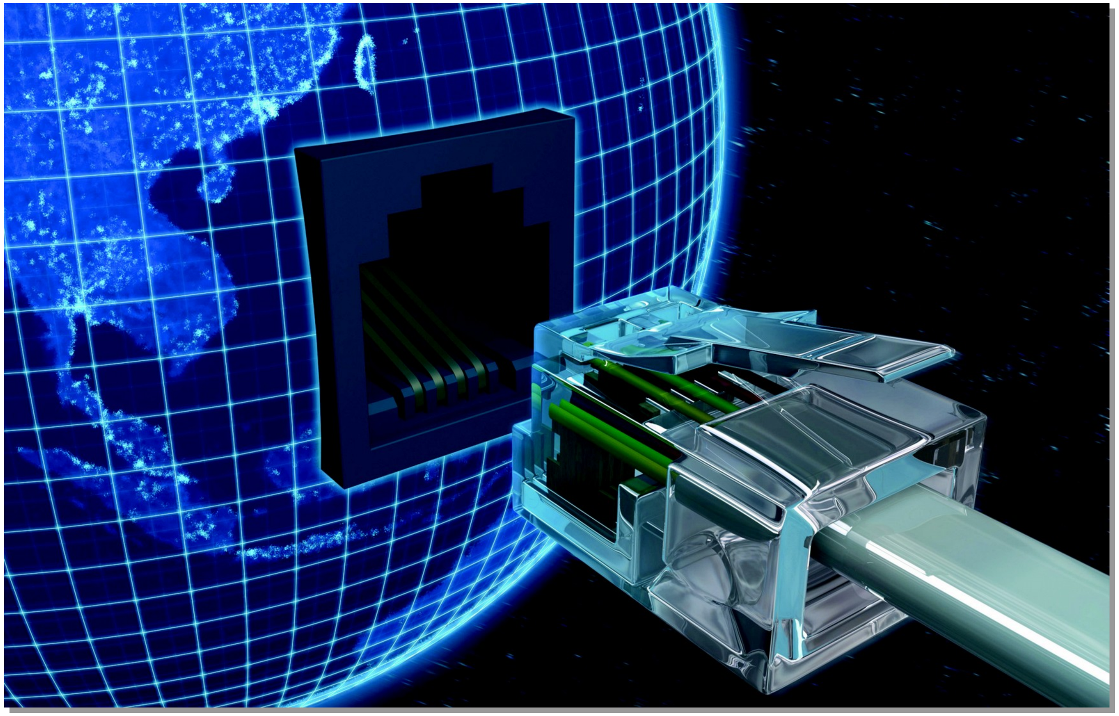
IPv6



Chapter 13

Success of IPv4

- IPv4 has worked amazingly well for over 30 years
  - Handled many different kinds of networks easily
  - Scaled up from a few networks to millions of networks
  - Accommodated new hardware and software technologies

Why Change from IPv4?

- **Main motivation is address space exhaustion**
  - IPv4 has about 4 billion addresses
  - However, inefficient use wastes a lot of them
  - Wireless devices are becoming big consumers of IP addresses
  - Billions of new users around the world
  - "Work arounds" like CIDR, NAT and DHCP have conserved IP addresses over the last few years.
  - However, we will soon run out of addresses. All CIDR blocks have been allocated

IPv6

- **Next IP is version 6**
- **Originally known as IP - The Next Generation (IPng)**
- **Version 5 was based on the OSI 7-layer model. It was skipped after a series of mistakes, misunderstandings, and a numbering mix-up**

IPv6

- **IPv6 retains many features of IPv4**
  - **Connectionless delivery**
  - **Variable size datagram**
  - **Concepts of most IPv4 options**

IPv6

- **Changes in IPv6**
  - Larger addresses (128 bits)
  - Fixed size base header for quicker processing
  - Variable length extension headers for fragmentation or for other options
  - More efficient routing
  - Better security and mobility

IPv6 Addresses

- 128 bits or 16 bytes long
- Supports 10^{38} addresses
- The number of addresses is about the same as the number of grains of sand on Earth
- Each of the 7 billion people on Earth can have 2^{88} addresses

IPv6 Addresses

- Expressing an IPv6 address as dotted decimal is possible, but addresses are too long for easy use

  1.2.3.4.5.6.7.8.9.10.11.12.13.14.15.16

- Instead, use colon hexadecimal notation for a more compact address

  0102:0304:0506:0708:090A:0B0C:0D0E:0F10

- 8 fields separated by colons
- Each field represents 16 binary bits (2 bytes)
- Hexadecimal digits (0 .. F)

Binary and Hex

hex	dec	bin
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111

hex	dec	bin
8	8	1000
9	9	1001
A	10	1010
B	11	1011
C	12	1100
D	13	1101
E	14	1110
F	15	1111
10	16	10000

Converting to Binary

- To convert colon hex to binary, convert each hex digit to 4 binary digits using the table on the previous slide.

- 0102:0304:0506:0708:090A:0B0C:0D0E:0F10

0000 0001 0000 0010 ….. 0000 1111 0001 0000

- Each binary address must be exactly 128 bits, so do not drop leading zeros.

Converting from Binary

- To convert binary to colon hex, convert each group of 4 binary digits to hexadecimal using the table on the previous slide

0000 0001 0000 0010 ….. 0010 1111 0001 0000

0102: … :2F10

Leading Zeros

- **Recall that in IPv4 dotted decimal notation, leading zeros in any field can be dropped**

- **051.103.000.006 same as 51.103.0.6**

(Note that the zero in the middle of the second field cannot be dropped. Note also that there must be 4 fields, so a field that is 000 is represented as 0.)

Leading Zeros

- Similarly, leading zeros in any colon hex field can be dropped
- 2001:0000:0000:3210:0800:200C:00CF:1234

  same as

  2001:0:0:3210:800:200C:CF:1234

(Note that the zeros in the middle or ends of fields cannot be dropped. Note also that there must be 8 fields, so a field that is 0000 is represented as 0.)

Zero Compression

- **String of repeated zeros can be replaced by ::**
- **Can only be applied once in an address**
- **Used to further reduce size of addresses and improve ease of use**
- **FF05:0:0:0:0:0:0:B3 can be compressed to FF05::B3**

Zero Compression

- **Show shortest form**
  - **2340:0:0:0:0:119A:A001:0**

    2340::119A:A001:0

  - **1:2:3:0:0:0:0:0**

    1:2:3:: OR 1:2:3::0

Zero Compression

- To return to the original form, replace :: with enough zeros so there are 8 colon hex fields

- Show original form of
  - 123::1:2

    123:0:0:0:0:0:1:2
  - CF90:3214::

    CF90:3214:0:0:0:0:0:0

Zero Compression

- Can only use :: once in an address
- If you use it twice, leads to ambiguous expansion - cannot tell how many zeros to replace each :: with
- FEDC::CF::BA98:1234 (INVALID!)

Is this FEDC:0:0:0:CF:0:BA98:1234

or FEDC:0:0:CF:0:0:BA98:1234

or FEDC:0:CF:0:0:0:BA98:1234 ?

IPv6 Addresses

- Two parts
  - Prefix identifies the network (similar to net id in IPv4)
  - Suffix identifies a particular computer on the network (similar to host id in IPv4)
- Split between prefix and suffix can be anywhere per the RFC, but all host addresses currently have 64 bits of network prefix and 64 bits of suffix

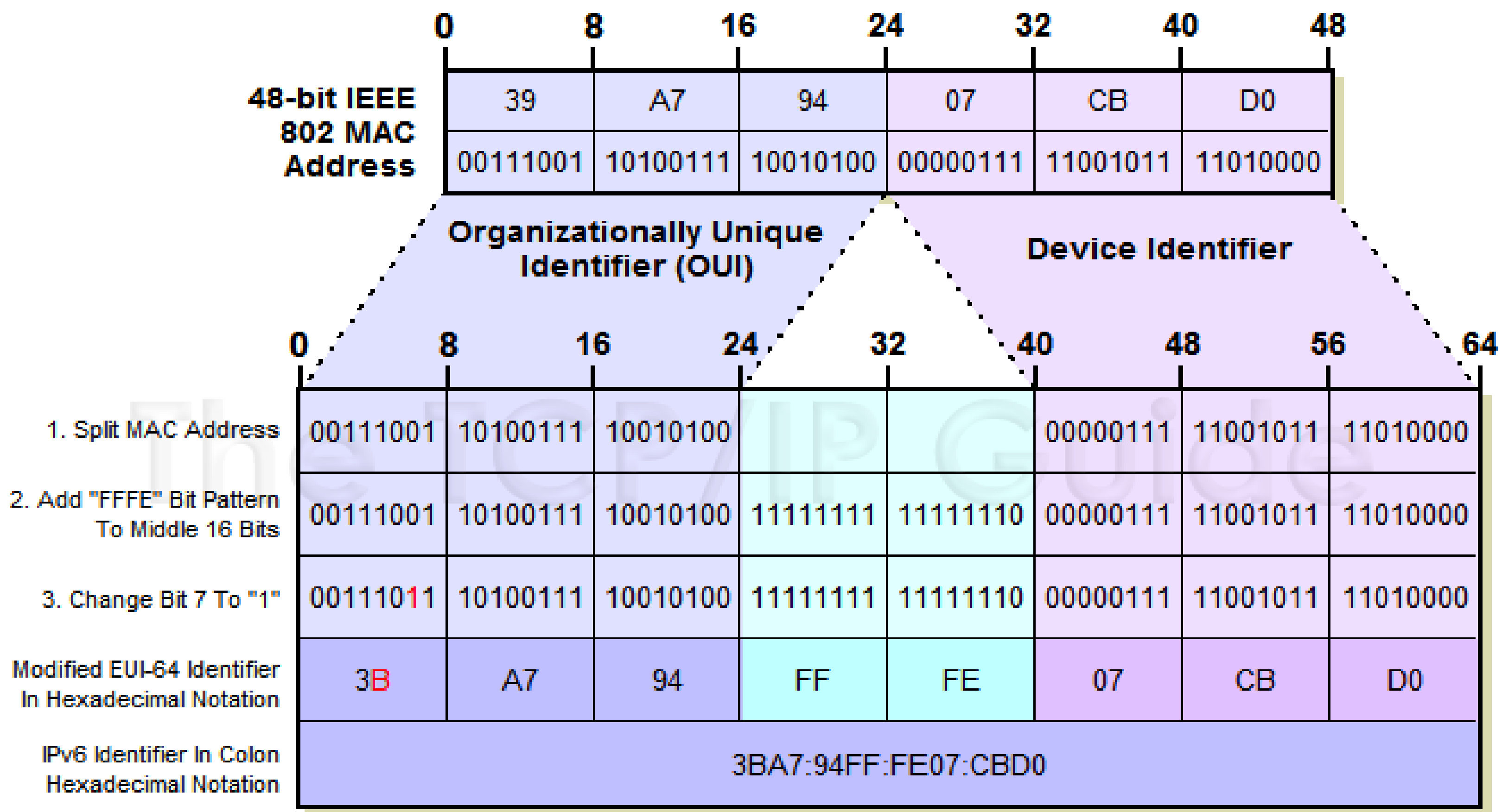
Suffix

- 64 bits of host ID can be assigned in several different ways
  - Auto configured from a MAC address to an EUI-64
  - Manually configured
  - Auto generated pseudo-random number (used in newer Windows)

EUI-64

- Extended Unique Identifier, 64 bit
- Created from the 48 bit MAC address

EUI-64



64-Bit IPv6 Modified EUI-64 Interface Identifier

EUI-64 Example

- **MAC address is 00-0C-29-53-45-CA**
- **Remove dashes and split in half**

  000C29 5345CA
- **Add FFEE in the middle**

  000C29FFFE5345CA
- **Flip bit 7 (makes the MAC address locally administered instead of globally unique)**

  Second hex digit = 0000, so change to 0010 (2 hex)
- **020C29FFFE5345CA**
- **Rewrite in standard form 020C:29FF:FE53:45CA**

Prefixes

- **Hosts can have several addresses, each with a different scope:**
  - **Node - Local - This host only**
  - **Link - Local - this network only**
  - **Global Unicast - Routed through the internet, one sender and one receiver**
  - **Multicast - one sender, many receivers**

Address Scope

- **Node-local scope**
  - **This host only**
  - **Loopback address 00:00:00:00:00:00:00:01 or ::1**

Address Scope

- **Link-local scope**
  - This network only
  - Every host has a link-local address
  - Similar to IPv4 local addresses, link-local addresses are not meant to be routed
  - Intended for local communication
  - Prefix is always FE80:0:0:0
  - Ex: FE80::020C:29FF:FE53:45CA

Global Scope

- **Global scope**
  - **Prefix assigned by ISP and distributed by router**
- **Multi-level hierarchy of addresses**
- **For example, in a global unicast address for a host:**
  - **First 48 bits of network prefix assigned by ISP**
  - **Last 16 bits of network prefix can be used for subnets**

Global Routing Prefix (48 bits)	Subnet ID (16 bits)	Suffix (64 bits)

IPv6 Address Types

- **Unicast - one source to one destination**
- **Anycast - one source to the one most reachable member of a group**
- **Multicast - one source to many destinations**
  - **Broadcast is treated as a special case of multicasting.**
  - **Support for multicasting is a required part of IPv6.**

Multi-Cast

- One source to many destinations
- Destination is a set of addresses
- Useful multicast prefixes
  - FF02::1 All nodes on a network
  - FF02::2 All routers on a network

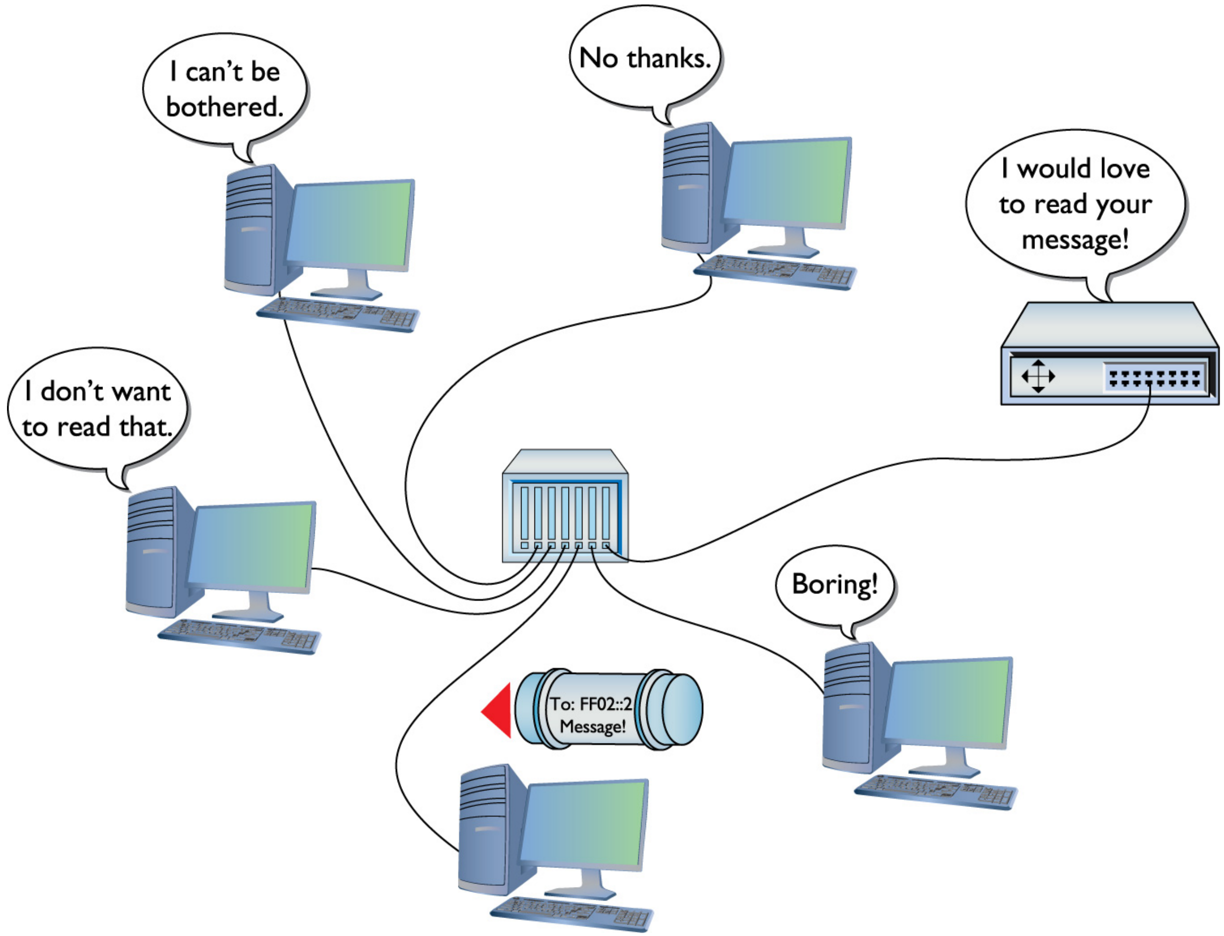


Figure 13.3 **Multicast to routers**

Anycast

- One source to most reachable member of a group
- "Most reachable" could be closest, fastest response, etc
- All members of an anycast group share a single unicast address
- Routers need to know which member is most reachable
- Example: there are 13 DNS (Domain Name Server) root servers around the world with duplicate information. Anycast will send the request to the closest root server.

CIDR-type Notation

- CIDR-type notation can also be used with IPv6 addresses
- IPv6 prefix is similar to the IPv4 netid
- /number identifies the length of the prefix
- Ex: 12AB::CD30:0:0:12/48

  prefix is 48 bits, so a mask of 48 consecutive ones will be used

Routing

- IPv6 makes routing easier
- Network ID assigned systematically
- Each router uses a subnet of it's parent router's IP address
- Reduces size and complexity of tables
- IPv6 makes it easier to change IP addresses

Getting a Global Address

- When a host boots, it sends out a router solicitation message to find its gateway router
- Router sends the global address prefix to the host
- Host combines this with its suffix (EUI-64 or random) to get global address

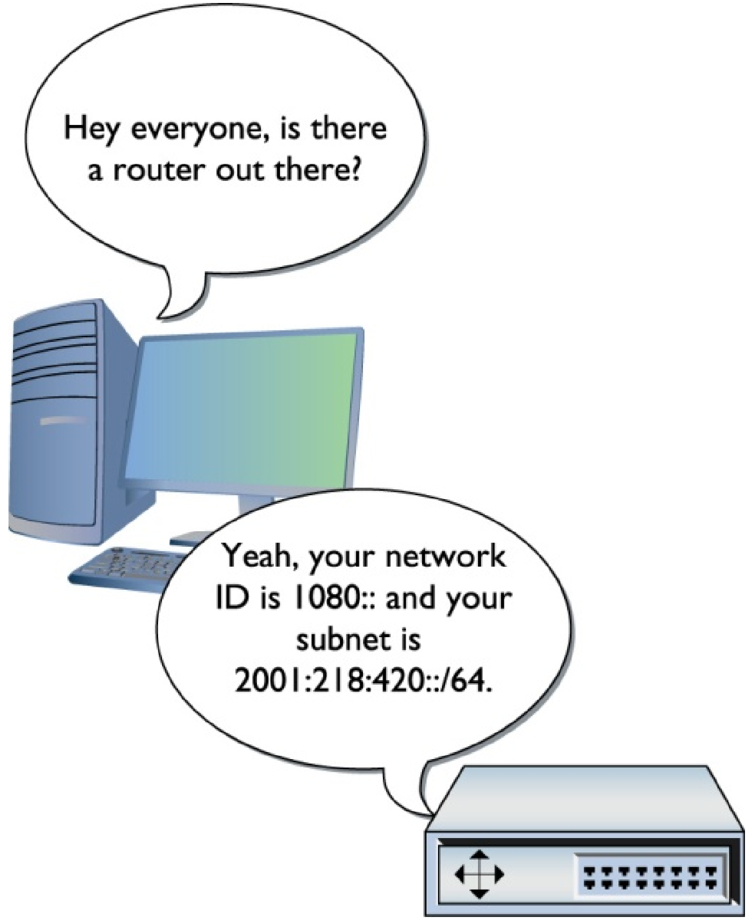


Figure 13.4 **Getting a global address**

Aggregation

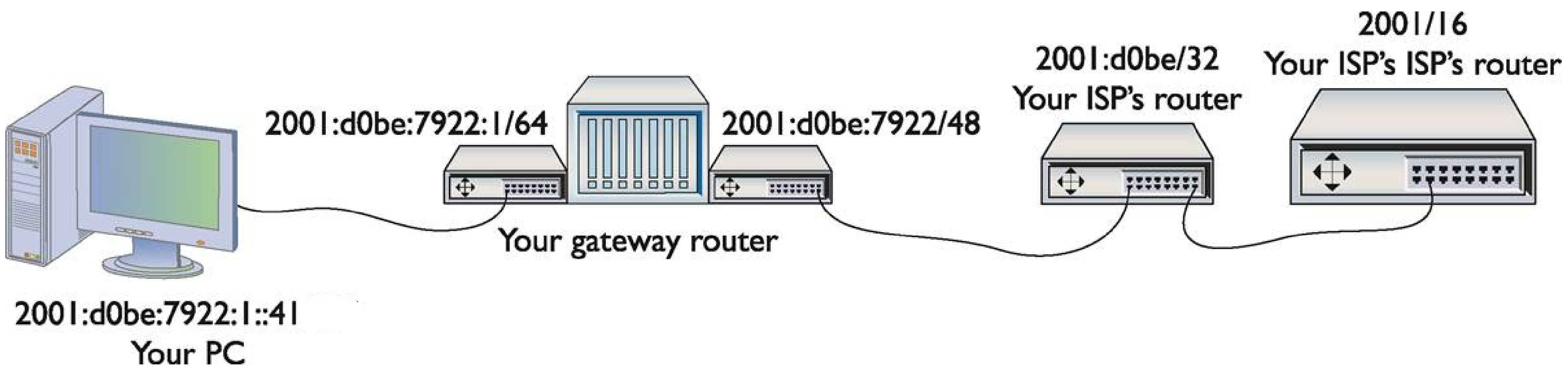
- Every router uses a subnet of the next higher router's routes
- Reduces size and complexity of tables
- Gives detailed geographic picture
- IP address shows location
- Too late to do this for IPv4, but part of IPv6

Aggregation Example

- **Address of a host is 2001:d0be:7922:1:fc2d:aeb2:99d2:e2b4**
  - **Network prefix is 2001:dObe:7922:1 /64**
  - **Host got prefix from gateway router**
- **Gateway router built its prefix from the upstream router's prefix plus a subnet id**
  - **Upstream router's prefix: 2001:d0be:7922/48**
  - **16 bit subnet id added at router**
  - **Network prefix is thus 2001:dObe:7922:1 /64**

Aggregation Example

- Upstream router built its prefix from it's parent router's prefix plus a subnet id
  - Parent router's prefix is 2001:D0BE /32
  - Parent routers prefix assigned by IANA
  - 16 bit subnet id added at router
  - Network prefix of parent router is thus 2001:dObe:7922/48



Aggregation in IPv6

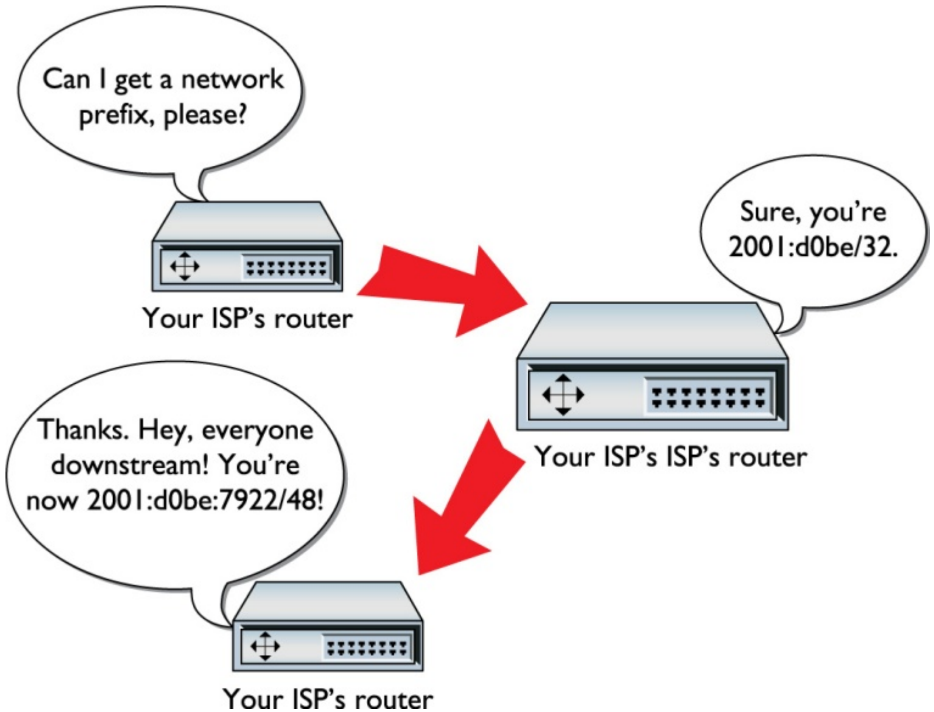


Figure 13.9 Adding the first prefix

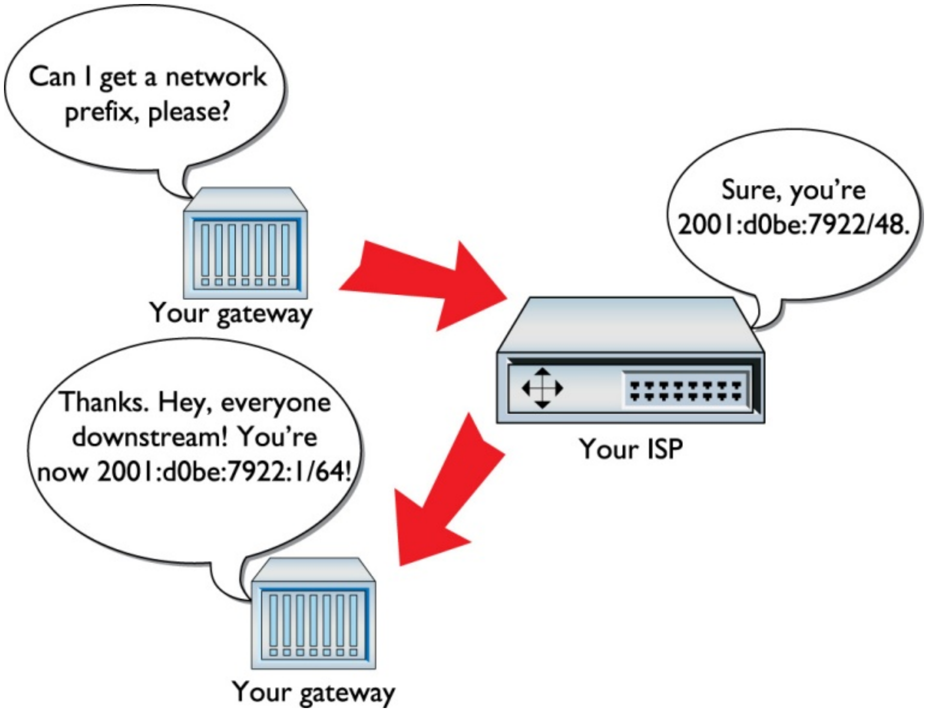


Figure 13.10 **Adding the second prefix**

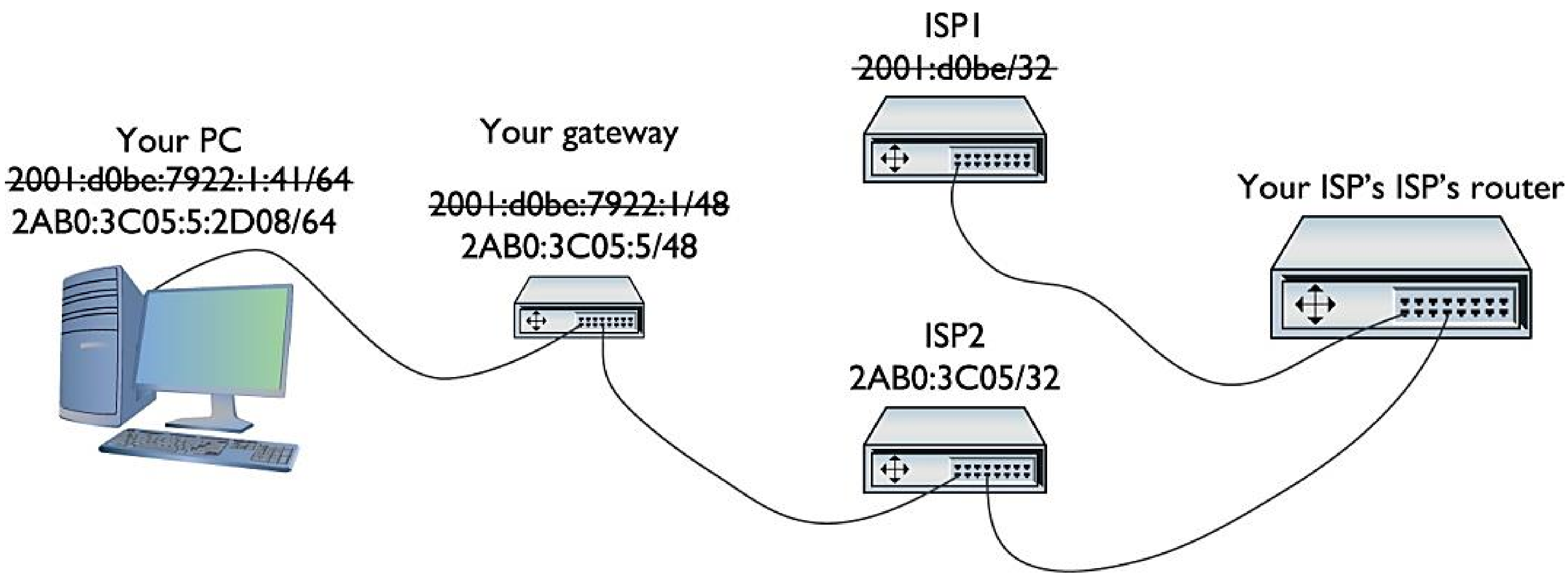
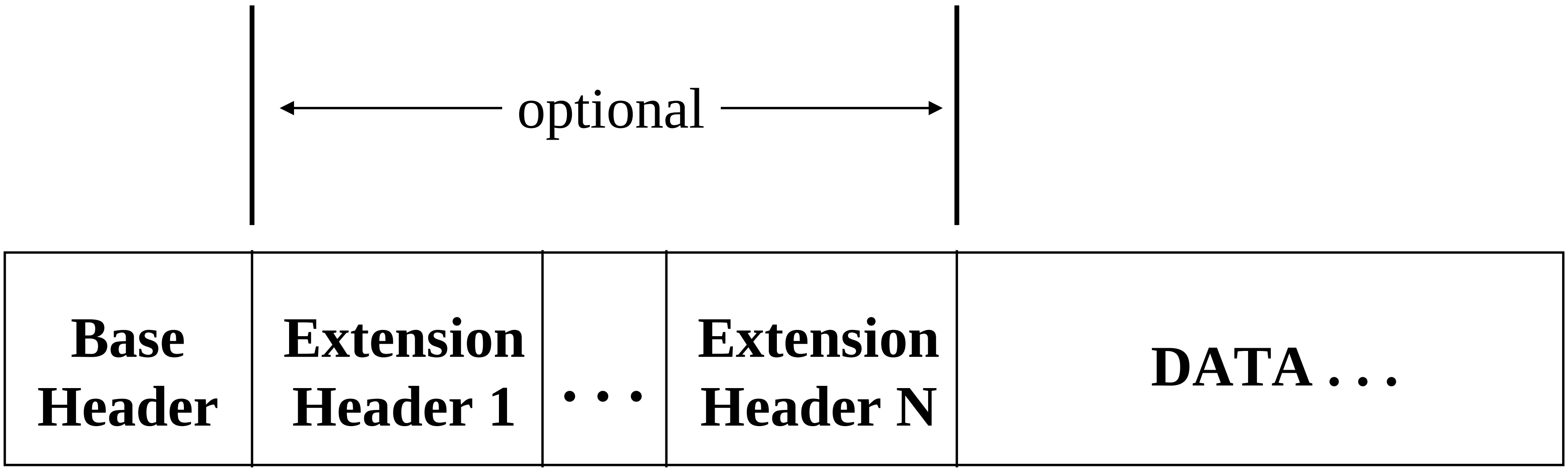


Figure 13.11 New IP address updated downstream

IPv6 Datagram



<table>
<tr><td>0</td><td>4</td><td>16</td><td>24</td><td>31</td></tr>
<tr><td>VERS</td><td colspan="2">TRAFFIC CLASS</td><td colspan="2">FLOW LABEL</td></tr>
<tr><td colspan="2">PAYLOAD LENGTH</td><td>NEXT HEADER</td><td colspan="2">HOP LIMIT</td></tr>
<tr><td colspan="5">SOURCE ADDRESS</td></tr>
<tr><td colspan="5">DESTINATION ADDRESS</td></tr>
</table>

IPv6 Base Header Fields

- **VERS - Version of the IP protocol used to create this datagram 6 for IPv6**
- **TRAFFIC CLASS - Same as IPv4 service class field - priorities, differentiated services**

IPv6 Base Header Fields

- **FLOW LABEL**
  - A flow is a path through the internet along which intermediate routers guarantee a specific quality of service
  - Flow label allows router to associate a particular datagram with a flow
  - Ex: A video transmission can use a high-bandwidth flow

IPv6 Base Header Fields

- **PAYLOAD LENGTH - Number of bytes in datagram excluding the base header**
- **NEXT HEADER - Type of information in the next section of the datagram**
- **HOP LIMIT - Similar to Time To Live in IPv4**
- **SOURCE and DESTINATION ADDRESSES - 128 bits each**

IPv6 Base Header Fields

- **Note there is no checksum as there is in IPv4**
- **Speeds up routing**
- **Must depend on the frame CRC in the data link layer and the header checksum at the transport layer (TCP or UDP) for error detection**

IPv6 Next Header

Base Header *Next = TCP*	TCP Segment

(a)

Base Header *Next = Route*	Route Header *Next = TCP*	TCP Segment

(b)

Base Header *Next = Route*	Route Header *Next = Auth*	Auth Header *Next = TCP*	TCP Segment

(c)

IPv6 Extension Headers

- **Hop-by-Hop Options - Options to be used only by routers**
- **Destination Options - Options to be used only by the final destination**
- **Routing - similar to Loose Source Routing Option in IPv4**
- **Fragment - Used for datagram fragmentation**
- **Encapsulated Security Payload and Authentication - both used for security**

Fragment Extension Header Format

0	8	16	29	31
NEXT HEADER	RESERVED	FRAGMENT OFFSET	RS	M
DATAGRAM IDENTIFICATION				

Fragment Extension Header Fields

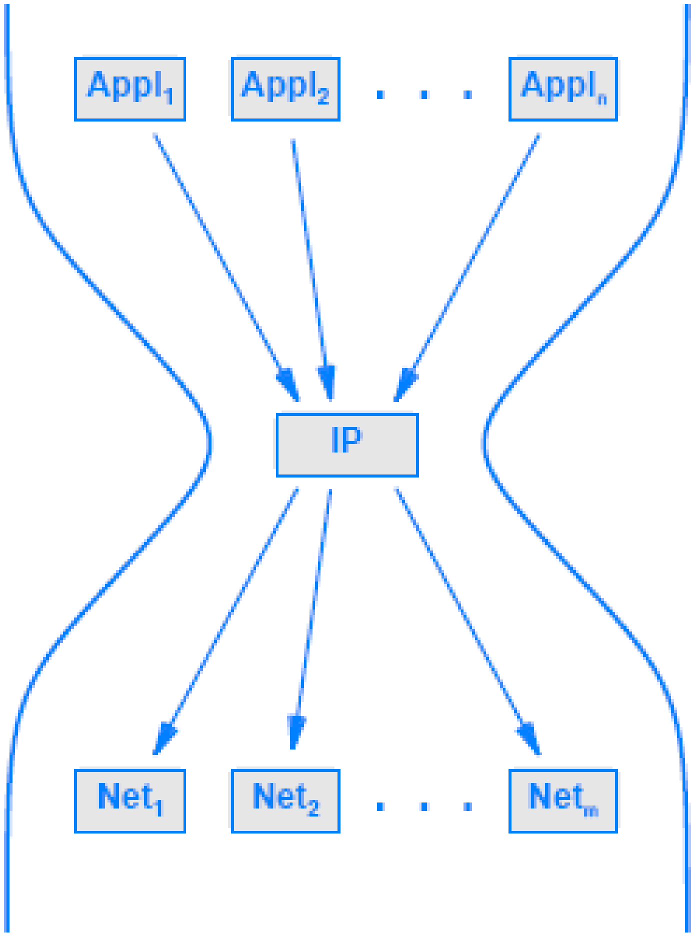
- **NEXT HEADER - Type of information in the next section of the datagram**
- **FRAGMENT OFFSET - Just as in IPv4. Number of bytes between the start of this fragment and the start of the datagram. In 8 byte units**
- **M - More fragments flag**
- **DATAGRAM IDENTIFICATION - Similar to IPv4. All fragments from the same datagram will have the same identification**

- **Enabling IPv6**
  - **All modern standard operating systems support IPv6**
  - **Check to see if IPv6 is running**
    - IPCONFIG in Windows
    - IFCONFIG in Linux or Mac OS X

Moving to IPv6

Change is Difficult

- IP is central to all Internet communication
- Changing IP requires a change to the entire Internet



- **IPv4 and IPv6**
  - **What is *not* ready for IPv6?**
    - Some home routers
    - Some Internet routers and servers
  - **What *is* ready for IPv6?**
    - All recent operating systems
    - All root DNS servers
    - All tier-one ISP routers
    - Many big sites, such as Google and Facebook

- For a while, IPv4 and IPv6 will co-exist.
- Use dual-stack devices to run both protocols simultaneously
- Use translation programs so that IPv4-only devices can communication with IPv6-only devices
- Use tunnels to send IPv6 packets through IPv6-ignorant routers

World IPv6 Day

- **June 8, 2011**
- **Many ISPs and web sites (Google and Facebook for example) switched to IPv6 for a 24 hour test**
- **Surprisingly successful - very few problems**

World IPv6 Launch

- **June 6, 2012**
- **Global permanent deployment of IPv6**
  - Participating major websites (Google, Facebook, etc) permanently enabled IPv6
  - Participating ISPs offer IPv6 connectivity
  - Router manufacturers offering routers enabled for IPv6 by default
- **As of this date, about 3% of internet traffic is IPv6**
  - 51% of Google Fiber traffic is IPv6 and 39% of Verizon Wireless traffic is IPv6
  - About 20% of traffic to Google is IPv6

- IPv6 is here, really!
  - IPv6 is happening now
  - IPv4 addresses are running out
  - Knowing IPv6 important to your future