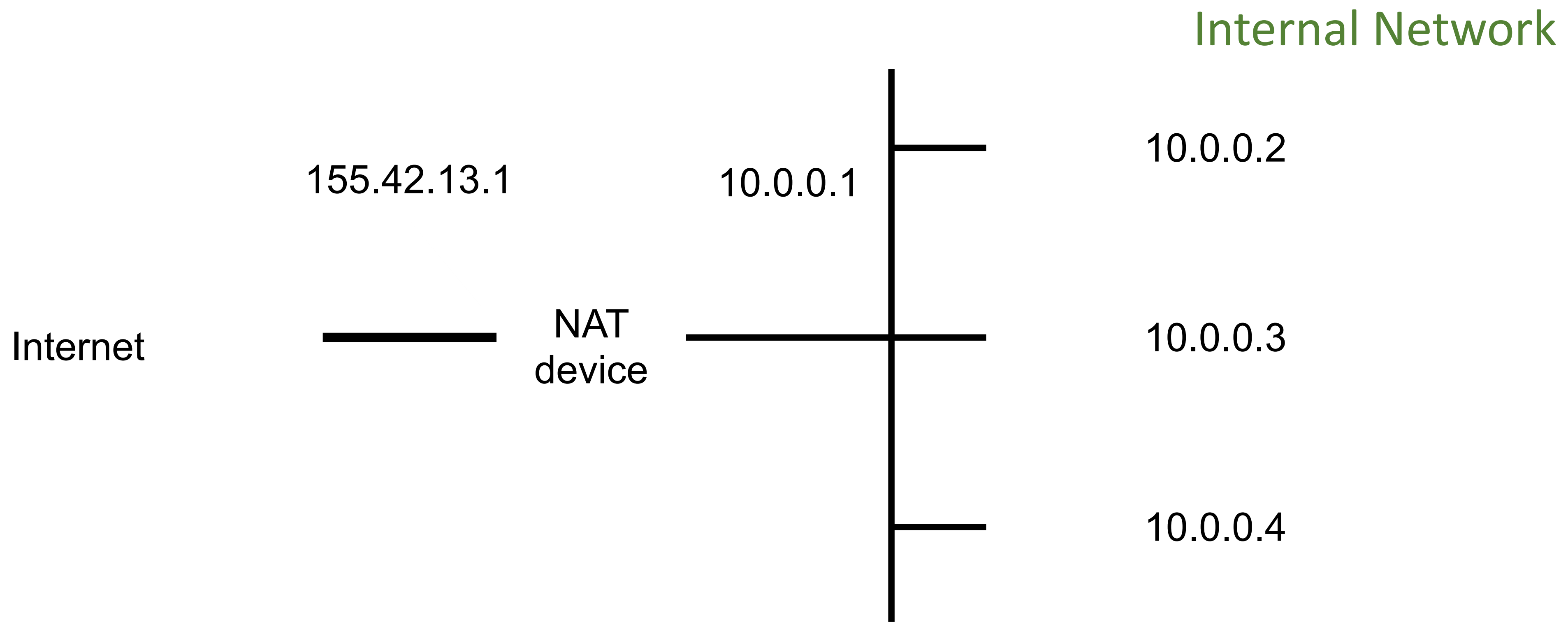
167.87.0.0/16

CIDR Deployed

- CIDR was deployed for all new allocations during the 1990s.
  - The collapse of the Internet was averted!
- However, old (class-style) address allocations remain.
  - A burden that can never be removed.

Network Address Translation

- NAT can be used to reduce pressure on IP addresses.
  - Maps single global address to entire network.



NAT Device

- Acts as a proxy.
  - Outgoing connections remapped.
    - NAT makes the real connection using the global interface.
    - Associates the port number it uses with the internal client.
    - Forwards all data between client and Internet.
    - Allows a single global address to support many machines!
  - Incoming connections are harder.
    - NAT device must be configured to listen for each internal server.
      - And so... must know about all internal servers.
  - Note: NAT is a natural location for firewall functions.

Problems Remain

- NAT not suitable for all situations.
  - Certain protocols don't work well through NAT devices.
    - Security protocols especially (the NAT device is a kind of “man in the middle” and security protocols are specifically designed to prevent such an agent from tampering).
    - Also protocols that “leak” to higher layers (IP addresses in application headers, etc.).
  - Limitation of 64K ports limits connection mappings.
- Still running out of addresses.
- Long term solution: Create a new protocol!

Introducing IPv6

- 128-bit addresses!
  - $2^{128} = 3.403 \times 10^{38}$ (big)
- Address format
  - 0123:4567:89AB:CDEF:0123:4567:89AB:CDEF
    - Displayed in hex, 16 bits at a time.
    - 8 sections separated by colon characters.
  - Zero sections can be dropped (zeros understood)
    - 0123:0000:0000:0000:0123:4567:89AB:CDEF
    - 123::123:4567:89AB:CDEF
    - Saves space; many IPv6 addresses have many zeros.
    - Can use :: only once in an address (to avoid ambiguity)

Special Addresses

- 0::0
  - The “unspecified” address. Used when an interface has no address (yet).
- ::1
  - The loop back address. Used to refer to yourself (like 127.0.0.1 in IPv4).
- ::FFFF:*IPv4-addr*
  - Example, ::FFFF:155.42.13.24
  - Used by IPv6 software to communicate with IPv4 nodes.
    - Emitted packets are actually IPv4.

Address Scopes

- An interface can have several addresses
  - Global unicast address
    - An address that is unique over the whole world
  - Site local address
    - An address only meaningful inside a site (such as VTSU)
  - Link local address
    - An address only meaningful on a particular link.
- Link local addresses are generated automatically by IPv6 software.
  - Link communication possible with no external help.

Link Local Addresses

- Always have the prefix FE80::/10
  - Notice: IPv6 uses CIDR-style addresses from the start.
  - Prefix bits...
    - 1111,1110,10...
    - All addresses that start with FE8, FE9, FEA, and FEB are link-local.
  - Format: FE80::*interface-id*
    - Where *interface-id* is a 64-bit number derived from the MAC address.
    - No need for user assignment; easy configuration.
  - Routers never forward link-local addresses.

Site Local Addresses (deprecated)

- Always have prefix FEC0::/10 (See RFC-3879)
  - Prefix bits: 1111,1110,11...
    - All addresses that start with FEC, FED, FEE, and FEF are site local.
  - Format: FEC0::*subnet-id*:*interface-id*
    - Where *subnet-id* is a 16 bit subnetwork number defined by the site administrators.
    - Where *interface-id* is a 64 bit number derived from MAC address of interface.
    - Allows an organization to use IPv6 internally.
  - Replaces IPv4 “private” addresses.

Unique Local Addresses

- Problems with site local addresses:
  - Not unique.
    - Addresses sometimes “leak” into higher level protocols and are then exposed to the Internet.

- RFC-4193
  - Reserves FC00::/7 for “Unique Local IPv6 Unicast Addresses” Prefix: 1111,110

7 bits 40 bits 16 bits 64 bits

Prefix 1 if locally assigned Global ID (random) Subnet ID Interface ID

Computing Global ID

- Algorithm described in RFC-4193
  - Example: FD25:F376:7B60::/48
  - FD… expands to 1111,1101. Thus the L bit is set to 1 (locally defined). Note L=0 is reserved for future expansion.
  - The 25:F376:7B60 is pseudo-random and intended to be unique globally.
- Random global ID unlikely to conflict.
  - ... But more likely than you might think.
  - Due to "birthday surprise" conflict probability is high after 2^{20} global IDs have been allocated.
    - That's only about 1,000,000.

Global Addresses

- Addresses *can* appear on the open Internet.
  - Prefix bits 001 (2000::/3). Thus if the first digit is 2 or 3, it is a global address.
  - Must be assigned by a global authority.

13 bits 8 24 bits 16 bits 64 bits

Interface ID

Prefix

Site level aggregation ID (SLA)

Next level aggregation ID (NLA)

Reserved

Top level aggregation ID (TLA)

Tunneling

- How to do IPv6 over IPv4 infrastructure?
  - Obviously can't change entire network in one step
  - But... IPv6 can't be routed by IPv4-only routers.
- Solution...
  - Use IPv4 for on-the-wire communication.
    - Negates many of the advantages of IPv6.
  - Encapsulate IPv6 traffic in IPv4 packets.

Configured Tunnel

lemuria.cis.vermontstate.edu
(Williston)

Tunnel endpoint
(IPv6 router that encapsulates IPv6 into IPv4)

IPv6 only host

IPv4
Internet

IPv6 only host

Tunnel endpoint
(IPv6 router that encapsulates IPv6 into IPv4)

twilight.cis.vermontstate.edu
(Randolph)

Automatic Protocol Conversion

IPv4/IPv6 host

IPv6-only software uses
`::FFFF:`*`155.42.14.106`*

Host sends IPv4 packets
“as usual.”

IPv4
Internet

IPv4 only host

155.42.14.106

Automatic Tunnel (deprecated; use 6to4)

IPv4/IPv6 host

IPv6-only software uses
`::`*155.42.14.106*

Host encapsulates
IPv6 packets in IPv4

IPv4
Internet

IPv4/IPv6 host
IPv6-only software

155.42.14.106

6to4 Tunneling (also deprecated!)

- RFC-3056
  - Allows IPv6 sites or hosts to communicate with each other over IPv4 infrastructure.
    - Does not require automatic or configured tunneling.
- Prefix 2002::/16
- A site with a valid IPv4 address gets prefix of
  - 2002:*IPv4-address*::/48
- Gateway machine does encapsulation, etc.

6to4 Example

Gateway machines encapsulate IPv6 packets in IPv4.

IPv4
Internet

155.42.13.22
(9B2A:0D16)

155.42.14.106
(9B2A:0E6A)

IPv6 internal routing
2002:9B2A:0E6A::/48

IPv6 internal routing
2002:9B2A:0D16::/48