

COMP 225: Network and System Administration Notes #7: Internet Protocol versions 4 and 6 Addressing Schemes

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To Cover

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

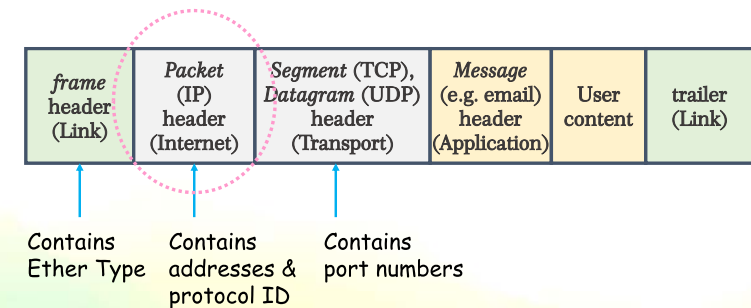
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The Internet Layer

- 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 effort traffic
 - Traffic type classification
 - QoS routing

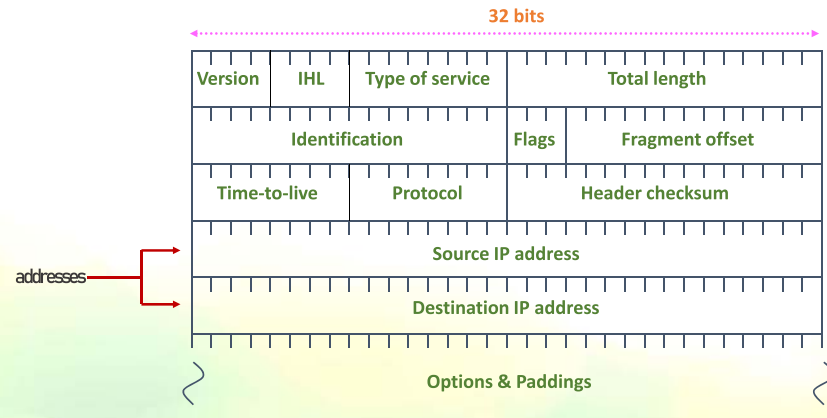
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A Typical Structure of a Transmitting Frame



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IPv4 Header Format



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Focus on 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:
340,282,366,920,938,463,374,607,431,768,211,456 or 2^{128} (about 340 undecillion) # of addresses

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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

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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: $x.y.z.n$

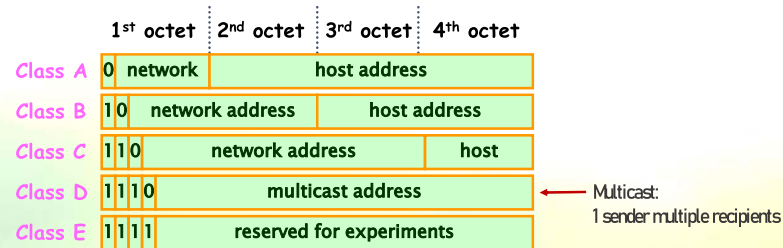
- where $x, y, z, n \in \{0, \dots, 255\}$
- e.g. 128.100.10.2



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Address Classes (IPv4)

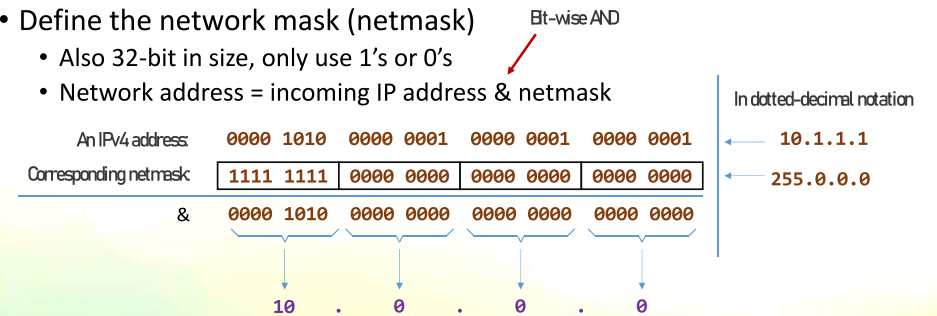
- Initially and historically, IPv4 address was classified into two parts
 - Network address and host address
- There were 5 classes, and only unicast classes A to C are mostly used



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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



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How 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	1 st bit = 0	8-bit	255.0.0.0
B	1 st two bits = 10	16-bit	255.255.0.0
C	1 st 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

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Then

- Class A (0.x.x.x to 127.x.x.x)
 - 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
 - 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... :_(

2 fewer hosts, why? Explain later...

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Problems with Classful Designs

In fact, all IPv4 addresses exhausted in 2011

- 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:
 - ⇒ Inflexible for different network sizes
 - ⇒ **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

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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 network address
 - One for broadcast address in the network
- 2 fewer hosts, why? Explain later...
- Hence, the provider 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

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Subnetting (cont'd)

- Netmask no longer based on class A, B or C
 - E.g., 255.255.255.240 \equiv 1111 1111 . 1111 1111 . 1111 1111 . 1111 0000, there are 28 one's
- A simpler notation is
network address / size of netmask
- Hence, the last example is 136.28.1.0/28

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2 Fewer Host Addresses

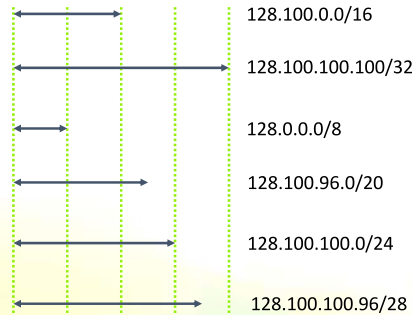
- For the last example, this network address is 136.28.1.0/28
 - There are 4 bits for assigning host address, **but**
 - The 136.28.1.0 is the **network name** (the network address) – should not be assigned to any host
 - For broadcasting, all bits for host address are set to 1's, i.e., 136.28.1.15 is 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

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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

128.100.100.100



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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

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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 Subnet Mask** (VLSM)
 - Notation: **x.y.z.n/m**
 - Network address: **x.y.z.n**
 - Length of netmask: **m**

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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, except Linux occasionally uses 127.0.1.1

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

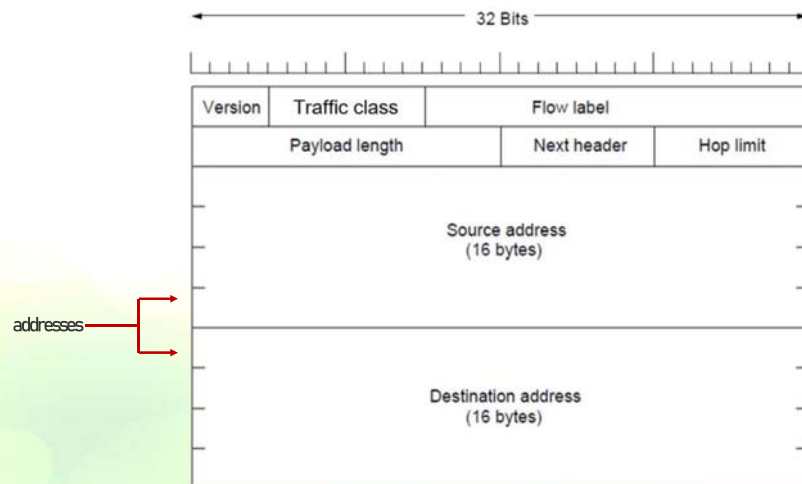
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IPv6

- 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

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IPv6 Header



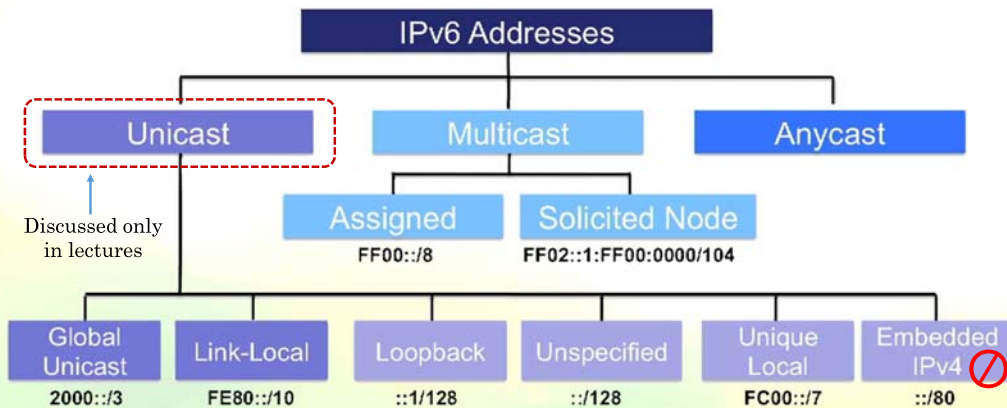
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Features of IPv6 More than Addresses

- Larger address space
- Stateless 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

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Types of IPv6 Addresses



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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

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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

FEDC : BA98 : 7654 : 3210 : 0123 : 4567 : 89AB : CDEF

16-bit 16-bit 16-bit 16-bit 16-bit 16-bit 16-bit 16-bit

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Two Rules Compressing IPv6 Addresses

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

trailing zero leading zeroes leading zero leading zeroes

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

leading zeroes leading zeroes leading zeroes

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

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Two Rules Compressing 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

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Two Rules Compressing 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**

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Two Rules Compressing IPv6 Addresses (cont'd)

- If more than 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

FED0:8:0:123:CDEF

FED0:8::123:0:0:CDEF ✓

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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

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IP Addressing

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

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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 hexet)
 - 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...

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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

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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

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Unicast Addresses Assignments (cont'd)

- Unique Local Address (ULA)
 - FC00::/7 (first hextet: FC00::/7 to FDFE::/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

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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

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Summary

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

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