Other approaches to solve address depletion problem:

• IPv6

$\rightarrow$ 128-bit addresses

$\rightarrow$ proposed mid-1990s

$\rightarrow$ IPv6 overhead and complexity

$\rightarrow$ resistance to wide-spread adoption

$\rightarrow$ IPv4 still dominant

IPv4 has found real-world workarounds limiting necessity of IPv6 deployment

$\rightarrow$ IPv6 has found niche in ISP core/periphery

$\rightarrow$ e.g., periphery: cellular devices

IPv6 header format:

| version 4 | traffic class 8 | flow label 20 | | |
|---|---|---|---|---|
| payload length 16 | | | next header 8 | hop limit 8 |
| source address 128 | | | | |
| destination address 128 | | | | |

- traffic class: similar role as TOS field in IPv4

- flow label: flow label + source address

    → per-flow traffic management

    → significant extra bits

    → header size twice as large: 40 bytes

- next header: similar to IPv4 protocol field

  → plus double duty for option headers

  → integrated with IPsec: authentication, encryption

- hop limit: same role TTL

- missing fields

  → fragmentation header optional: only allowed at source

Network/socket programming

→ slight differences compared to IPv4

Key features of IPv4 global Internet:

• Classless (vs. classful) IP addressing

$\rightarrow$ variable length subnetting

$\rightarrow$ that is, *a.b.c.d/x* ($x$: mask length)

$\rightarrow$ e.g., 128.10.0.0/16, 128.210.0.0/16, 204.52.32.0/20

Prefix specifies organization: autonomous system

$\rightarrow$ IPv4 and IPv6 addresses allocated to autonomous systems

$\rightarrow$ Purdue University: ASN 17

$\rightarrow$ AT&T: ASN 7018 (and others)

$\rightarrow$ used in inter-domain routing

$\rightarrow$ CIDR (classless inter-domain routing)

$\rightarrow$ de facto global Internet addressing standard

• Dynamically assigned IP addresses

→ share an IP address pool

→ addresses are temporary

→ used in access ISPs, enterprises, home networks, etc.

→ e.g., WiFi hot spots

Past: Internet access ISPs exploit that only a fraction requires global Internet access at the same time

→ serve large customer base with small IP address space

Today: residential customers expect to stay online continually

→ limited saving effect of IP address space

DHCP (Dynamic Host Configuration Protocol):

→ UDP-based client/server: server port 67, client port 68

→ 4-way handshake (called DORA)

- Discovery: DHCP client broadcasts request

  → destination IP 255.255.255.255, MAC address all 1's, source IP 0.0.0.0

- Offer: DHCP server responds with IP address (and other relevant info)

  → client's MAC address (Ethernet type field 0x0800, IP protocol field 17)

  → UDP payload contains DHCP packet

- Request: client accepts offered IP address

- Ack: server confirms assignment

• Network address translation (NAT)

→ use of both permanent private IP address and dynamic public IP address

→ address translation from private IP to public IP when accessing global Internet

→ useful for enterprise networks, home networks, etc.

In practice: additional name translation layer

→ configure local DNS (Domain Name System) server with private IP addresses

→ local machines can communicate with each other using symbolic names

→ DNS: global distributed name resolution database system

Example: recent change at Purdue to assign private addresses to lab and instructional machines

→ amber01.cs.purdue.edu: 10.168.53.10

→ borg01.cs.purdue.edu: 10.168.53.41

→ data.cs.purdue.edu: 128.10.2.13


When amber01 accesses global Internet

→ e.g., run web browser

→ 10.168.53.10 translated to 128.10.127.250


Note: amber01.cs.purdue.edu not meaningful outside of Purdue

→ only Purdue's DNS server configured to translate amber01.cs.purdue.edu to 10.168.53.10


. . . IPv4 Address depletion problem remains

- NAPT: NAT + port number

$\rightarrow$ variant of NAT: borrow src port field as address bits

Ex.: 192.168.10.10 and 192.168.10.11 both map to single public address 128.10.27.10; in addition

$\rightarrow$ 192.168.10.10 maps to 128.10.26.10:6001

$\rightarrow$ 192.168.10.11 maps to 128.10.26.10:6002

What about port numbers of 192.168.10.10 and 192.168.10.11?

$\rightarrow$ e.g., client process bound to 192.168.10.10:22222

$\rightarrow$ e.g., client process bound to 192.168.10.11:33333

Does not matter: NAPT translation table entries

$\rightarrow$ 192.168.10.10:22222 maps to 128.10.26.10:6001

$\rightarrow$ 192.168.10.11:33333 maps to 128.10.26.10:6002

Example:

if 192.168.10.10:22222 is a web browser (say Firefox) downloading web page from https://www.purdue.edu:443

$\rightarrow$ web server knows client as 128.10.27.10:6001

NAPT yields huge increase in effective IP address space

$\rightarrow$ IP address bits are increased to 48 (= 32 + 16)

$\rightarrow$ biggest factor preventing IP address depletion

Well-suited for systems with asymmetric traffic

$\rightarrow$ problem when running servers

$\rightarrow$ in general, need permanent IP addresses

Ex.: SOHO (small office/home office)

$\longrightarrow$   now:  home networking
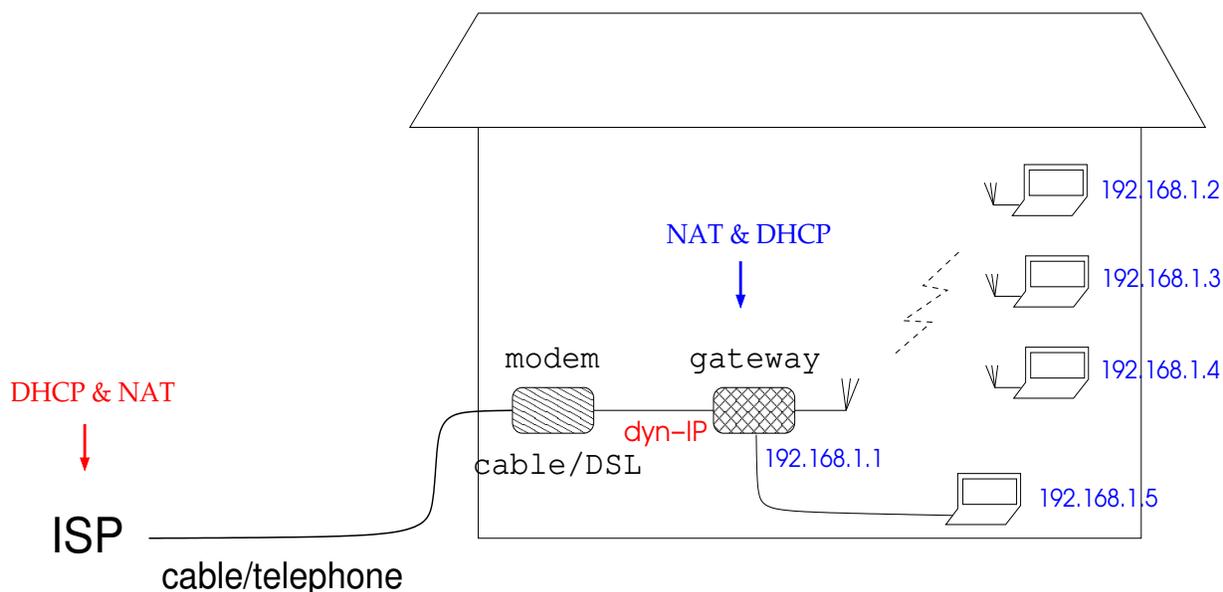


- dynamic IP address provided by ISP is shared through NAT

- recall:  private IP addresses

  $\rightarrow$ 10.0.0.0/8, 172.16.0.0–172.31.255.255, 192.168.0.0/16

DHCP: 2-phase protocol

1. Discovery

$\rightarrow$ client sends broadcast discovery message (UDP, client port 68, server port 67) on LAN

$\rightarrow$ one or more DHCP servers respond with dynamic IP address

2. Allocation

$\rightarrow$ client sends broadcast message requesting selected IP address

$\rightarrow$ DHCP server confirms assignment

DHCP does other network configuration chores:

$\rightarrow$ provides DNS server names

$\rightarrow$ first-hop router/gateway

$\rightarrow$ subnet mask

CIDR and dynamically assigned IP addresses with NAPT alleviated IPv4 address depletion problem

$\rightarrow$ significant increase of Internet's effective address space

$\rightarrow$ IPv4 still dominant

Last free IPv4 address block allocated by IANA (suborganization of ICANN) to regional registries early 2011

$\rightarrow$ RIRs: ARIN, RIPE, APNIC, LACNIC, AFRINIC

Last available/recovered address pool allocated mid-2014

$\rightarrow$ from central Internet authorities to autonomous systems

$\rightarrow$ ISPs manage their own address blocks

IPv6 has found foothold in ISP intranet and explosion of customer premises equipment (e.g., mobile devices)

$\rightarrow$ struggled to find relevance since introduction in mid-1990s

$\rightarrow$ draft standard 1998

$\rightarrow$ full standard 2017

IPv6 benefit in ISP environment

$\rightarrow$ no need for NAT for mobile-to-mobile and mobile-to-IPv6 server communication

In general

$\rightarrow$ dual stack overhead

$\rightarrow$ e.g., my cell phone: 12.75.17.199, 2600:387:11:39d::e (with a few bit flips)