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COMP 225 Network and System Administration

Notes #7: IP Addressing

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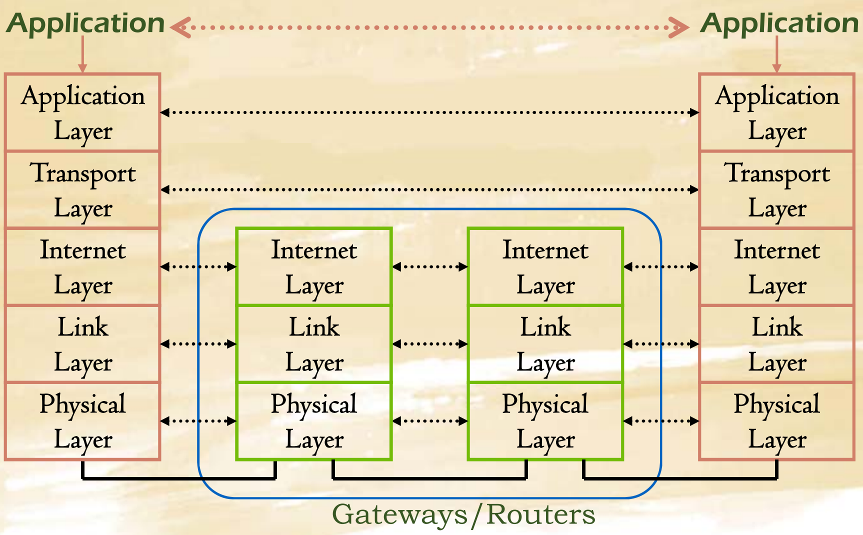
To Cover

- Internet Protocol (IP) naming and addressing
- Format and basic operations
- Address resolution
- IP packet control

Internet Model

- The traditionally five-layer model for the Internet



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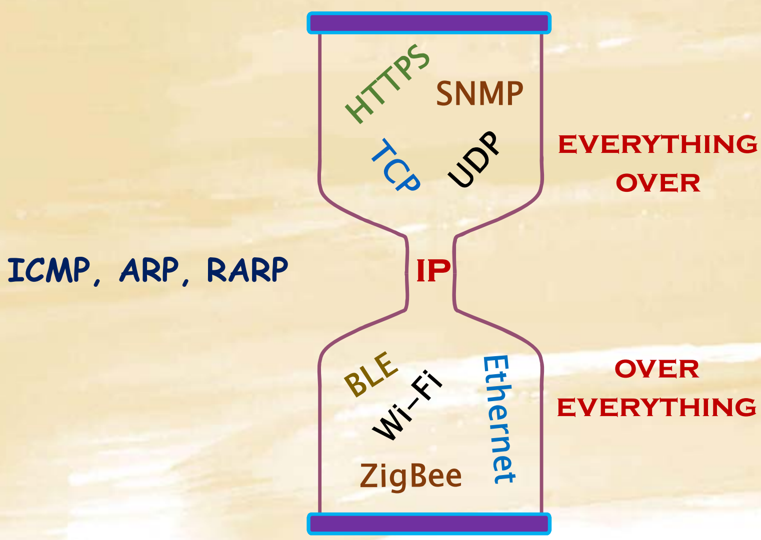
TCP/IP Protocol Suite

- The layered architecture is like an hourglass model



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The Internet Layer

- Basic functions:
  - Addressing
  - Routing with sub-networks resolution and forwarding!!
- Traditionally
  - Connectionless
  - Serving best effort traffic: unreliable and no performance guarantees
- Today, in addition to best effect traffic
  - Traffic type classification
  - QoS routing

Typical Structure of a Frame

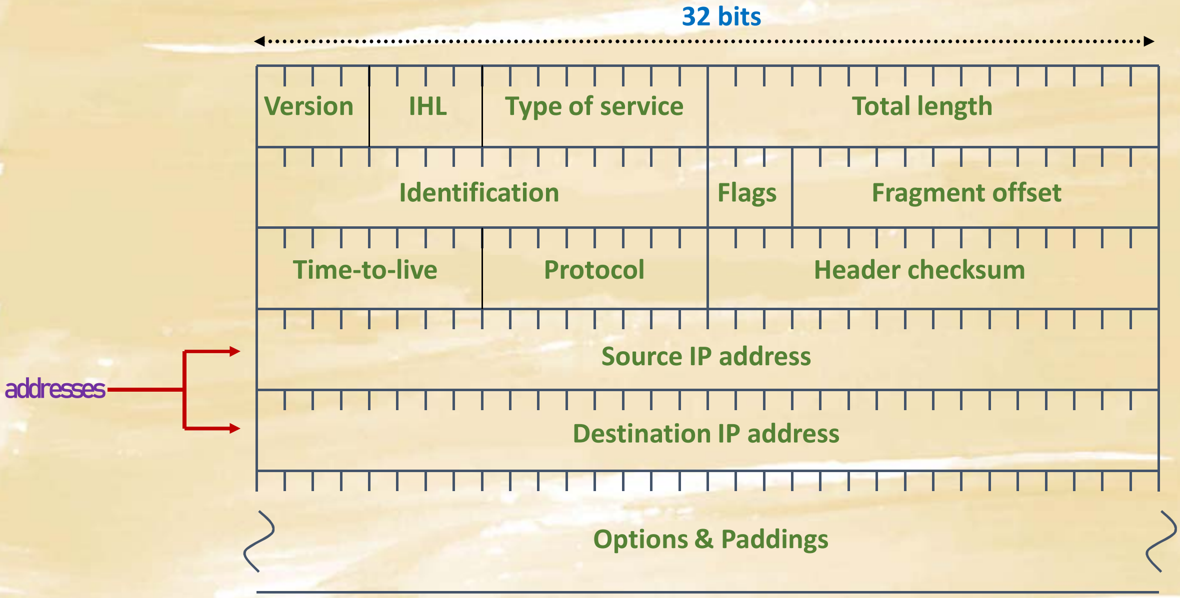
frame header (Link)	*Packet* (IP) header (Internet)	*Segment* (TCP), *Datagram* (UDP) header (Transport)	*Message* (e.g. email) header (Application)	User content	trailer (Link)

Contains Ether Type

Contains addresses & protocol ID

Contains port numbers

IPv4 Header Format



IP Addresses

- An network ID reveals the location of an entity on the Internet, and routers know how to route a packet there
- Should be unique to identify each end host
- For host-to-host connections:
  - 32-bit IPv4 addresses:
    4,294,967,296 or 2^{32} (about 4 trillion) # of addresses
  - 128-bit IPv6 addresses:
    340,282,366,920,938,463,463,374,607,431,768,211,456 or 2^{128} (about 340 undecillion) # of addresses

IP Address Assignment

- The Internet Assigned Number Authority (IANA)
  - Assigns IPv4 addresses to the five Regional Internet Registries (RIRs) in /8 address blocks; IANA is also responsible for allocating IPv6 address space to RIRs
- Five RIRs are
  - African Network Information Centre (AFRINIC): Africa
  - American Registry for Internet Numbers (ARIN): United States, Canada, some parts of the Caribbean region, and Antarctica
  - Asia-Pacific Network Information Centre (APNIC): Asia, Australia, New Zealand, and neighboring countries
  - Latin America and Caribbean Network Information Centre (LACNIC): Central America, South America, and most of the Caribbean region
  - Réseaux IP Européens (RIPE) Network Coordination Centre: Europe, the Middle East, and Central Asia

IPv4

- Starting from IPv4 – since early 1980s
- Latest version: IETF RFC 791, Sept. 1981
- 32-bit address space represented in dotted-decimal notation
- Dotted decimal notation: *x.y.z.n*
  - where *x*, *y*, *z*, *n* ∈ {0,..,255}
  - e.g. 128.100.10.2

$$\underbrace{\texttt{0000 1010}}_{\text{first octet}}\ \underbrace{\texttt{0000 0001}}_{\text{second octet}}\ \underbrace{\texttt{0000 0001}}_{\text{third octet}}\ \underbrace{\texttt{0000 0001}}_{\text{fourth octet}}$$

$$\texttt{10 . 1 . 1 . 1}$$

Address Classes (IPv4)

- Initially and historically, IPv4 address was classified into two parts
  - Network address and host address
- There were 5 classes, and only unicast classes *A* to *C* are mostly used

	1st octet	2nd octet	3rd octet	4th octet
Class A	0 | network	host address		
Class B	1 | 0 | network address		host address	
Class C	1 | 1 | 0 | network address			host
Class D	1 | 1 | 1 | 0 | multicast address			
Class E	1 | 1 | 1 | 1 | reserved for experiments			

Multicast:
1 sender multiple recipients

How to Identify the Network Address?

- Define the network mask (netmask)
  - Also 32-bit in size, only use 1's or 0's
  - Network address = incoming IP address & netmask

Bit-wise AND

					In dotted-decimal notation
Given an IPv4 address:	0000 1010	0000 0001	0000 0001	0000 0001	10.1.1.1
Corresponding netmask:	1111 1111	0000 0000	0000 0000	0000 0000	255.0.0.0
&	0000 1010	0000 0000	0000 0000	0000 0000	
	10 .	0 .	0 .	0	

- Result: 10.0.0.0 – class A address

Old Way to Determine Netmask

- The initial few bits of the first octet of the incoming IP packet determines both the network address and netmask

Class		Size of Network Address	Netmask
A	**1st bit = 0**	8-bit	255.0.0.0
B	**1st two bits = 10**	16-bit	255.255.0.0
C	**1st three bits = 110**	24-bit	255.255.255.0

- The first octet of class A address is from 0000 0000 to 0111 1111
- If in decimal numbers, from 0 to 127

Then

- Class A (**0**.x.x.x to **127**.x.x.x) 24-bit, 2^{24} = 16,777,126
  - Network mask **255.0.0.0** (the leftmost 8 bits are network address)
  - 16,777,124 hosts for each class A network
- Class B (**128**.x.x.x to **191**.x.x.x)
  - Network mask **255.255.0.0** 2 fewer hosts, why? Explain later...
  - 65,534 hosts for each class B network
- Class C (**192**.x.x.x to **223**.x.x.x)
  - Network mask **255.255.255.0**
  - 254 hosts for each class C network
- Remarks: class D (**224**.x.x.x to **239**.x.x.x) for multicast; class E not used… :_(

Problems with Classful Designs

- Difficult to find one organization which needs a class A address (more than 16 million hosts)
- Even for one class B network address, how often we can find a company using up to 60,000 host computers
- Problems:

  $\Rightarrow$ Inflexible for different network sizes

  $\Rightarrow$ ***Concept of subnets*** created for handling smaller network sizes
- Moreover, IP address exhausted rapidly if giving out one class A network address easily

In fact, all IPv4 addresses exhausted in 2011

Subnetting – Resizing a Network

- Example: If a service provider has a class B network to give, e.g., 136.28.0.0 with netmask 255.255.0.0. Then a company *X* requests only 8 IP host addresses, then what can service provider do?
- Normally, 3 bits are enough for 8 addresses, but IPv4 addressing has two special address designs
  - One for naming the "network address" 2 fewer hosts, why? Explain later...
  - One for broadcast address in the network
- E.g., gives out 136.28.1.0 with **subnet mask 255.255.255.240**, this is a class B address but the network size is smaller than a class C address

Subnetting (cont'd)

- Netmask no longer based on class A, B or C
  - E.g., 255.255.255.240 ≡ 1111 1111 . 1111 1111 . 1111 1111 . 1111 0000, there are 28 one's
- A simpler notation is

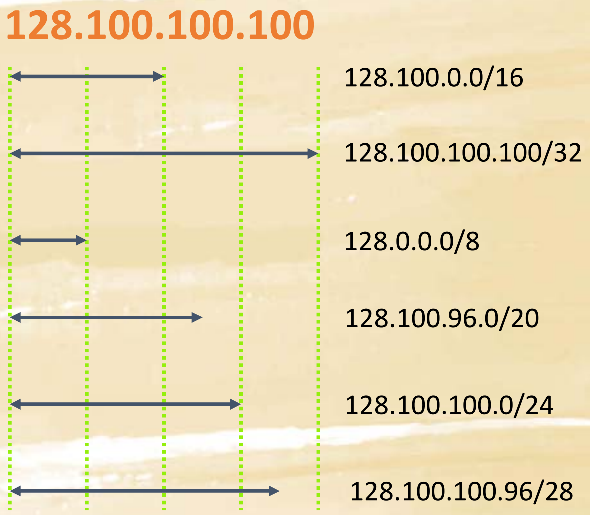
  network address / size of netmask ← CIDR (Classless Inter-Domain Routing) VLSM (Variable Length Subnet Mask)
- Hence, the last example is 136.28.1.0/28

2 Fewer Host Addresses

- For the last example, this network address is 136.28.1.0/28
  - There are 4 bits for assigning host address, ***but***
  - The 136.28.1.0 is the **network name** (the network address) – should not be assigned to any host
  - For broadcasting, all bits for host address are set to 1's, i.e., 136.28.1.15 is the **broadcast address** – cannot be assigned to any host
- Therefore, given *n* bits for host addresses, we have $(2^n - 2)$ for host address assignments
  - If *n* = 8, we have 254 host addresses

Summary on IPv4 Addressing

- Natural class B network mask 255.255.0.0
- Host address mask 255.255.255.255
- Supernetted range of Class B's mask 255.0.0.0
- Class B with 4 bits subnetting mask 255.255.240.0
- Class B with 8 bits subnetting mask 255.255.255.0
- Class B with 12 bits subnetting mask 255.255.255.240



Reserved Private IPv4 Addresses

- Reserved private addresses are critical in extending life of IPv4
- **10**.x.x.x ⇒ private class A networks
- **172.16**.x.x to **176.31**.x.x ⇒ private class B networks
- **192.168**.x.x ⇒ private class C networks

How to Extend the Life of IPv4?

- NAT – network address translation for private addresses
  - Private IP addresses can be used for those local networks setting behind a firewall or NAT (Network Address Translation) device
  - Of course, any networks not connected to the Internet can use any IPv4 addresses
- Use no classes, e.g., CIDR (classless inter-domain routing)
- ***Variable Length Submit Mask*** (VLSM)
  - Notation: ***x.y.z.n/m***
  - Network address: *x.y.z.n*
  - Length of netmask: *m*

Special Addresses

- **0.0.0.0**

⇒ Unknown local host address, this network host

⇒ This **consumes one Class A network address**, sorry :_(

- **255.255.255.255**

⇒ Local LAN broadcast address, **cannot cross routers**; Class E, erh??

- **127.0.0.1** ⇒ local host loopback

⇒ This **consumes another Class A network address** too, sorry :_(
  - Never leaves local computer
  - Other 127.x.x.x addresses are rarely used, but Linux (Ubuntu) sets 127.0.1.1, and many container technology makes uses of these unused addresses

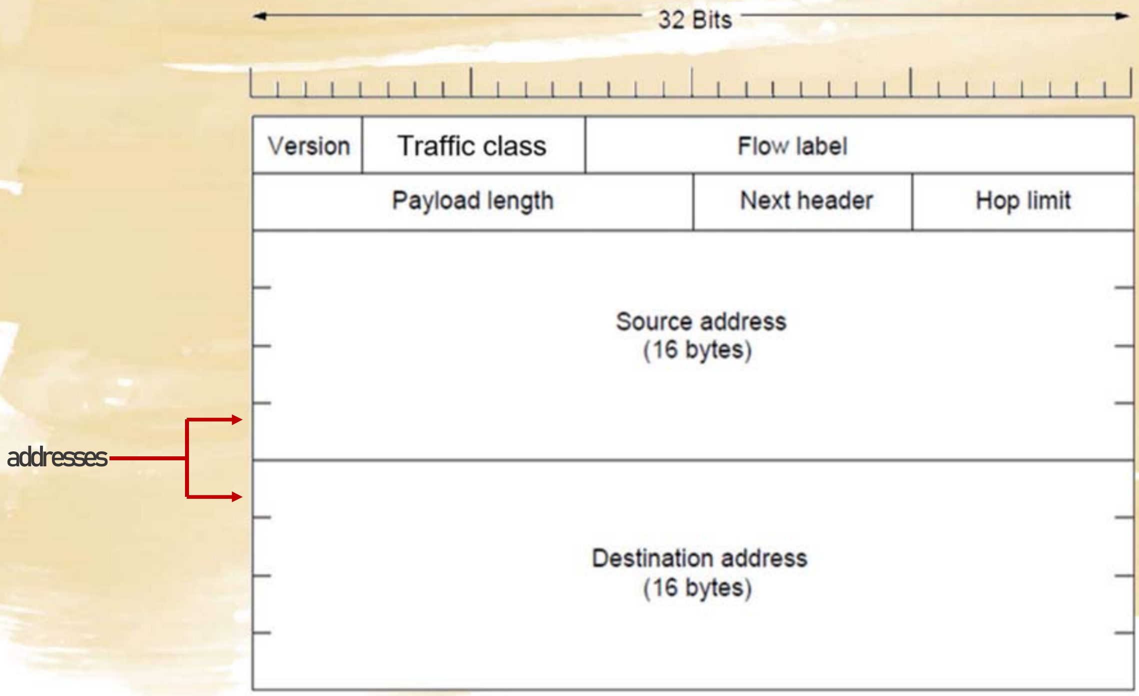
IPv6 Arriving…

- All IPv4 was exhausted around 2011
- But “short-term” solutions to IPv4 address exhaustion: CIDR and NAT with private IPv4 addresses
  - CIDR (Classless Inter-Domain Routing)
  - NAT (Network Address Translation)
  - Private addresses
- Long-term solution: IPv6

IPv6

- Developed mid to late 1990s
- S. Deering, R. Hinden, Internet Protocol, Version 6 (IPv6) Specification, IETF RFC 2460, Dec. 1998
- 128-bit address space, gives 340 undecillion addresses (undecillion = 10^{36})
  - About 10 nonillion per person! (nonillion = 10^{30})
  - 655,570,793,348,866,943,898,599 addresses per square meter of the Earth’s surface
- Representation in colon-hexadecimal numbers
  - No dotted-decimal anymore

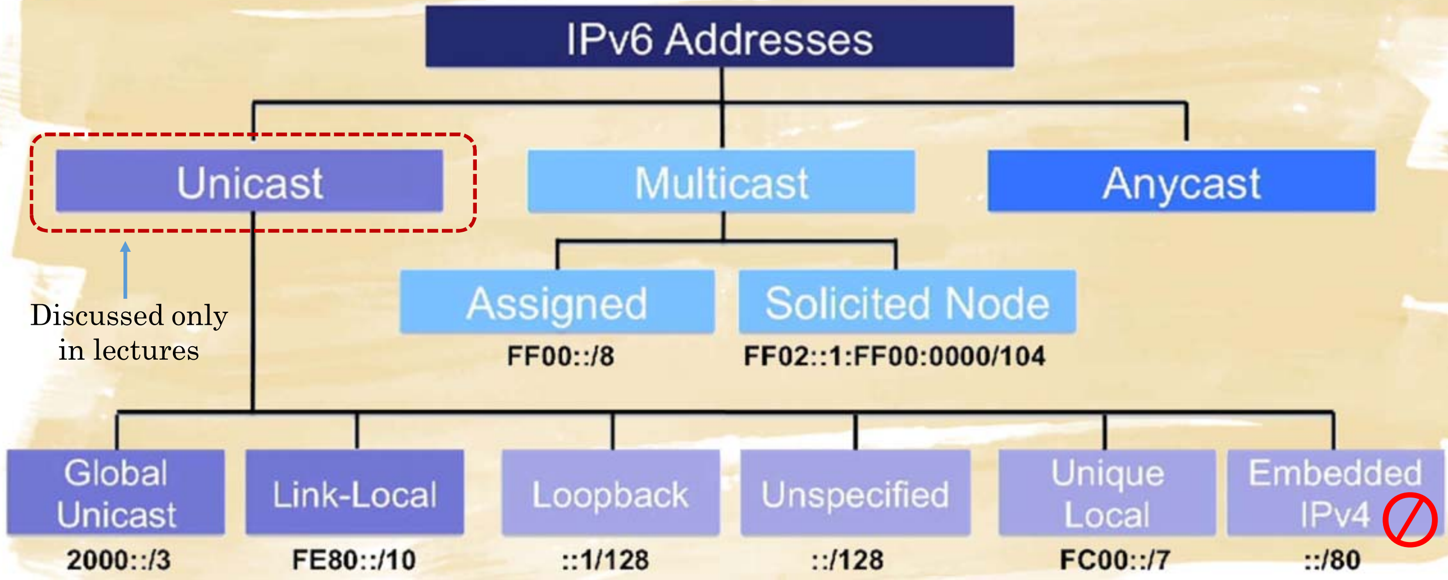
IPv6 Header



Features of IPv6 More than Addresses

- Larger address space
- Stateless address autoconfiguration
- End-to-end reachability without using private addresses and NAT
- Better mobility support
- Peer-to-peer networking easier to create and maintain, and services such as VoIP and Quality of Service (QoS) become more robust
- Fixed sized IPv6 header, no fragmentation IPv6 packets

Types of IPv6 Addresses



Hexadecimal Numbers

- Base-16
- 16 digits - {0, 1, 2, …, 8, 9, A, B, C, D, E, F}
- One hex number represents a 4-bit number

Dec	Hex	Binary	Dec	Hex	Binary
0	0	0000	8	8	1000
1	1	0001	9	9	1001
2	2	0010	10	A	1010
3	3	0011	11	B	1011
4	4	0100	12	C	1100
5	5	0101	13	D	1101
6	6	0110	14	E	1110
7	7	0111	15	F	1111

IPv6 Address Notation

- Each hex represents 4 bits (0000 to 1111 in binary)
- 128 bits = 32 × 4 bits, i.e., 32 concatenated 4-bit units
- This 4-bit unit sometime is called nibble
- Separate each 16 bits (4 units of 4 bits, i.e., 4 hex numbers) by colon except the beginning and ending colons
- Example

$$\underbrace{\texttt{FEDC}}_{\text{16-bit}} : \underbrace{\texttt{BA98}}_{\text{16-bit}} : \underbrace{\texttt{7654}}_{\text{16-bit}} : \underbrace{\texttt{3210}}_{\text{16-bit}} : \underbrace{\texttt{0123}}_{\text{16-bit}} : \underbrace{\texttt{4567}}_{\text{16-bit}} : \underbrace{\texttt{89AB}}_{\text{16-bit}} : \underbrace{\texttt{CDEF}}_{\text{16-bit}}$$

Two Rules Compressing IPv6 Addresses

- **Rule 1**: omitting leading 0s (no trailing 0 to avoid ambiguity)

$$\overset{\text{trailing zero}}{\texttt{FED0}} : \underbrace{\texttt{0008}}_{\text{leading zeroes}} : \overbrace{\texttt{0000}}^{\text{leading zeroes}} : \underbrace{\texttt{0000}}_{\text{leading zeroes}} : \overset{\text{leading zero}}{\texttt{0123}} : \underbrace{\texttt{0000}}_{\text{leading zeroes}} : \overbrace{\texttt{0000}}^{\text{leading zeroes}} : \texttt{CDEF}$$

- After rule 1, we have `FED0 : 8 : 0 : 0 : 123 : 0 : 0 : CDEF`

2 Rules on IPv6 Addresses (cont'd)

- **Rule 2**: double colons (::) replacing any single, contiguous string one or more 16-bit segments consisting of all zeroes
- On rule 2:
  - Double colons can be applied ***only once*** for an address
  - (RFC 5952) If more than one such string, then only the longest string of zeroes must be replaced
  - (RFC 5952) If two strings of identical lengths, then the first string of 0's should use the :: representation

2 Rules on IPv6 Addresses (cont'd)

- Combining both rules

1: leading zeroes

2: collapsing segments of all zeroes with ::

1: leading zeroes

1: leading zeroes

1: leading zeroes

0EDD : 0000 : 0000 : 0000 : 0123 : 0004 : 0008 : CDEF

- Result: **EDD :: 123 : 4 : 8 : CDEF**

2 Rules on IPv6 Addresses (cont'd)

- If more then one segment that has the longest number of segments of zeroes and they are equal in lengths…
- From RFC 5952, always the first one selected
- Given

  FED0 : 0008 : 0000 : 0000 : 0123 : 0000 : 0000 : CDEF

- We have the final representation

  FED0:8::123::CDEF

  FED0:8:0:0:123::CDEF

  FED0:8::123:0:0:CDEF ✓

Subnet Mask

- Prefix and prefix length are used in IPv6
- All zeroes and all ones interface ID can be used in IPv6
- That is, there are prefix lengths for setting network addresses
- Prefix examples
  - 2001:DB8:1::/48
  - 2001:DB8:CAFE:1234::/62
- IPv6 device address examples
  - 2001:DB8:CAFE::99:2/48
  - 2001:DB8:CAFE:1::100/64

IP Addressing

- IPv6 source
  - Always a unicast address (GUA or link-local)
- IPv6 destination
  - Unicast, multicast, or anycast address
  - IPv6 has no broadcast addresses

Unicast Addresses Assignments

- Global Unicast Address (GUA)
  - Host address identification on the Internet
  - Globally unique and routable (similar to public IPv4 addresses)
  - Address from 2000::/3 (usually showing at least the first hextet)
    - Check in binary, the initial 3-bit setting is always 001….
  - 2000::/3 (fyi, from IETF, usually /48 assigned for Global Routing Prefix)
  - 2001:DB8::/32 (RFC 2839 / RFC 6890) addresses reserved for documentation
  - An interface may get more than one IPv6 address
  - Keeping the terminologies from IPv4: “prefix,” “prefix length,” “interface ID”
- That’s it, but in fact, there are more on address allocation issues…

Unicast Addresses Assignments (cont'd)

- Link-local Unicast
  - Unique only on the link (the Link layer – local area network, subnet, etc.)
  - Not routable off the link
  - From FE80::/10 to FEBF::/10
  - Created through MAC addresses or randomly generated numbers
  - An IPv6 device must have at least one link-local address -
    - A host communicates to the IPv6 network before obtaining its GUA
    - Router's link-local address is used by hosts as the default gateway address
    - Adjacent routers to exchange routing updates

Unicast Addresses Assignments (cont'd)

- Loopback address
  - ::1/128
  - Same function as the 127.0.0.1 in IPv4
  - Used by a node to send back IPv6 packets to itself, typically used for testing the TCP/IP stack
  - Not routable
- Unspecified Address
  - :: (all 0's)
  - Indicates the absence, or anonymity of an IPv6 address (e.g., for router solicitation)
  - Used as a source IPv6 address during duplicate address detection process

Unicast Addresses Assignments (cont'd)

- Unique Local Address (ULA)
  - FC00::/7 (first hextet: FC00::/7 to FDFF::/7)
  - Should not be routable on the Internet
  - Similar to RFC 1918 IPv4 addresses (private addresses) but not meant to be translated to a global unicast (for security purposes)
  - Used in more limited area such as within a site or devices inaccessible from the global Internet
  - For the first hextet 1111 110*x* (*x* = local flag bit)

    (for *x*=0) FC00::/8 - /48 prefix assigned using RFC 4193 algorithm (dormant)

    (for *x*=1) FD00::/8 - /48 prefix assigned locally

Remark: Site local addresses (FEC0::/10) was deprecated

Unicast Addresses Assignments (cont'd)

- Embedded IPv4 Address (was deprecated)
  - Was used by dual-stack devices that support both IPv4 and IPv6
  - Other transition methods used when required to send IPv6 packets over IPv4-only networks, such as tunneling or NAT64

Summary

- Both the IPv4 and IPv6 addressing schemes are covered
- IPv4 addresses all exhausted
  - But still living quite well today
- IPv6 too abundant and generously assigned at the current stage
  - GUA
  - Link-local
  - ULA

QA