IPv6

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"One of the chief factors that has prevented this transformation, though objectively it has been on the agenda for years, is the absence or the repression of the need for transformation, which has to be present as the qualitatively differentiating factor among the social groups that are to make the transformation." – Herbert Marcuse

Overview

- Motivation for IPv6
- Key Differences between IPv4 and IPv6
- Security Considerations
- Infrastructure Migration
- Migrating Code to IPv6

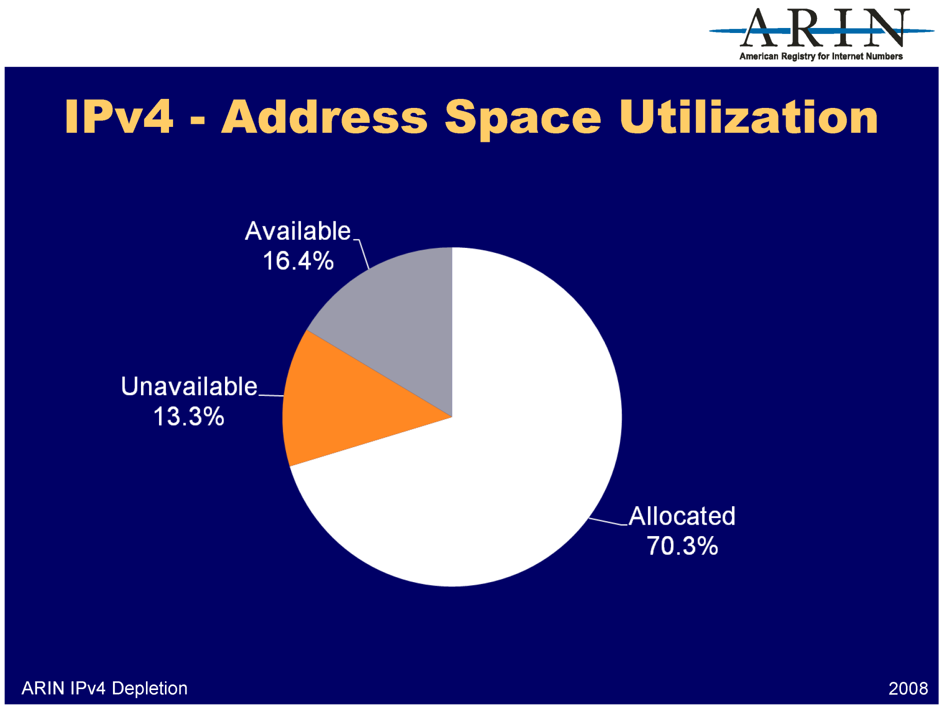
Motivation

We're running out of IPv4 addresses:

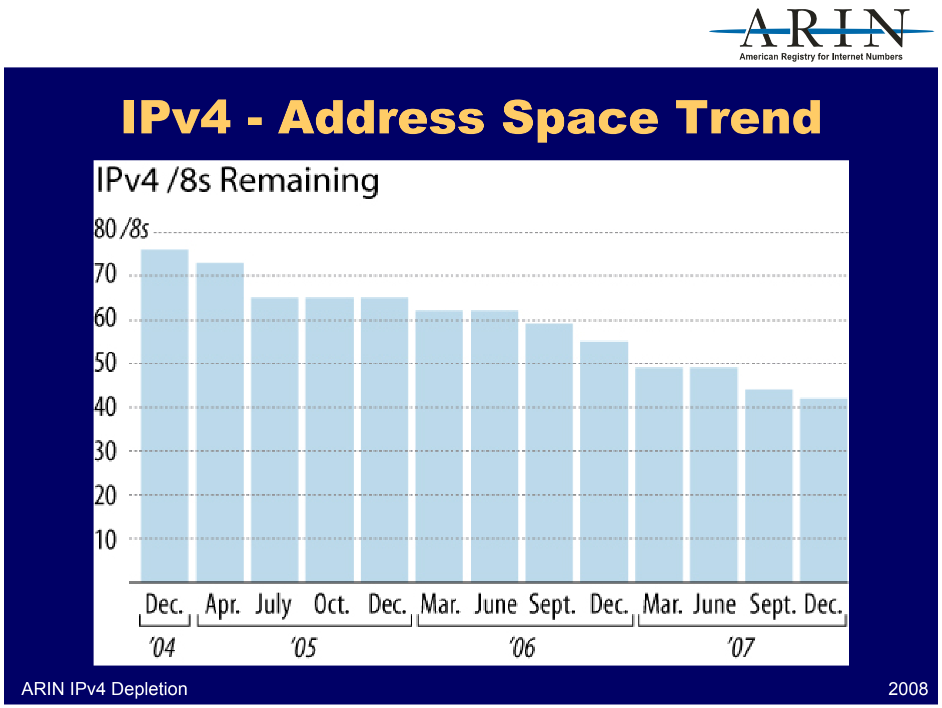
- 32-bit
- Routing considerations limit use (CIDR, renumbering costs)
- Impact differs by geography (see RIR assignments)
- New services accelerate pace of address consumption (mobiles!)

US Federal Networks must be IPv6-capable since June 2008.

IPv4 Address Space Utilization



IPv4/8s Remaining



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085 RIPE	086 RIPE	089 RIPE	090 RIPE	101 Reserved	102 Reserved	105 Reserved	106 Reserved	149 Various	150 Various	153 Various	154 Various	165 Various	166 Various	169 Various	170 Various

IPv4 Address Fractal Map Jan-2008

000 Reserved	001 Reserved	014 PDN	015 HP	016 DEC	019 Ford	020 CsC	021 US DoD	234 Multicast	235 Multicast	236 Multicast	239 Multicast	240 Class E	241 Class E	254 Class E	255 Class E
003 GE	002 Reserved	013 Xerox	012 AT&T	017 Apple	018 MIT	023 Reserved	022 US DoD	233 Multicast	232 Multicast	237 Multicast	238 Multicast	243 Class E	242 Class E	253 Class E	252 Class E
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005 Reserved	006 US DoD	009 IBM	010 Private	031 Reserved	028 US DoD	027 Reserved	026 US DoD	229 Multicast	228 Multicast	227 Multicast	224 Multicast	245 Class E	246 Class E	249 Class E	250 Class E
058 APnic	057 SITA	054 Merck	053 Cap Debis	032 AT&T	035 MERIT	036 Reserved	037 Reserved	218 APnic	219 APnic	220 APnic	223 Reserved	202 APnic	201 LACnic	198 Various	197 Reserved
059 APnic	056 US Postal	055 US DoD	052 El duPONT	033 US DoD	034 Haliburton	039 Reserved	038 PSI	217 RIPE	216 ARIN	221 APnic	222 APnic	203 APnic	200 LACnic	199 ARIN	196 AFRnic
060 APnic	061 APnic	050 Reserved	051 UK DSS	046 Reserved	045 Interop	040 Eli Lily	041 AFRNic	214 US DoD	215 US DoD	210 APnic	209 ARIN	204 ARIN	205 ARIN	194 RIPE	195 RIPE
063 ARIN	062 RIPE	049 Reserved	048 Prudential	047 Bell North	044 Radio	043 Inet	042 Reserved	213 RIPE	212 RIPE	211 APnic	208 ARIN	207 ARIN	206 ARIN	192 RIPE	192 Various
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065 ARIN	066 ARIN	071 ARIN	070 ARIN	121 APnic	120 APnic	125 APnic	126 APnic	129 Various	130 Various	135 Various	134 Various	185 Reserved	184 Reserved	189 LACnic	190 LACnic
078 RIPE	077 RIPE	072 ARIN	073 ARIN	118 APnic	119 APnic	114 APnic	113 Reserved	142 Various	141 Various	136 Various	137 Various	182 Reserved	183 Reserved	178 Reserved	177 Reserved
079 RIPE	076 ARIN	075 ARIN	074 ARIN	117 APnic	116 APnic	115 APnic	112 Reserved	143 Various	140 Various	139 Various	138 Various	181 Reserved	180 Reserved	179 Reserved	176 Reserved
080 RIPE	081 RIPE	094 RIPE	095 RIPE	096 ARIN	097 ARIN	110 Reserved	111 Reserved	144 Various	145 Various	158 Various	159 Various	160 Various	161 Various	174 Reserved	175 Reserved
083 RIPE	082 RIPE	093 RIPE	092 RIPE	099 ARIN	098 ARIN	109 Reserved	108 Reserved	147 Various	146 Various	157 Various	156 Various	163 Various	162 Various	173 Reserved	172 Various
084 RIPE	087 RIPE	088 RIPE	091 RIPE	100 Reserved	103 Reserved	104 Reserved	107 Reserved	148 Various	151 Various	152 Various	155 Various	164 Various	167 Various	168 Various	171 Various
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Fractal map: Layout by Randall Munroe, Time Sequence by Tony Hain, Highlighted by Jeff Apcar

IPv4 Address Fractal Map Jan-2009

000 Reserved	001 Reserved	014 Reserved	015 HP	016 DEC	019 Ford	020 CsC	021 US DoD	234 Multicast	235 Multicast	236 Multicast	239 Multicast	240 Class E	241 Class E	254 Class E	255 Class E
003 GE	002 Reserved	013 Xerox	012 AT&T	017 Apple	018 MIT	023 Reserved	022 US DoD	233 Multicast	232 Multicast	237 Multicast	238 Multicast	243 Class E	242 Class E	253 Class E	252 Class E
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060 APnic	061 APnic	050 Reserved	051 UK DSS	046 Reserved	045 Interop	040 Eli Lily	041 AFRNic	214 US DoD	215 US DoD	210 APnic	209 ARIN	204 ARIN	205 ARIN	194 RIPE	195 RIPE
063 ARIN	062 RIPE	049 Reserved	048 Prudential	047 Bell North	044 Radio	043 Inet	042 Reserved	213 RIPE	212 RIPE	211 APnic	208 ARIN	207 ARIN	206 ARIN	192 RIPE	192 Various
064 ARIN	067 ARIN	068 ARIN	069 ARIN	122 APnic	123 APnic	124 APnic	127 Loopback	128 Various	131 Various	132 Various	133 Various	186 LACnic	187 LACnic	188 Various	191 Various
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078 RIPE	077 RIPE	072 ARIN	073 ARIN	118 APnic	119 APnic	114 APnic	113 Next	142 Various	141 Various	136 Various	137 Various	182 Reserved	183 Reserved	178 Next	177 Next
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Fractal map: Layout by Randall Munroe, Time Sequence by Tony Hain, Highlighted by Jeff Apcar

IPv4 Address Fractal Map Jan-2010

000 Reserved	001 Reserved	014 Reserved	015 HP	016 DEC	019 Ford	020 CsC	021 US DoD	234 Multicast	235 Multicast	236 Multicast	239 Multicast	240 Class E	241 Class E	254 Class E	255 Class E
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063 ARIN	062 RIPE	049 Reserved	048 Prudential	047 Bell North	044 Radio	043 Inet	042 Reserved	213 RIPE	212 RIPE	211 APnic	208 ARIN	207 ARIN	206 ARIN	192 RIPE	192 Various
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078 RIPE	077 RIPE	072 ARIN	073 ARIN	118 APnic	119 APnic	114 APnic	113 Next	142 Various	141 Various	136 Various	137 Various	182 Next	183 Next	178 Next	177 Next
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Fractal map: Layout by Randall Munroe, Time Sequence by Tony Hain, Highlighted by Jeff Apcar

IPv4 Address Fractal Map Jan-2011

Fractal map: Layout by Randall Munroe, Time Sequence by Tony Hain, Highlighted by Jeff Apcar

000 Reserved	001 Reserved	014 Next	015 HP	016 DEC	019 Ford	020 CsC	021 US DoD	234 Multicast	235 Multicast	236 Multicast	239 Multicast	240 Class E	241 Class E	254 Class E	255 Class E
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IPv4 Depletion

Stephan Lagerholm predicts[1] IANA IPv4 depletion at:

2011-02-10

and full central IPv4 pool depletion (all RIRs) at

2012-04-15

We're currently allocating a full /8 about every 8 weeks.

[1] http://ipv4depletion.com/dashboard/

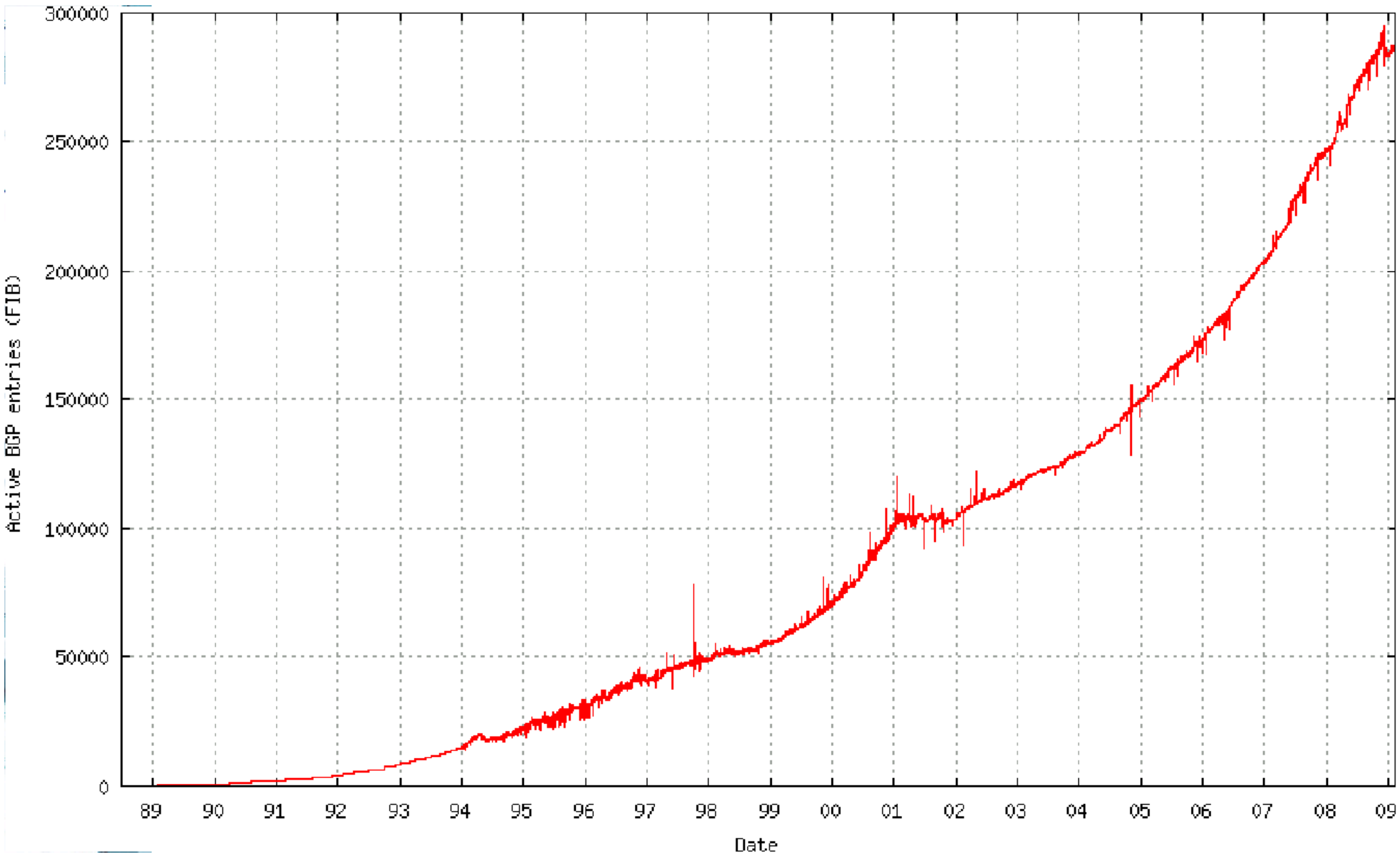
Other Reasons

- Many changes in details for IPv6
- Research $\neq$ KISS
- Can have advantages, but without address space issues nobody would think twice of adopting any of them

Mitigation Risks

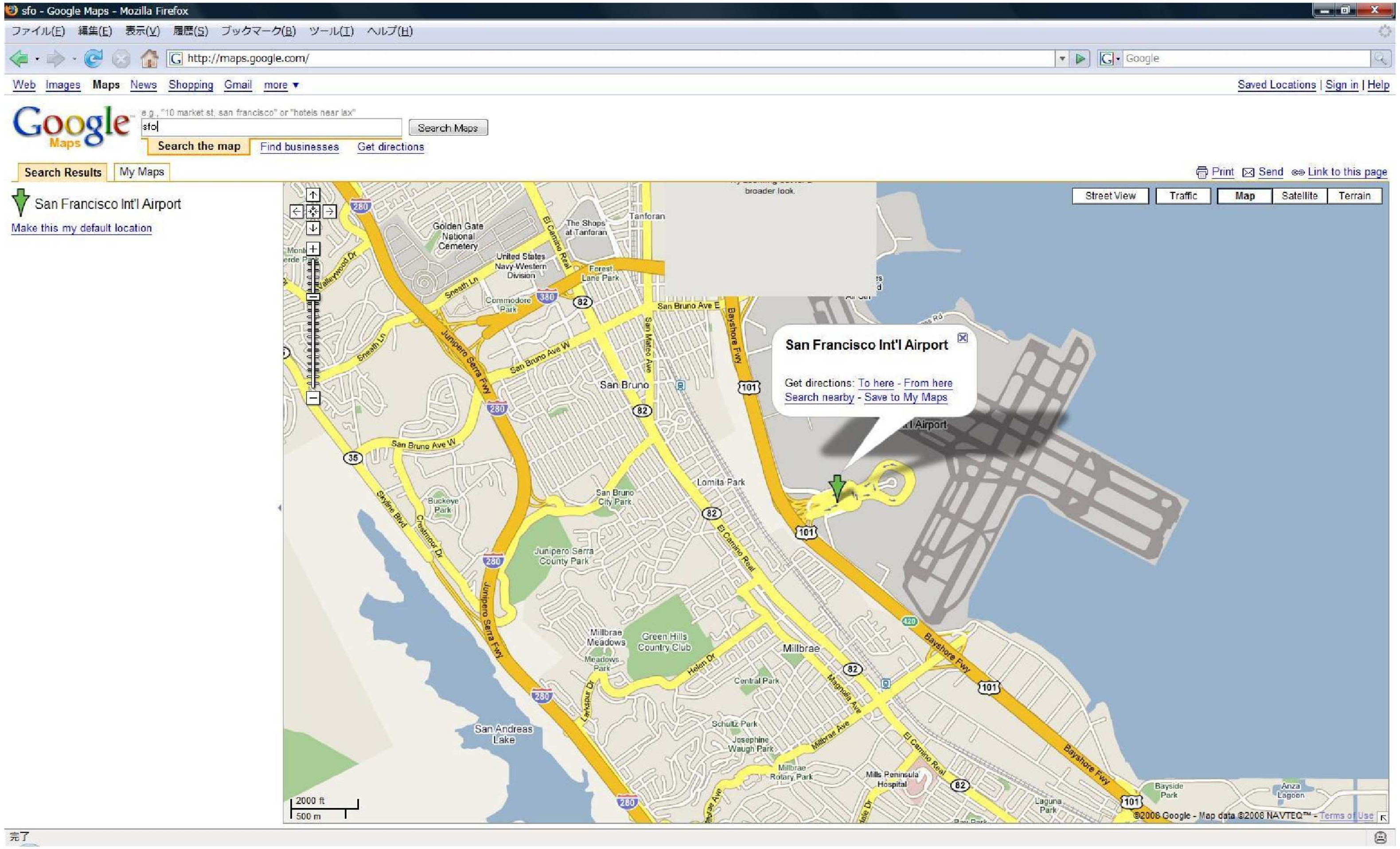
- Using smaller address blocks will cause the global IPv4 routing table to grow in size
- Using NAT limits the number of parallel connections

Current IPv4 BGP Database



Multiple connection applications

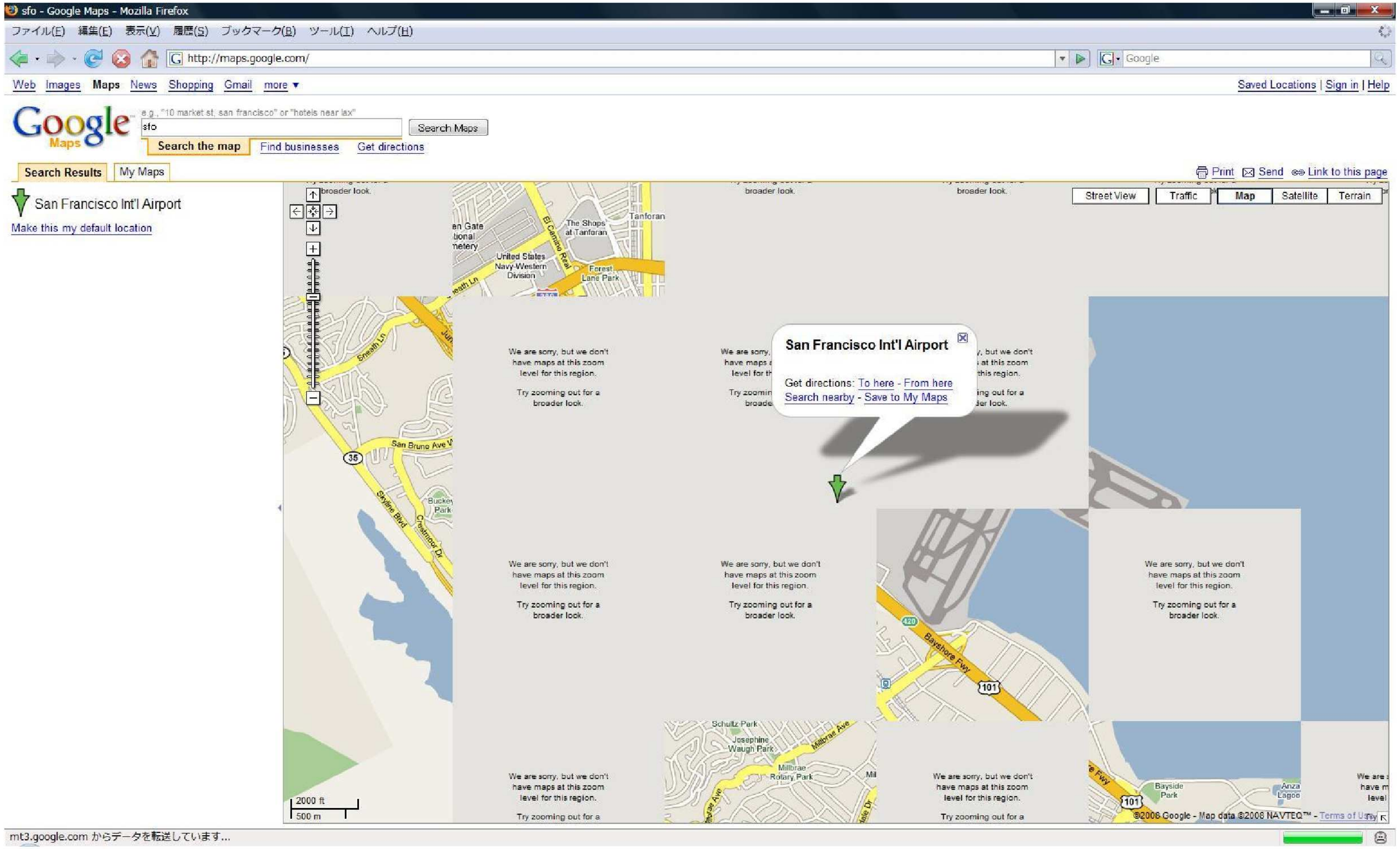
Max 20 Connections



Source: Shin Miyakawa , Ph.D. NTT Communications Corporation

Multiple connection applications

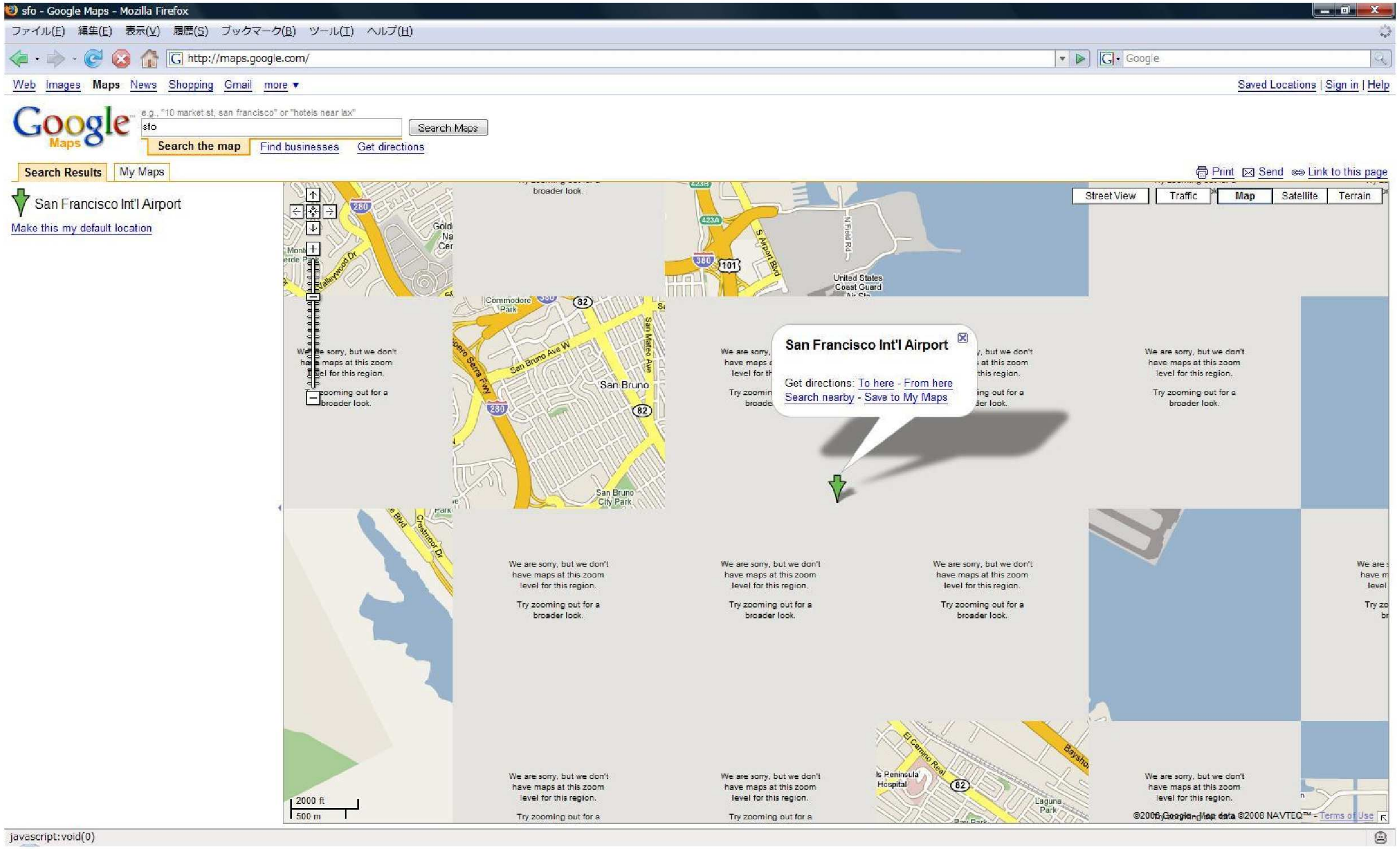
Max 15 Connections



Source: Shin Miyakawa , Ph.D. NTT Communications Corporation

Multiple connection applications

Max 10 Connections



Source: Shin Miyakawa , Ph.D. NTT Communications Corporation

Multiple connection applications

Max 5 Connections

Source: Shin Miyakawa , Ph.D. NTT Communications Corporation

Multiple connection applications

- Google maps opens about 70 parallel connections, iTunes as many as 300
- IPv4/NAT multiplexes users through the port range

$$\frac{64k \quad \texttt{ports}}{300 \quad \texttt{connections}} \approx 200 \quad \texttt{customers per ISP based NAT}$$

The Business Case

- Access providers need more addresses than content providers, so they want to switch once their customers are willing

- Content providers need to deploy IPv6 before access providers can switch, but they don't need that many addresses (thanks to virtual hosting)

The Research Case

- Autoconfiguration, large sensor networks, 6LoWPAN (RFC 4919 & 4944): Routing Over Low power and Lossy networks
- Migration strategies (6over4, 6to4, Teredo, ISATAP, etc.)
- IPv6 multicast `http://www.videolan.org/`, `http://www-mice.cs.ucl.ac.uk/multimedia/software/`
- Moblile IPv6 (RFC 3775 & 4584)

Key Differences between IPv4 and IPv6

- Header
- Fragmentation
- Address Space
- QoS (not discussed today)

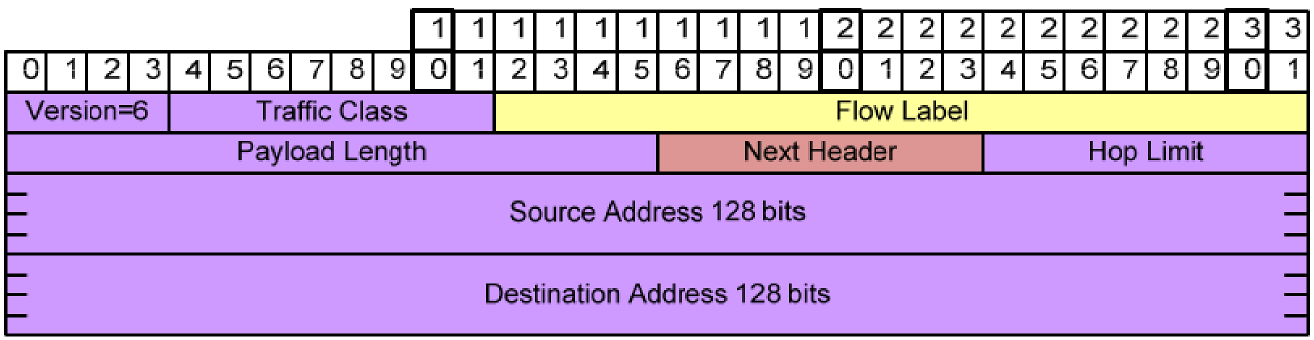
IPv6 Header

- Fixed length (40 bytes) $\Rightarrow$ more efficient
- Fewer fields $\Rightarrow$ more efficient
- No header error checking $\Rightarrow$ more efficient
- Fragmentation fields removed $\Rightarrow$ more efficient
- Aligned on 64-bit boundaries $\Rightarrow$ more efficient
- Extensible via extension header

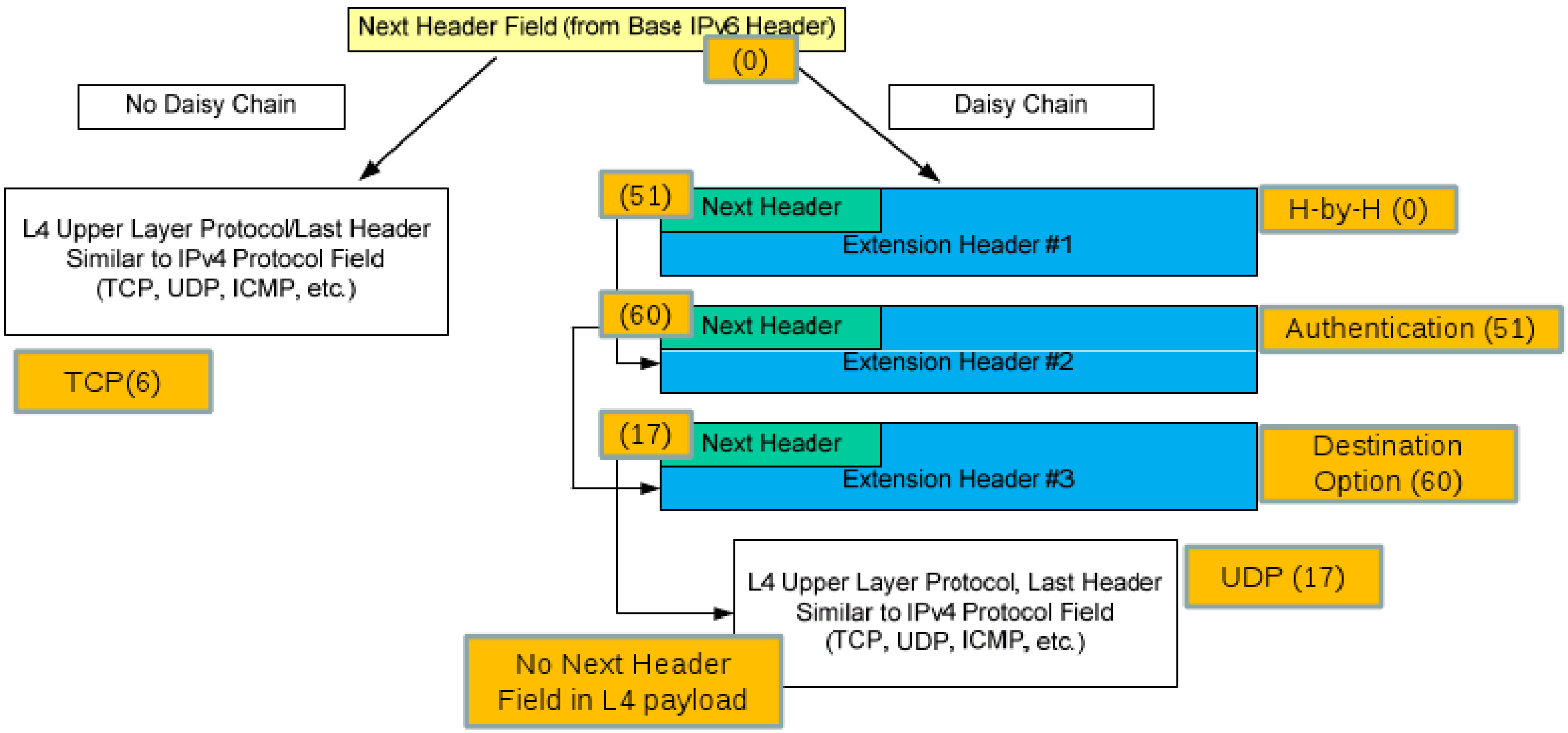
IPv6 Header

IPv4 Header

IPv6 Header



IPv6 Extension Headers



Fragmentation

- IPv6 routers do not fragment packets
- IPv6 MTU must be at least 1280 bytes, recommended 1500
- Nodes should implement MTU PD or not exceed 1280 bytes
- MTU path discovery uses ICMPv6 “packet to big” messages

⇒ Do not filter those!

IPv6 Addresses

IPv6 address is 128 bits long:

- First 32 bits typically ISP (::/32)
- First 48 bits typically Enterprise (::/48)
- First 64 bits typically subnet (::/64)
- Low 64 bits often include interface MAC address

Written in Hex, colon breaks into 16-bit "chunks"

Writing IPv6 Addresses

The written format is "<address>/<prefix-length>". Example:

`2001:ABAD:9252:0000:0032:0000:0000:0102/64`

The "/64" in the above example is the number of leftmost bits that constitutes the prefix.

Zeros in IPv6 Addresses

Addresses often contain many 0 (zero) bits. **One** such group can be abbreviated, and leading zeros in each chunk can be dropped:

`2001:ABAD:9252:0:32::0102/64`

IPv6 Address Types

- Unicast
- Multicast
- Anycast

IPv6 Addresses

Address Type	Binary Prefix	IPv6 Notation
Unspecified	$0 \dots 0$	::/128
Loopback	$0 \dots 01$	::1/128
Link-local unicast	1111111010	FE80::/10
Unique Local unicast	1111110	FC00::/7
Site-local unicast	1111111011	FEC0::/10
Multicast	11111111	FF00::/8
Global unicast	(everything else)	

Table 1: Address types and binary representations.

Link-local Addresses

- Only valid on a single link or subnet
- Begin with prefix “FE80::/10”, then contain 54 bits of zeros, followed by the 64-bit interface ID
- Can be automatically generated or manually configured

Unique Local Addresses (RFC 4193)

- Replace site-local unicast which replaced "10.x.x.x" private addresses
- Not routable on Internet; routable within organization
- Site-scoped prefix based on 40 bit hash + 16 bit subnet + interface ID

⇒ Likely globally unique

⇒ Organizations can likely merge without problems

64-bit Interface Identifiers

- Must be unique on the link
- Need not be unique across multiple links
- May be globally unique (i.e., based on MAC address, google EUI-64 construction rules)
- Some IIDs are reserved for subnet-router anycast (all-zeros) and subnet anycast (certain high IIDs)

IPv6 Privacy/Temporary Addresses

- IPv6 autoconfigured addresses can be tracked over time
- IPv6 autoconfigured addresses relate to MAC address

$\Rightarrow$ Location tracking possibility, privacy issues!

Privacy addresses randomize IPv6 address IID so that there is no fixed EIU-64 identifier enabling tracking despite the (possibly) changing /64 prefix.

Multicast Address Format

8 bits FF – Multicast!

4 bits flags, for example:

- 0000 = permanent (IANA)
- 0001 = temporary (local/random)

4 bits scope, for example:

- 0x2 = link-local
- 0x5 = site-local
- 0x8 = organization-local
- 0xE = global

112 bits multicast group ID

Anycast Addresses

- Used to reach a "nearest" instance of a given address
- Drawn from the unicast address space — no special format!
- Should be used for DNS servers

Required Addresses

- Link-local: Required for each interface
- Loopback: Required
- All-Nodes Multicast: Required
- Solicited-Node Multicast: Required for each unicast and anycast address
- Additional unicast, multicast and anycast are optional for hosts
- Router has more, such as “all routers multicast”

ICMPv6

- Router redirect
- Destination unreachable
- Packet too big
- Time exceeded
- Parameter problem
- Echo request/reply
- **Neighbour Discovery** — replace ARP!

Neighbor Discovery Messages

- Neighbour Solicitation uses multicast, not broadcast:

  2001:DB8::1234:5678:9ABC ⇒ FF02::1:FF**78:9ABC**
  ⇒ 33-33-FF-78-9A-BC

- Router Solicitation uses multicast, can replace DHCP!

Neighbour Solicitation is also used to detect duplicate addresses.

Router Solicitation

When an interface is initialized, it can send a router solicitation instead of waiting for a router advertisement:

33-33-00-00-00-02

Router Advertisement

RAs are sent periodically and on-demand. Include:

- Router lifetime
- Lifetime values for prefixes
- Possibly a hop limit
- Possibly default router preference and specific routes
- Possibly recursive DNS server addresses
- ... or information telling node to use DHCP

DHCPv6

- Similar to DHCP for v4
- "stateless" configuration does not provide addresses (only "other" configuration parameters)
- Can be used to delegate entire prefix (not just single address)
- Currently **no** option to set a host's default route in the standard! This must be done using RA!

Security Considerations

- Hosts reachable over **two** protocols
- Hosts reachable under **many** addresses
- IPv4 hosts reachable via IPv6 **tunnels** (6over4)

$\Rightarrow$ Traditional Layer-2 firewall rules for IPv4 don't work!

New Attacks

- Abuse of IPv4 compatible addresses
- Abuse of 6to4 addresses
- Abuse of IPv4 mapped addresses
- Attacks by combining different address formats
- Attacks that deplete NAT-PT address pools

Reconnaissance

- Address space is larger, no more ping sweeps
- Ping FF02::1 and neighbor cache will give results for insider!
- Node Information Queries (RFC 4620)
- Stateless auto-configuration makes MITM attack easy by spoofing RAs or DHCPv6
- ICMP redirects (still) exist

Transition Mechanism Threats

- Dual Stack: only as secure as the weaker stack
- Tunnels: 6to4 relay routers are “open relays”

What to do?

"Be liberal in what you accept, and conservative in what you send."
— John Postel, RFC 760.

- Today, organizations are attempting to reach mail and webservers via IPv6
- In the near future, there will be organization that have no choice but to reach you via IPv6

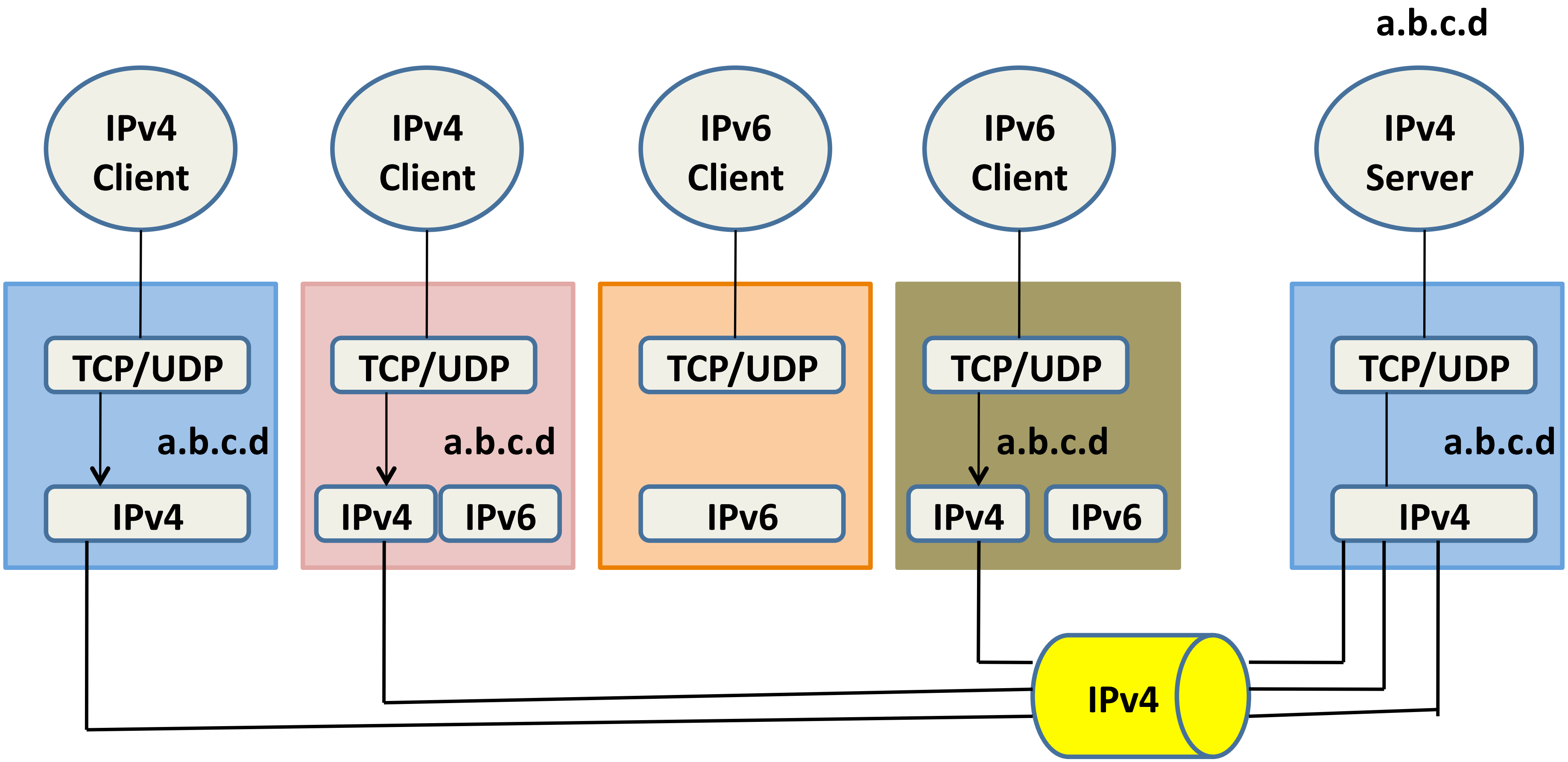
$\Rightarrow$ Dual stack where you can, tunnel where you must

Dual Stack

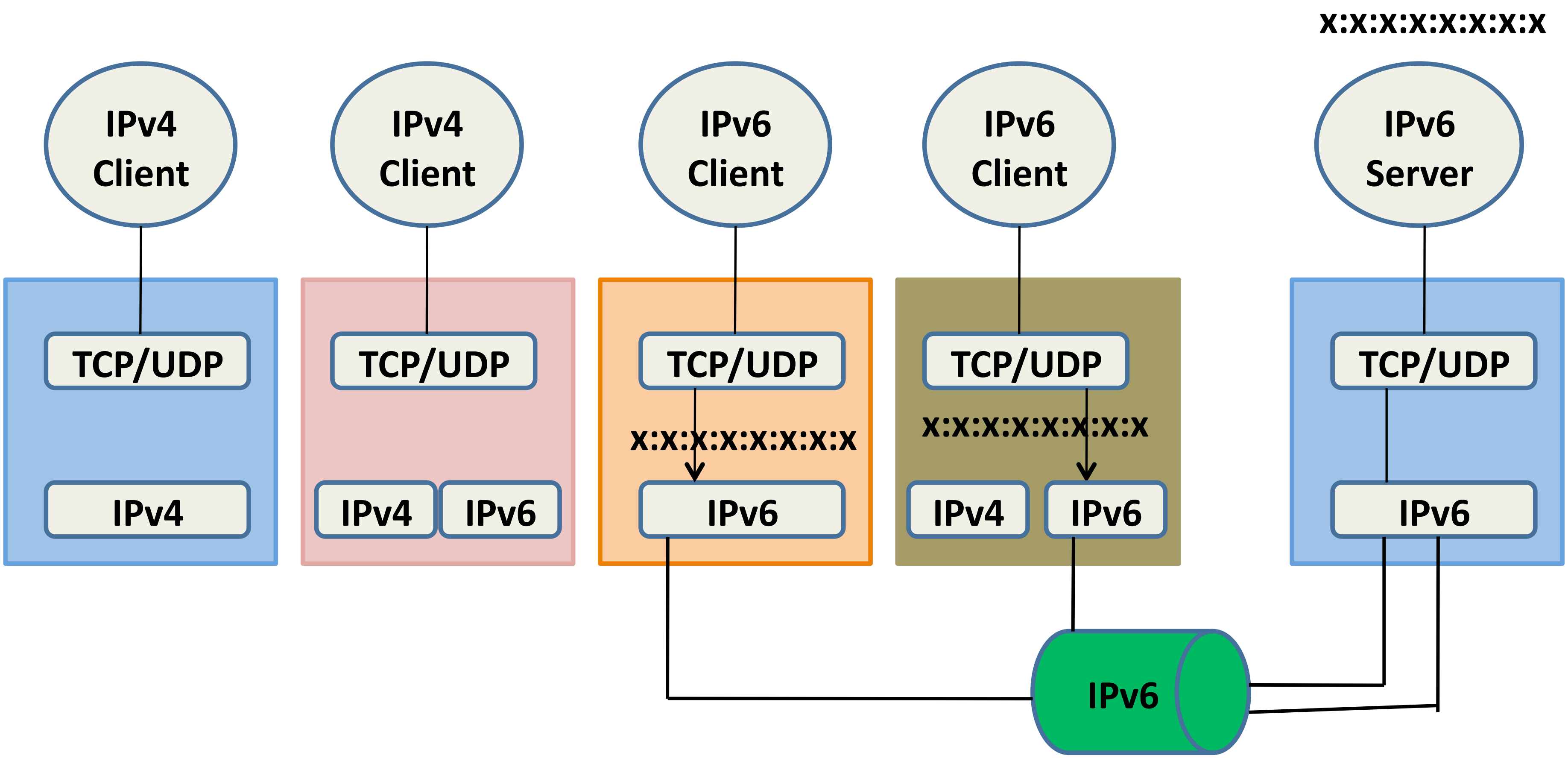
- Evolve the Internet to have two IP versions at the same time
- Interoperate (possibly with limitations) for a while
- Use IPv6 alone in the future

Dual-stacking increases CPU and memory utilization by 15-25% (for routers).

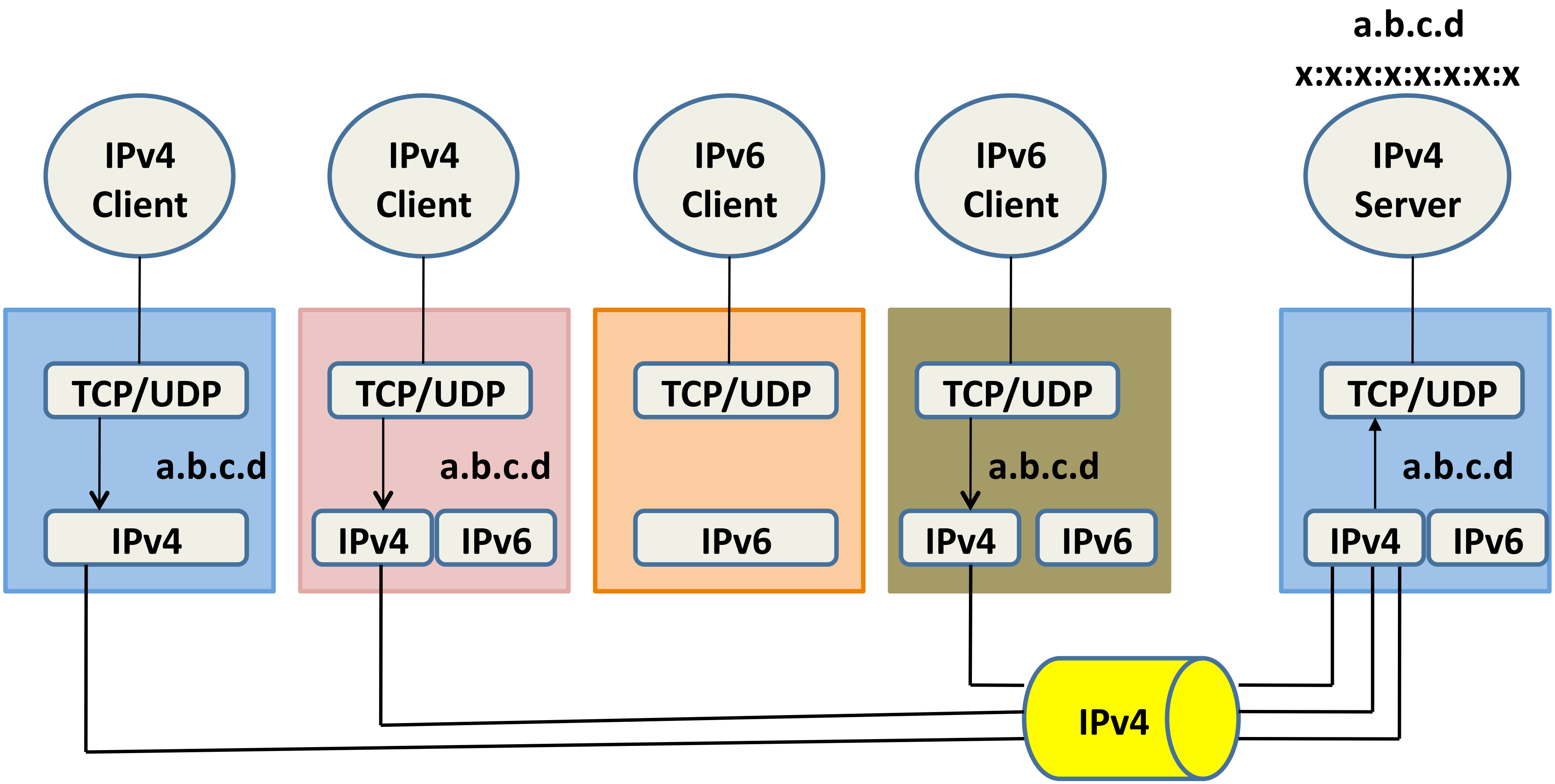
1 IPv6/IPv4 clients connecting to an IPv4 server at IPv4-only node



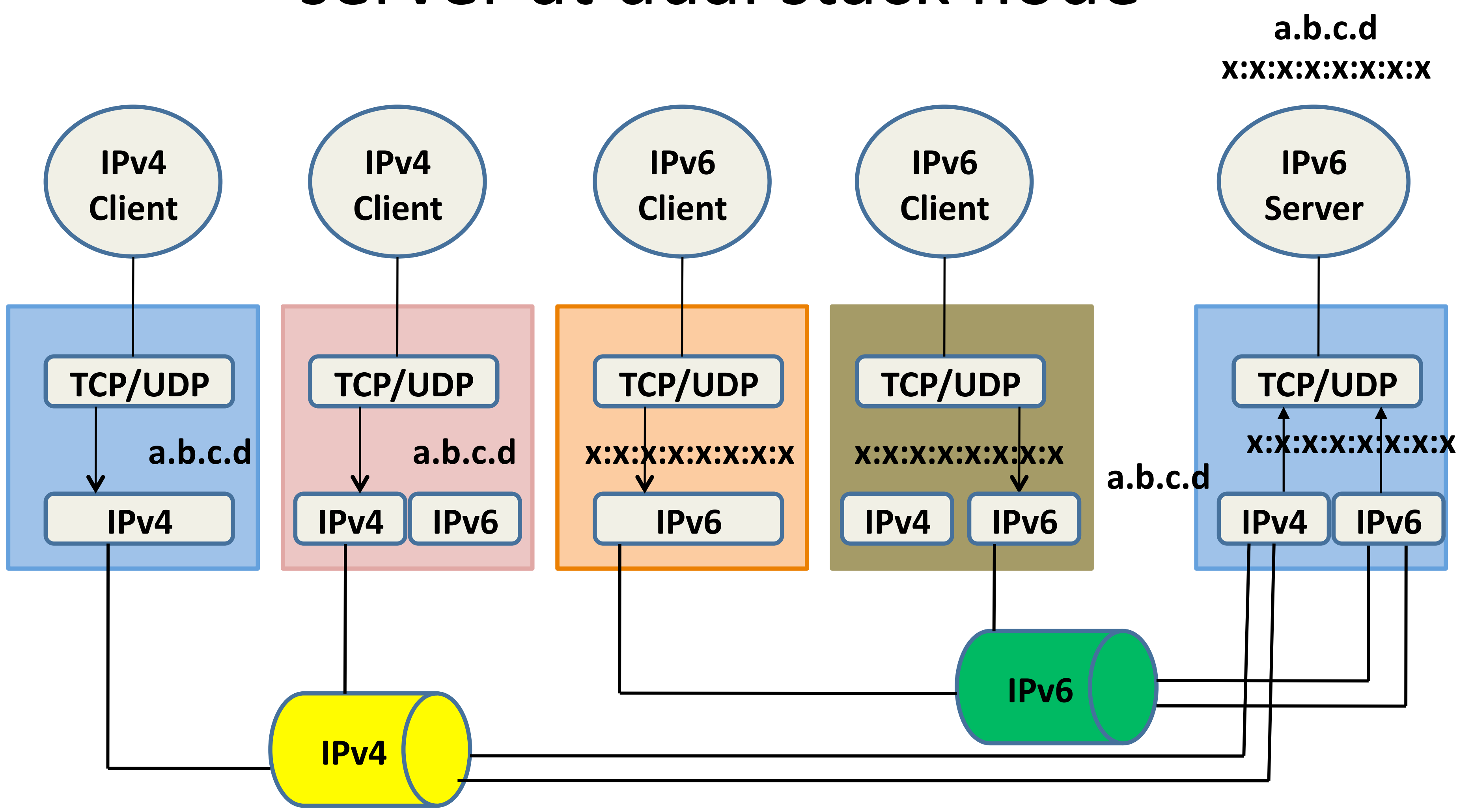
2 IPv6/IPv4 clients connecting to an IPv6 server at IPv6-only node



3 IPv6/IPv4 clients connecting to an IPv4 server at dual stack node



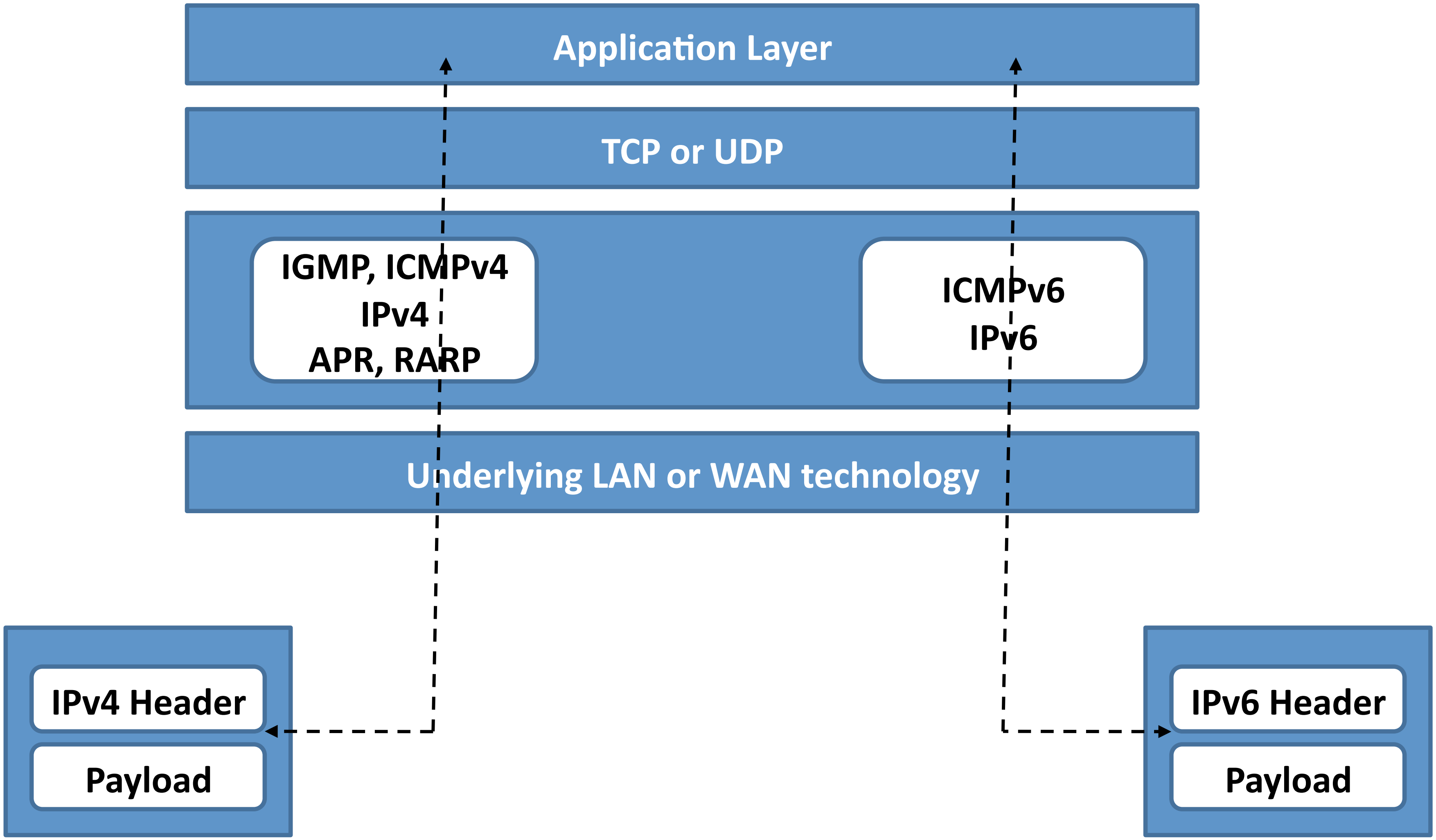
4 IPv6/IPv4 clients connecting to an IPv6 server at dual stack node



Client server & network type combinations

		IPv4 Server Application		IPv6 Server Application	
		IPv4 Node	Dual-Stack	IPv6 node	Dual-Stack
IPv4 client	IPv4 node	IPv4	IPv4	X	IPv4
	Dual-stack	IPv4	IPv4	X	IPv4
IPv6 client	IPv6 node	X	X	IPv6	IPv6
	Dual-stack	IPv4	IPv4/X	IPv6	IPv6

Application Perspective within a Dual Stack

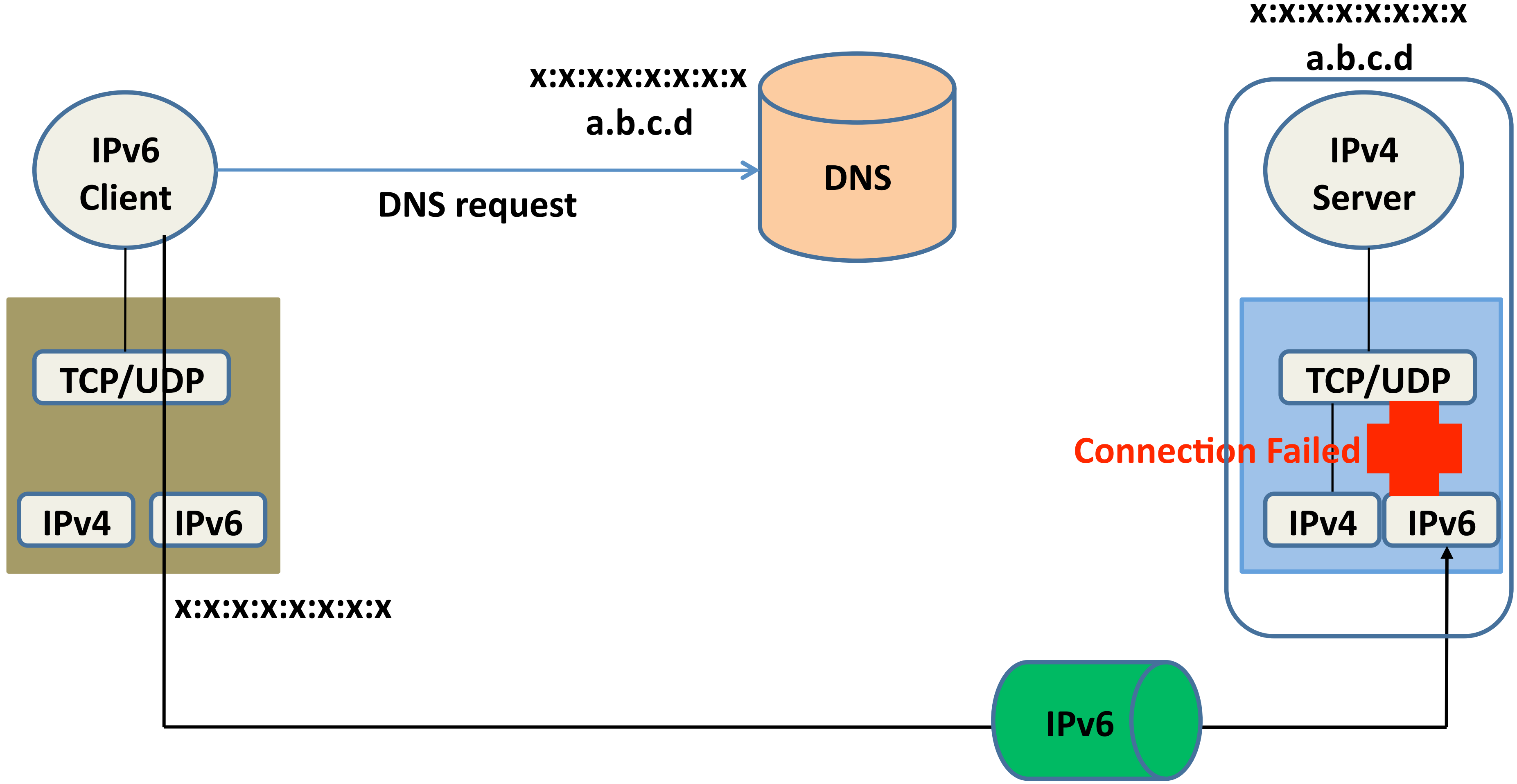


Impact of IPv6 stack on Applications

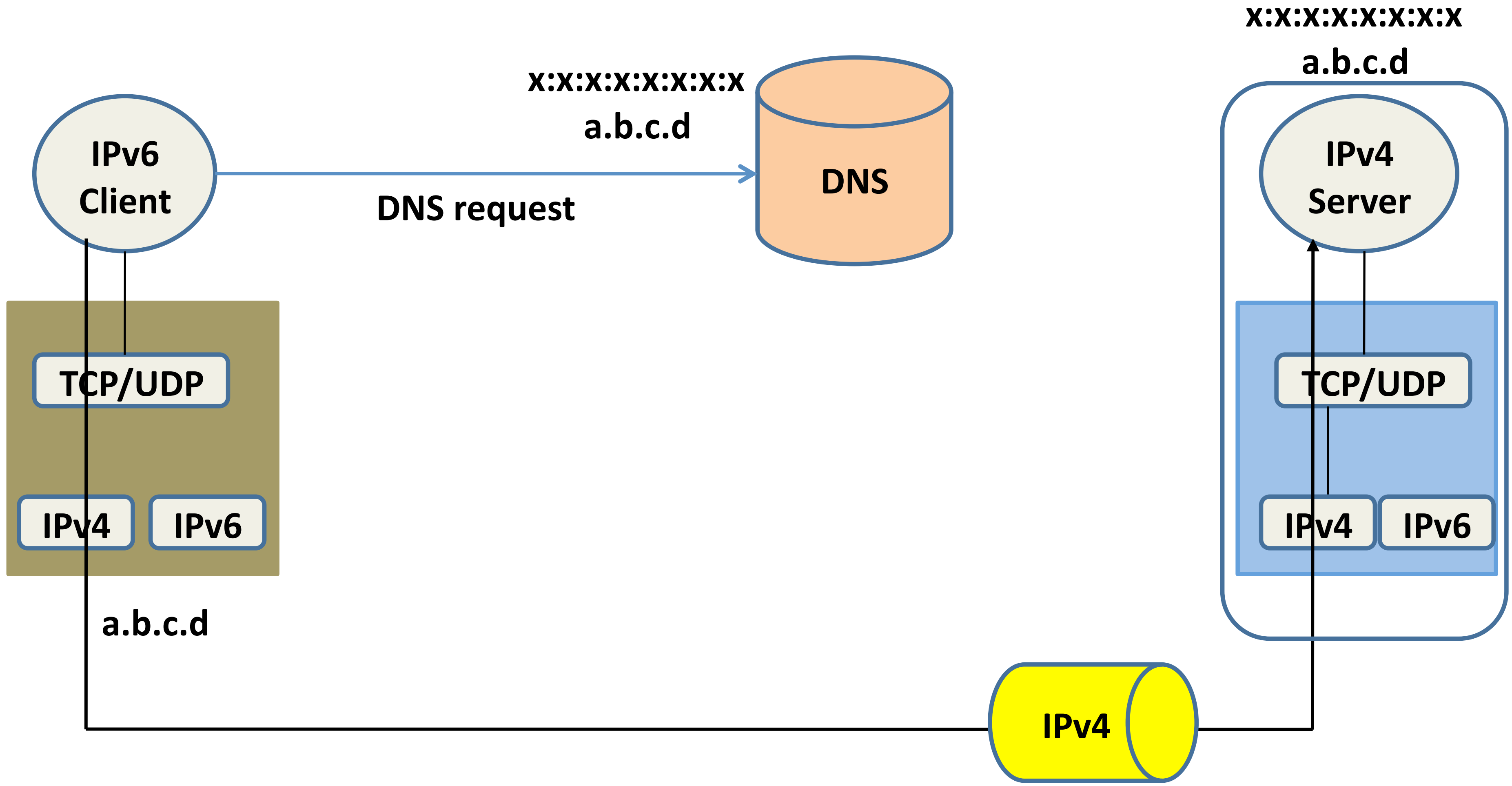
Applications should support dual stack:

- Applications in a dual stack host prever to use IPv6
- In IPv6, it is **normal** to have multiple addresses associated with an interface.
- A configurable default address selection algorithm decides which sender address use (if the application does not specify)
- Applications should try all addresses (both v4 and v6) they get from DNS if necessary

IPv6 enabled client connecting to an IPv4 server at dual stack node



IPv6 enabled client connecting to an IPv4 server at dual stack node



Migrating Code to IPv6

- A minimal example: TCP server and client
- Migration of the minimal example
- DNS, URLs and other migration concerns
- Hard problems
- Checking application IPv6 readiness

Example: minimal IPv4 TCP server

Functionality (as before):

- Listen to port 5002
- Write incoming TCP stream to disk
- Support multiple clients in parallel using `pthreads`

Use of `select` or `epoll` instead of `pthreads` to handle multiple clients never changes anything for IPv6.

Keeping it short...

- No declarations of variables unrelated to IPv4/6
- No error handling code
- Minor details ignored

$\Rightarrow$ Read man-pages to easily fill the gaps

Server Example: processing

```
static void * process (struct T * t) {
  int n;
  char buf[4092];

  int f = creat (filename, S_IRUSR | S_IWUSR);
  while ( (-1 != (n=read (t->a, buf, sizeof (buf))) &&
          (n != 0) )
    write (f, buf, n);
  close (f);
  close (t->a);
  return NULL;
}
```

IPv4 Server Example: accepting

```
struct sockaddr_in addr;
int s = socket (PF_INET,  SOCK_STREAM, 0);
memset (&addr, 0, sizeof (addr));
struct sockaddr * ia = (struct sockaddr*) &addr;
addr.sin_family = AF_INET; addr.sin_port = htons (5002);
bind (s, ia, sizeof (addr));
listen (s, 5);
while (1) {
  memset (&addr, 0, sizeof (addr));
  socklen_t alen = sizeof (struct sockaddr_in);
  t->a = accept (s, &addr, &alen);
  pthread_create (&pt, NULL, &process, t);         }
```

IPv6 Server Example: accepting

```
struct sockaddr_in6 addr;
int s = socket (PF_INET6, SOCK_STREAM, 0);
memset (&addr, 0, sizeof (addr));
struct sockaddr* ia = (struct sockaddr*) &addr;
addr.sin6_family=AF_INET6; addr.sin6_port= htons (5002);
bind (s, ia, sizeof (addr));
listen (s, 5);
while (1) {
  memset (&addr, 0, sizeof (addr));
  socklen_t alen = sizeof (struct sockaddr_in6);
  t->a = accept (s, &addr, &alen);
  pthread_create (&pt, NULL, &process, t);          }
```

Client Example: processing

```
static void process (int s) {
  char buf[4092];
  int f = open (FILENAME, O_RDONLY);
  while ( (-1 != (n = read (f, buf, sizeof (buf)))) &&
          (n != 0) ) {
    pos = 0;
    while (pos < n) {
      ssize_t got = write (s, &buf[pos], n - pos);
      if (got <= 0) goto END;
      pos += got;                                     } }
END:
  close (f);                                          }
```

IPv4 Client Example

```
struct sockaddr_in addr;
struct sockaddr *ia;

int s = socket (PF_INET,  SOCK_STREAM, 0);
memset (&addr, 0, sizeof (addr));
addr.sin_family = AF_INET;
addr.sin_port = htons (5002);
addr.sin_addr.s_addr = htonl (INADDR_LOOPBACK);
ia = (struct sockaddr *) &addr;
connect (s, ia, sizeof (addr));
process(s);
close (s);
```

IPv6 Client Example

```
struct sockaddr_in6 addr;
struct sockaddr *ia;

int s = socket (PF_INET6, SOCK_STREAM, 0);
memset (&addr, 0, sizeof (addr));
addr.sin6_family= AF_INET6;
addr.sin6_port= htons (5002);
addr.sin6_addr = in6addr_loopback;
ia = (struct sockaddr*) &addr;
connect (s, ia, sizeof (addr));
process(s);
close (s);
```

What are we missing?

What about...

- ... running on an OS that does not support IPv6?
- ... parsing user-specified addresses?
- ... IP-based access control?
- ... DNS resolution?
- ... URL support?

Levels of OS support

The OS could:

- Lack basic IPv6 definitions in the C libraries (i.e., no `PF_INET6` constant defined)
- Have support in the C libraries but lack kernel support (IPv6 operations fail)
- Have kernel support enabled but only use IPv4 addresses for networking (some IPv6 operations succeed)
- Use IPv4 and IPv6 for networking, possibly depending on the interface
- Only use IPv6

Handling lack of IPv6 OS support (1/2)

```
  int v6 = 0;
  int s = -1;
#if HAVE_INET6_DEFINES
  s = socket (PF_INET6, SOCK_STREAM, 0);
  if (s != -1)
    v6 = 1;
  else
#endif
    s = socket (PF_INET4, SOCK_STREAM, 0);
  memset (&addr, 0, sizeof (addr));
```

Handling lack of IPv6 OS support (2/2)

```
#if HAVE_INET6_DEFINES
  if (v6 == 1) {
    ia6.sin_family = AF_INET6;
    socklen = sizeof(struct sockaddr_in6);
    addr = (struct sockaddr_in*) &ia6;
  } else
#endif
  { ia4.sin_family = AF_INET;
    socklen = sizeof(struct sockaddr_in);
    addr = (struct sockaddr_in*) &ia4;
  }
  connect (s, &addr, socklen);
```

IP-based access control

- Bind socket to limited IP addresses
- Check that connection is from trusted network
- Check that IP matches certain DNS names

IPv4 Server Example: loopback only

```
struct sockaddr_in ia;
int s = socket (PF_INET,  SOCK_STREAM, 0);
memset (&ia, 0, sizeof (ia));
ia.sin_family = AF_INET;
ia.sin_addr.s_addr = htonl (INADDR_LOOPBACK);
ia.sin_port = htons (5002);
struct sockaddr *addr = (struct sockaddr *)&ia;
bind (s, addr, sizeof (ia));
// ...
```

IPv6 Server Example: loopback only

```
struct sockaddr_in6 ia;
int s = socket (PF_INET6, SOCK_STREAM, 0);
memset (&ia, 0, sizeof (ia));
ia.sin6_family= AF_INET6;
ia.sin6_addr = inaddr6_loopback;
ia.sin6_port= htons (5002);
struct sockaddr* addr = (struct sockaddr*)&ia;
bind (s, addr, sizeof (ia));
// ...
```

Parsing IPv4 addresses

```
int parse_v4(const char * in,
             struct in_addr * out) {
  int ret = inet_pton(AF_INET,  in, out);
  if (ret < 0)
    fprintf(stderr, "AF_INET not supported!\n");
  else if (ret == 0)
    fprintf(stderr, "Syntax error!\n");
  else
    return 0;
  return -1;
}
```

Parsing IPv6 addresses

```
int parse_v6(const char * in,
             struct in6_addr * out) {
  struct in_addr v4;
  int ret = inet_pton(AF_INET6, in, out);
  if (ret > 0) return 0;
  ret = inet_pton(AF_INET, in, &v4);
  if (ret < 0) return -1; /* error */
  memset(out, 0, sizeof(struct in6_addr));
  ((unsigned int *) out)[2] = htonl (0xffff);
  memcpy (&((char *) out)[sizeof (struct in6_addr) -
                        sizeof (struct in_addr)],
          &v4, sizeof (struct in_addr)); return 0; }
```

IPv4 network check

```
int
test_in_network_v4 (const struct in_addr * network,
                    const struct in_addr * mask,
                    const struct in_addr * addr) {
  return ( (addr->s_addr & mask.s_addr)
           == network.s_addr & mask.s_addr)
}
```

IPv6 network check

```
int test_in_network_v6 (const struct in6_addr * network,
                        const struct in6_addr * mask,
                        const struct in6_addr * addr) {
  unsigned int i;
  for (i=0; i<sizeof(struct in6_addr)/sizeof (int); i++)
    if ( ((((int *) ip     )[i] & ((int *) mask)[i])) !=
          (((int *) network)[i] & ((int *) mask)[i]))
      return 0;
  return 1;
}
```

Generic network check

```
int test (struct in_addr * n4, struct in_addr * m4,
          struct in6_addr* n6, struct in6_addr* m6,
          struct in6_addr * addr) {
  struct in_addr ip4;
  if (test_in_network_v6(n6, m6, addr)) return 1;
  memcpy (&ip4, &((char *) &ip6)
     [sizeof(struct in6_addr)-sizeof(struct in_addr)],
     sizeof (struct in_addr));
  if (IN6_IS_ADDR_V4MAPPED (&a6->sin6_addr))
    return test_in_network_v4(n4, m4, addr);
  return 0; }
```

IPv4 DNS request

```
int
resolve_v4 (const char * hostname,
            struct in_addr * addr) {
  struct hostent * he;
  struct sockaddr_in *addr;
  he = gethostbyname(hostname);
  assert (he->h_addrtype == AF_INET);
  assert (hp->h_length == sizeof (struct in_addr));
  memcpy (addr, hp->h_addr_list[0], hp->h_length);
  return OK;
}
```

`gethostbyname` issues

- Synchronous
- IPv4 only

⇒ `gethostbyname2`

`gethostbyname` issues

- Synchronous
- IPv4 only

⇒ `gethostbyname2`

- Not reentrant

⇒ both are obsolete!

DNS request with getaddrinfo

```
void resolve_v6 (const char * hostname) {
  struct addrinfo hints;
  struct addrinfo *result;
  memset (&hints, 0, sizeof (struct addrinfo));
  hints.ai_family = AF_INET6;
  getaddrinfo (hostname, NULL, &hints, &result);
  process_result (result);
  freeaddrinfo (result);
}
```

Processing DNS reply from getaddrinfo

```
void process_result (const struct addrinfo *pos) {
 for (;NULL != pos;pos = pos->ai_next) {
  switch (pos->ai_family) {
   case AF_INET : if (OK == tryv4
     ((struct sockaddr_in  *) pos->ai_addr)) return;
     break;
   case AF_INET6: if (OK == tryv6
     ((struct sockaddr_in6 *) pos->ai_addr)) return;
     break;
 }  }
 fail(); }
```

Generic Client Example

```
struct sockaddr * addr;
resolve(HOSTNAME, &addr, &alen, &af);
s = socket (af == AF_INET ? PF_INET : PF_INET6,
            SOCK_STREAM, 0);
if (af == AF_INET)
  ((struct sockaddr_in*)addr)->sin_port=htons (5002);
else
  ((struct sockaddr_in6*)addr)->sin6_port=htons (5002);
connect (s, addr, alen);
process(s);
free(addr); close (s);
```

URL support

- IPv4: `http://127.0.0.1:8080/`

URL support

- IPv4: `http://127.0.0.1:8080/`
- IPv6: `http://::1:8080/` – does not work!

URL support

- IPv4: `http://127.0.0.1:8080/`
- IPv6: `http://::1:8080/` – does not work!
- Solution: `http://[::1]:8080/`

Other considerations

- Use `getnameinfo` instead of `gethostbyaddr` for reverse lookup
- Check if your system uses IPv4 binary addresses embedded in network protocols
- You must specify the interface if you use IPv6 link local addresses (or do not use them!)
- Check IPv6 support in libraries (GNU ADNS does not support IPv6!)

IPv6 and Infrastructure

- IPv6 clients talking to IPv4-only server
- IPv4 clients talking to IPv6-only server
- Improved security / new IPv6 options:
  - Some new options require using raw sockets
  - Compatibility and migration nightmare
  - Applications already use SSL/IPsec

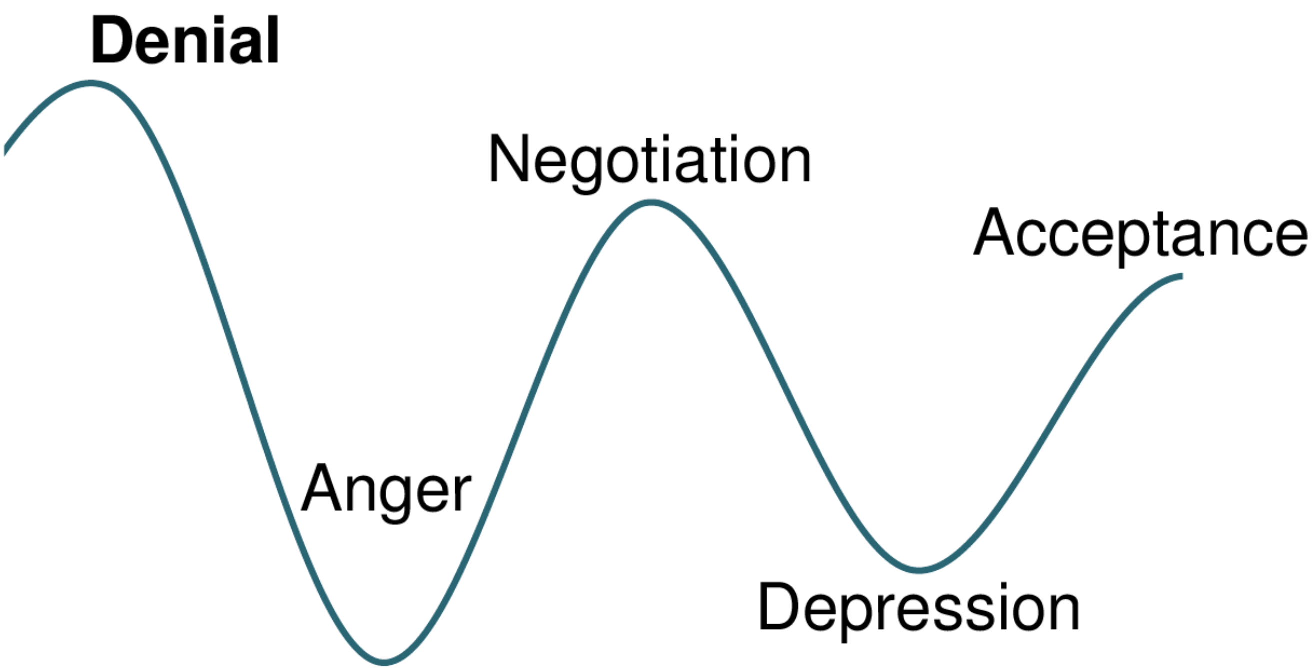
  $\Rightarrow$ Rarely supported (nicely) by OS

Are we done yet?

On a GNU/Linux system, run:

- `$ netstat -nl`

The Stages of Grief



"Misery motivates, not utopia." – Karl Marx

Questions

?

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