TCP/IP Network Layer

CT2108 – Nets & Comms 1

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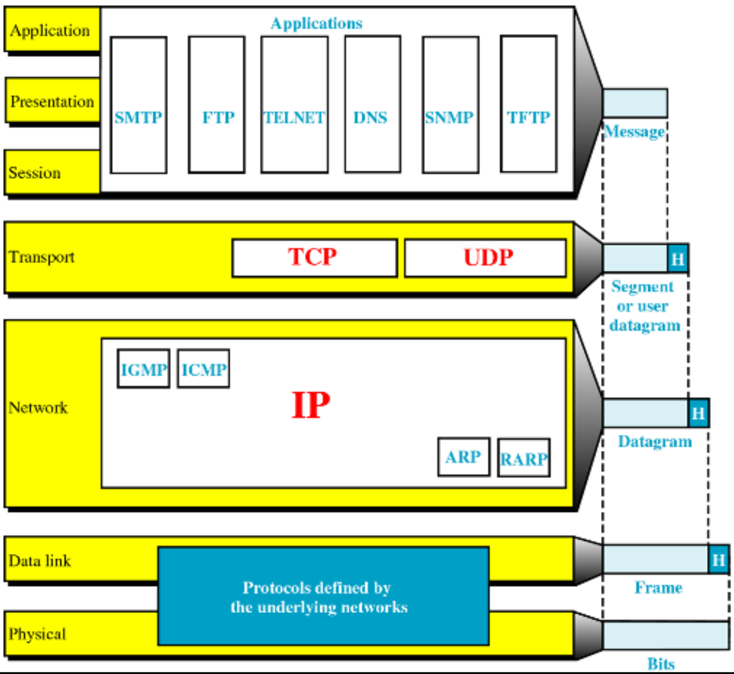
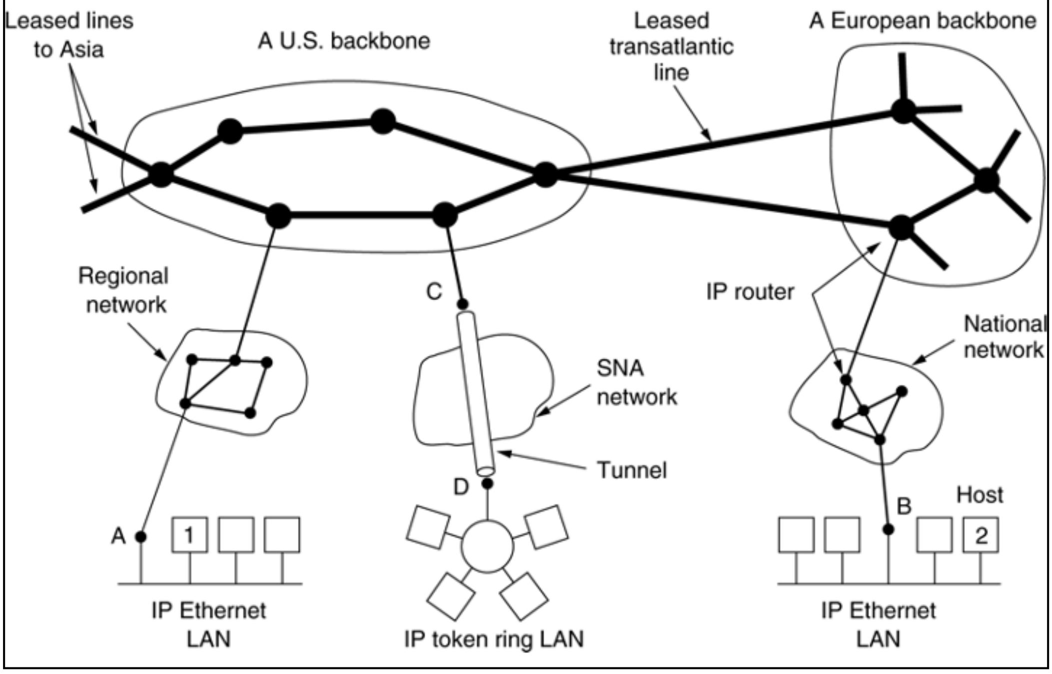
The network layer in the Internet



Principles that drove the design

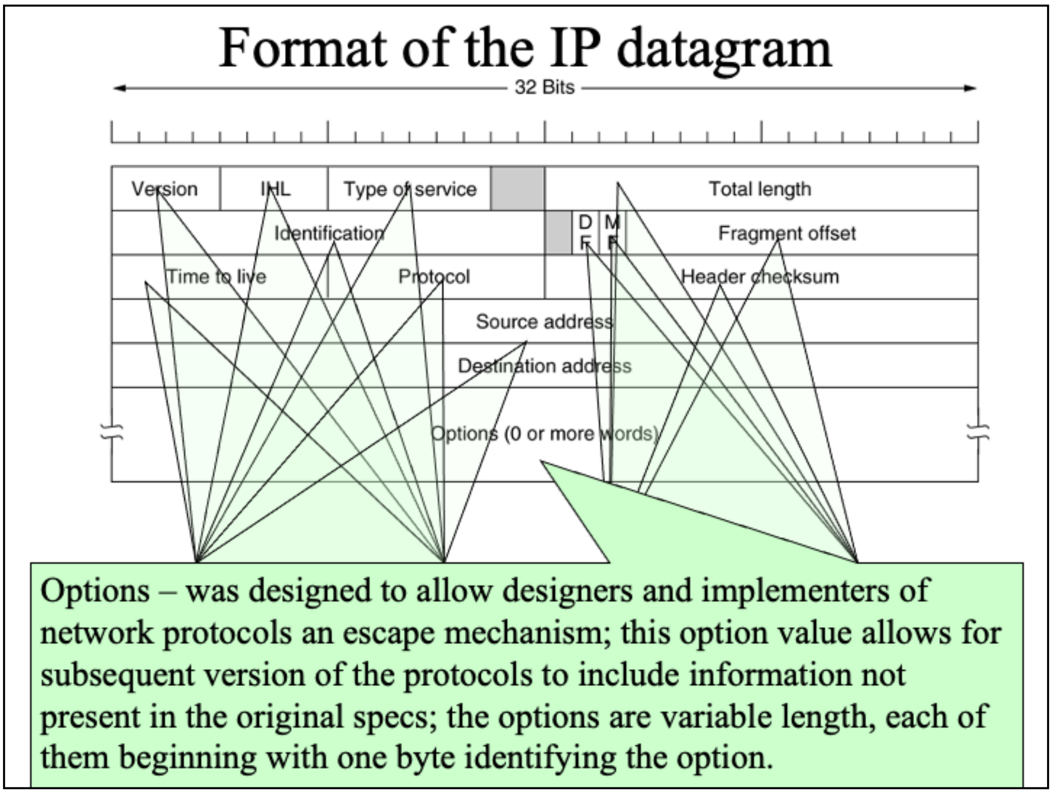
- **Make sure it works** – first test and then write specs
- **Keep it simple** – fight features (leave out non essential features)
- **Make clear choices** – if multiple ways to do same thing, choose just one
- **Exploit modularity** – have protocol stacks
- **Expect heterogeneity** – different types of hardware, etc..
- **Avoid static options and parameters** – negotiate a value than define a fixed one (where absolutely needed)
- **Look for a good design, not need to be perfect** – do a god design, don't complicate it to handle special wired cases
- **Be strict when sending, tolerant when receiving** – comply with the standards when sending, try to accommodate errors when receiving
- **Think about scalability** – systems that have to use millions of users don't accommodate well centralized databases
- **Consider performance and cost** – a solution that is either expensive or performs poorly is not usable

Internet – collection of subnets



Internet Protocol (IP)

- The glue that holds together the Internet
- Provides a best-efforts (not guaranteed) way to transport datagrams from source to destination
- Workflow:
  - The transport layer takes the data streams and breaks them into datagrams (in theory they can be up to 64KB, but in practice they are no more than 1500 bytes)
  - Each datagram is transmitted through the Internet (possible being fragmented into smaller pieces as it goes)
  - When all pieces get to the destination machine, they are reassembled by the network layer into the original datagram
  - This datagram is handed to the transport layer which inserts it into the receiving process input stream



IP packet is transferred in big endian : from left to right, with the high order bit of the version control going first. All 8086 based machines are little endian, so whenever sending or receiving, a conversion is required

•Versioning (keeps track of the versioning control). Currently we can have IPV4 (0100) or IPV6 (0110)

•Header Length – how long the header is in 32 bit-words; the minimum value is 5, which applies when no option is present; maximum value is 15 giving a maximum of 60 bytes for the header, when options are present (thus options field is limited to 40 bytes)

•Type of service – defines how the datagram should be handled; it includes bits that define priority of the datagram; it also include bits that define the type of service the sender desires, such as level of throughput, reliability and delay; most of the times, this filed is completely ignored by routers

•Total length – includes everything in the datagram, both header and data; the maximum length is 65,535 bytes; at this stage, this limit is OK, but with future gigabit networks, larger datagrams may be needed

•Identification – is needed to allow the destination host to determine which datagram a newly arrived fragment belongs to. All the fragments of the datagram contains the identification field.

•DF – bit specifying Don't Fragment; this is helpful for systems that can't put back together the fragments of a datagram

•MF – stands for More Fragments; all fragments except the last one have this bit set. It is needed to know when the fragments of a datagram have arrived

•Fragment offset – tells where in the current datagram the current fragments belongs. All fragments, except the last one have to be multiple of 8 bytes (elementary fragment unit); since 13 bits are provided, there are a number of 8192 fragments per datagram, giving a maximum datagram length of 65536 bytes

•Time to live – is a counter used to limit the packets life times; it is suppose to count time in seconds, allowing a maximum life time of 255 seconds, but in practice it counts only hops. When it hits 0, the packet is discarded and a warning packet is sent back to the host; this feature prevents datagrams from going around forever.

•Protocol – tells which transport process to give it to…in other words is specifies the transport layer protocol (TCP, UDP, etc…)

•Header checksum – verifies only the header; the algorithm is to add up all 16 bit half words as they arrive, using one's complement arithmetic and then take one's complement result; the header checksum must be computed at each hope, since there are values in the header that modifies (i.e. hops count)

•Options – was designed to allow designers and implementers of network protocols an escape mechanism; this option value allows for subsequent version of the protocols to include information not present in the original specs; the options are variable length, each of them beginning with one byte identifying the option.

IP Options

Option	Description
Security	Specifies how secret the datagram is
Strict source routing	Gives the complete path to be followed
Loose source routing	Gives a list of routers not to be missed
Record route	Makes each router append its IP address
Timestamp	Makes each router append its address and timestamp

Time stamp – same with the Record route option, but beside the IP address, the routers have to record also a 32 bit time stamp value; this option is mostly for debugging routing algorithms.

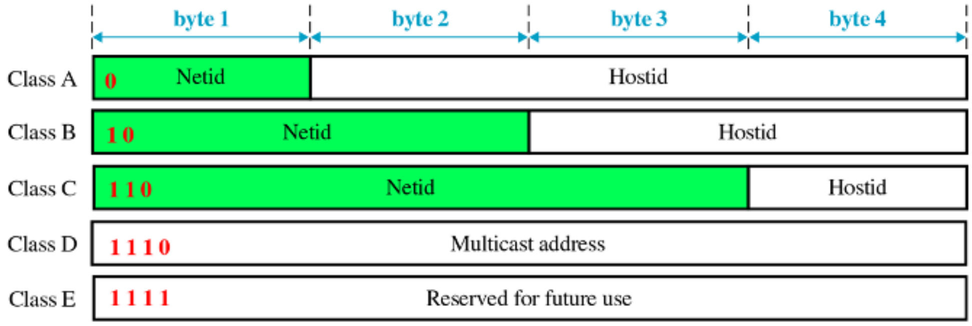
Security – i.e., a military router might use this field not to route through certain countries; in practice, all of the routers ignore it, so it can be used to spy easily on interesting stuff …
Strict source routing – gives the complete path from source to destination, as a list of IP address (sequence). The datagram is forced to follow that exact route; useful when routing tables are corrupted or for timing measures.
Loose source routing – requires the packet to traverse the list of routers specified, and in the specified order; it allows a pass through other routers on the way; this is useful when avoiding or force passing through certain countries (economical or political reasons)
Record route – tells the routers along the way to append their address to the option list. This allows tracking down of bugs in routing algorithms. At first, ARPANET was having at most 9 routers…so 40 bytes was plenty…but now this is too short.
Time stamp – same with the Record route option, but beside the IP address, the routers have to record also a 32 bit time stamp value; this option is mostly for debugging routing algorithms.

IP Addressing

An Internet address is made of four bytes (32 bits) that define a host's connection to a network.

- Three fields of variable sizes (dependent on the class of the address)
  - Class Type field defines the class (5 possible classes that an internet address is part off)
  - Network ID – up the class type, this field can be anywhere between 7 and 24 bits
  - Host ID – up to the class type it can be anywhere between 8 and 24 bits
- ICANN (Internet Corporation for Assigned Names and Numbers), non profit corporation that manages the assignment of IP address space to various regional authorities that deal with IP address assignment

Internet Classes



- 10011101 10001111 11111100 11001111 (Class B)
- 11011101 10001111 11111100 11001111 (Class C)
- 01111011 10001111 11111100 11001111 (Class A)
- 11101011 10001111 11111100 11001111 (Class D)
- 11110101 10001111 11111100 11001111 (Class E)
- Class A, B are full; class C still has available addresses; D is reserved for multicasting and class E is reserved for future use

Dotted decimal notation

10000000 00001011 00000011 00011111

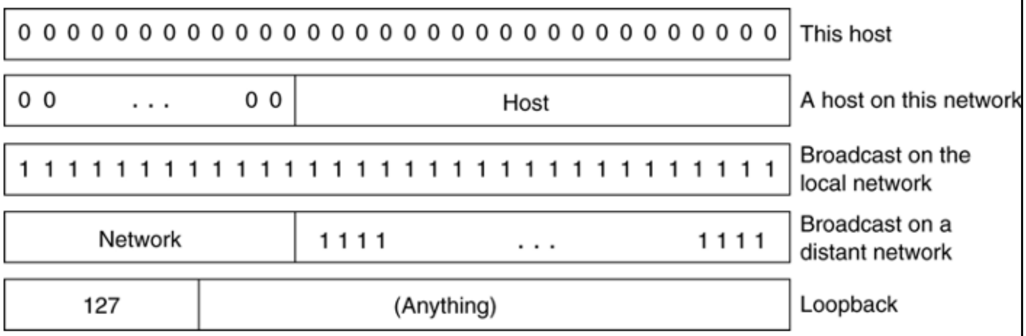
128.11.3.31

- Used to make the form shorter and easier to read
- Internet addresses are usually written using this form
- Looking at the first byte of an address in decimal form will allow us to determine which class the particular address belongs (for the example it belongs to class B)

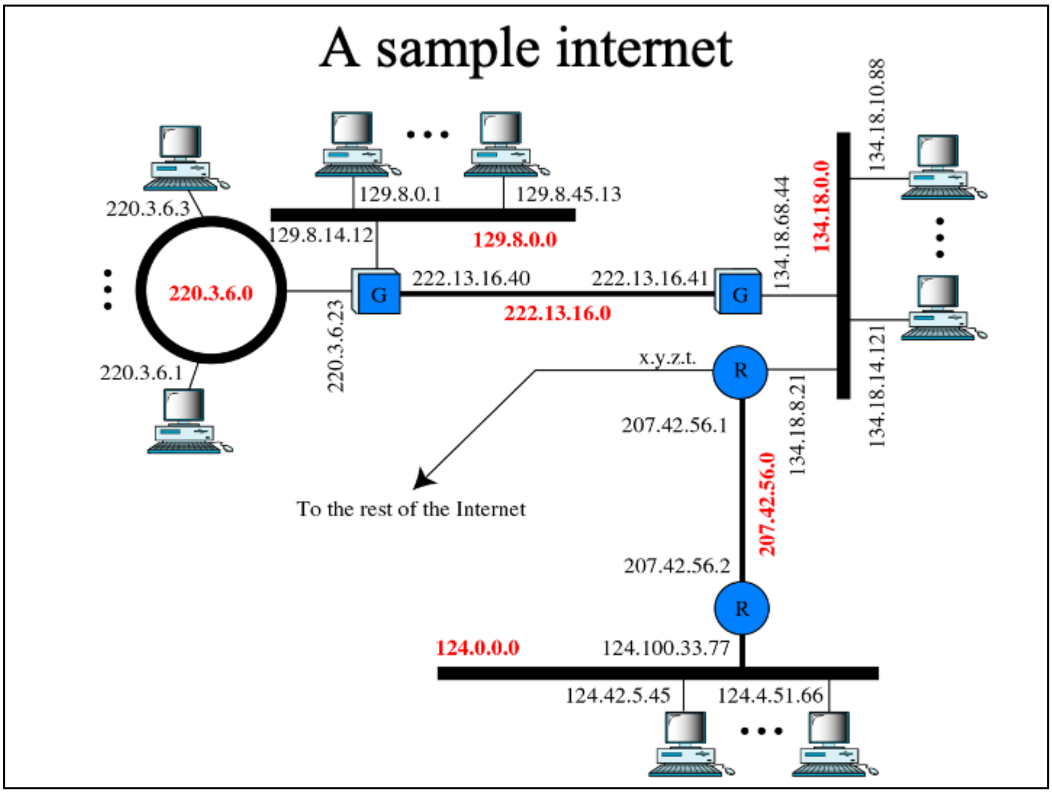
Class ranges for Internet addresses

	From	To
Class A	0.0.0.0 Netid Hostid	127.255.255.255 Netid Hostid
Class B	128.0.0.0 Netid Hostid	191.255.255.255 Netid Hostid
Class C	192.0.0.0 Netid Hostid	223.255.255.255 Netid Hostid
Class D	224.0.0.0 Group address	239.255.255.255 Group address
Class E	240.0.0.0 Undefined	255.255.255.255 Undefined

Special IP addresses



- Loopback – the packets sent to these addresses are not sent over the wire;
  - they are treated as incoming packets and processed locally
  - Very useful for testing/debugging an TCP/IP stack



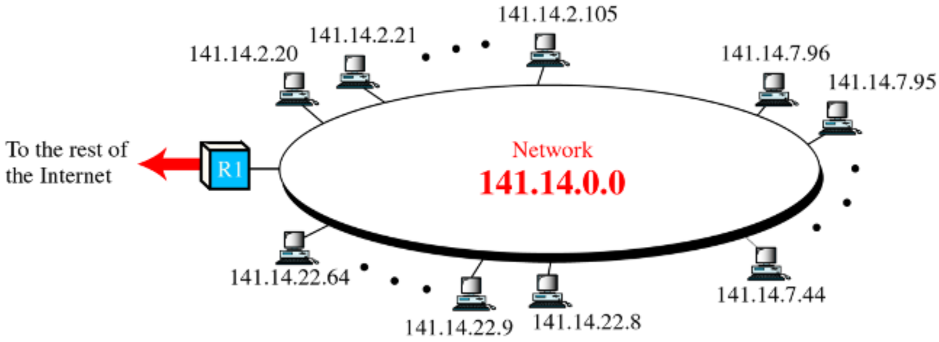
Three LANs

One Token Ring

G – gateway

R – router

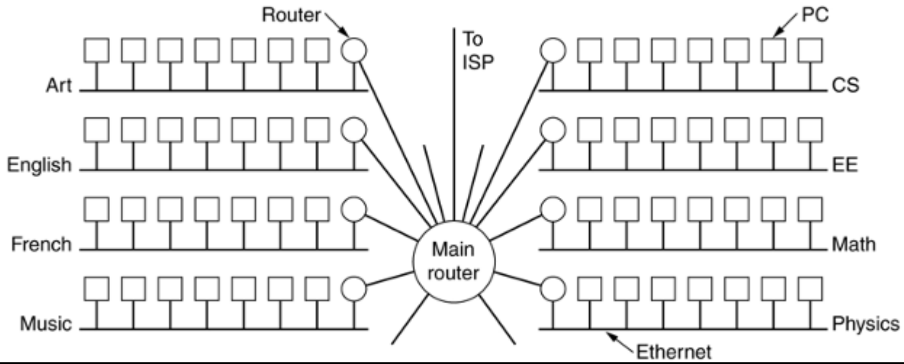
Two levels of hierarchy



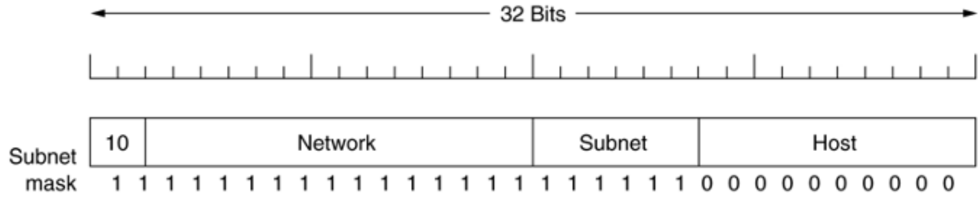
- As we have seen, all the addresses on Internet have a network id and a host id; this means that there is a hierarchy in IP addressing
- To reach a specific host, first we have to reach the network this host is part of, using the first portion of the address; then we will reach the host itself using the second portion of the IP address.
- Then, classes A, B and C in IP addressing are designed with two levels of hierarchy

Campus network example

- Consider a large organization with class B addresses (140.203.0.0)
- With two level addressing schema, the organization can't have more than one physical network
- Solution: allow subnets, allow a network to be split into several parts for internal use, but still act as a single network to the outside world

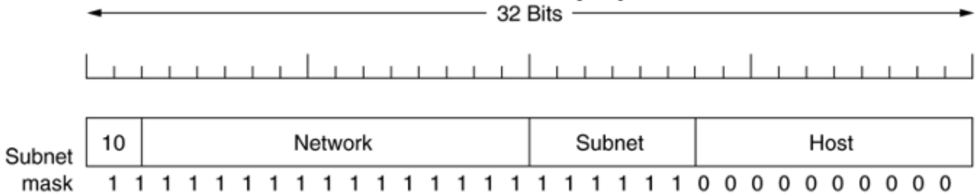


Subnets (1)



- Instead of having a single class B address with 14 bits for network and 16 bits for host number, some bits are taken away from the host number to create a subnet number
- For example, if the university (large organization) has 35 departments it could use 6 bits for the subnet number and a 10 bit host number, allowing for up to 64 Ethernets, each with a maximum of 1022 hosts (all 0 and all 1 are not allowed); this split can be changed later if it proves to be wrong

Subnets (2)



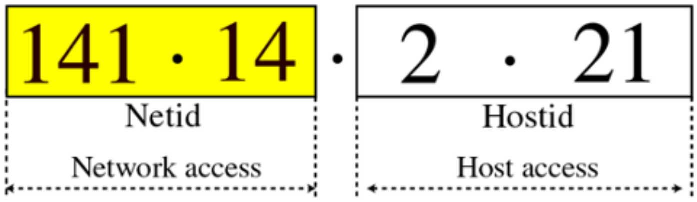
- To implement subnetting, the main router will need a subnet mask that indicates the split between network + subnet number and host number
- The masking process extracts the address of the physical network from an IP address (bitwise AND between the IP and mask); masking can be done either we have subnetting or not
- Subnet mask is also written in dotted decimal notation or as a slash followed by the number of bits in the network
- Subnet mask for this example is 255.255.252.0; an alternative notation is /22 to indicate that the subnet mask is 22 bit long, so we can have 255.255.252/22

Subnets (3)

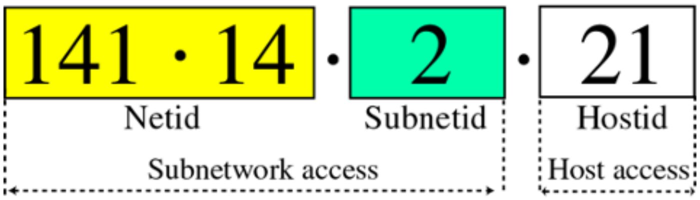
- In our example, the subnets are as follows:
  - Subnet 1: 10001100 11001011 000001|00 00000000
    - Subnet: 140.203.4.0
    - Subnet mask: 255.255.252.0
    - First host in the subnet 1: 140.203.4.1
  - Subnet 2: 10001100 11001011 000010|00 00000000
    - Subnet: 140.203.8.0
    - Subnet mask: 255.255.252.0
    - First host in the subnet 2: 140.203.8.1
  - Subnet 3: 10001100 11001011 000011|00 00000000
    - Subnet: 140.203.12.0
    - Subnet mask: 255.255.252.0
    - First host in the subnet 3: 140.203.12.1

Outside the network, the subnetting is not visible, so allocating a new subnet doesn’t require contacting any official organization (that assigns IP addresses) nor changing any external databases

Another Practical example



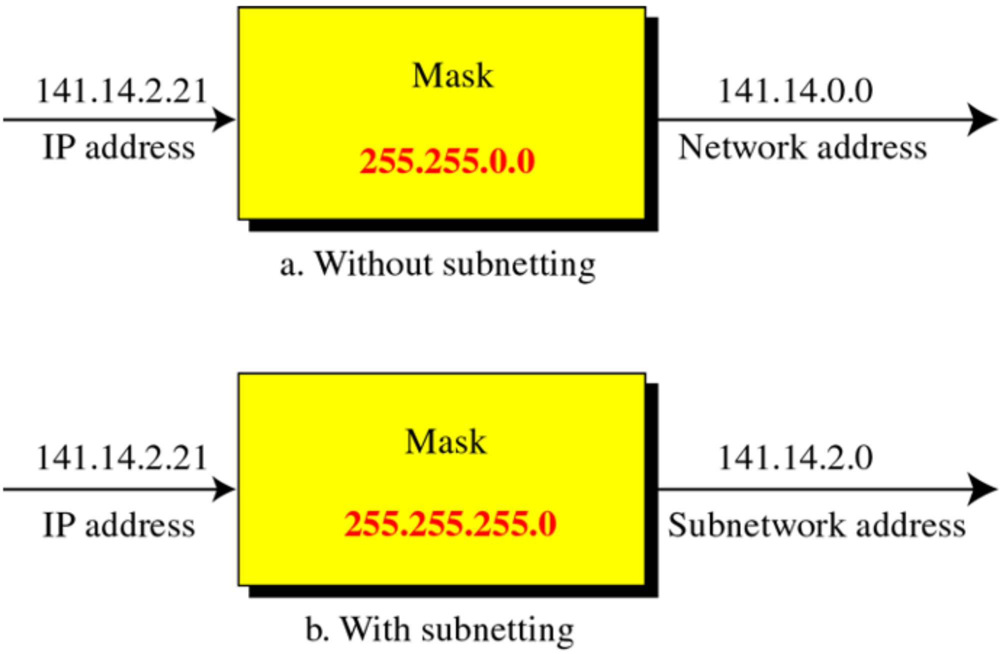
a. Without subnetting



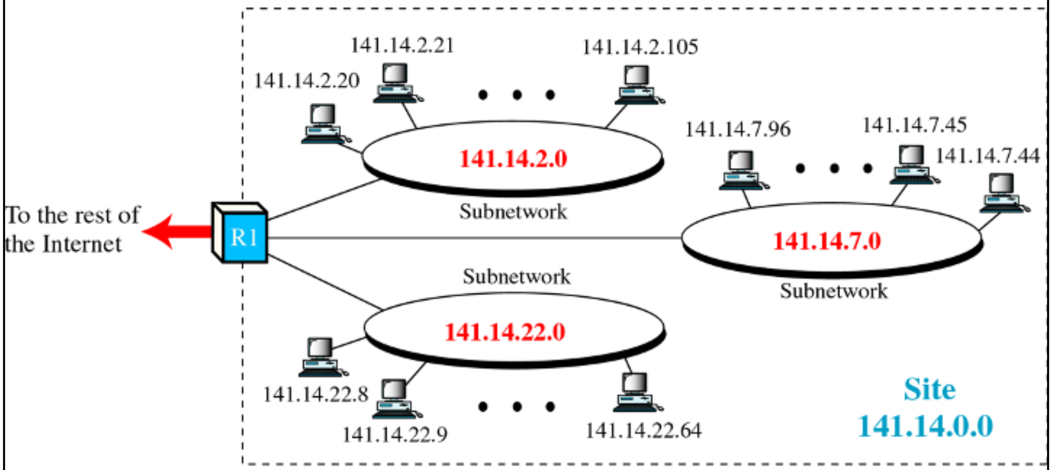
b. With subnetting

Consider network address 141.14.0.0, create 256 subnets with 254 hosts per subnet

Masking


141.14.2.21
IP address
Mask
255.255.0.0
141.14.0.0
Network address
a. Without subnetting
141.14.2.21
IP address
Mask
255.255.255.0
141.14.2.0
Subnetwork address
b. With subnetting

Three level hierarchy network



IP addresses shortage

- IP is running out of addresses
  - Class A networks (with 16 million host addresses) is too big for most of the organizations
  - Class C networks (with 256 host addresses) is too small for most of the organizations
  - Class B networks (with 65,536 host addresses) is about right for a medium sized organizations
- In reality a class B address is too large for most of the organizations; studies show that half of the class B networks have less than 50 hosts….
- Two solutions to cope with the shortage problem
  - Use of CIDR (**C**lassless **I**nter**D**omain **R**outing)
  - Use of NAT (**N**etwork **A**ddress **T**ranslation)

CIDR

- Basic idea is to allocate the remaining IP addresses in variable-sized blocks, without regard to the classes.
- If a site needs, say 2000 addresses, it is given a block of 2048 addresses on a 2048 byte boundary
- Dropping classes makes the routing more complicated, the old routing algorithm is not working anymore

Old routing algorithm

- Incoming packet to the router (i.e. with destination address 140.203.8.22
- Router extracts the destination IP address and shift a copy of it with 28 bits to the right to obtain a 4 bit class number (i.e. 1000)
- Have a 16 way branch that sorts the packet into A, B, C and D (if supported):
  - 8 cases for class A; 4 cases for class B, 2 cases for class C and one case for each D and E
- Once the router knows the class (in our example class B), it will know what mask to apply (i.e. 16 bit mask, or 255.255.0.0), in order to find out the network address (140.203.0.0) and look it up into appropriate class routing tables (class B routing tables) to find out the outgoing physical line

CIDR routing algorithm

- Each routing table entry is extended by giving it a 32 bit mask
- There is now a single routing table for all networks consisting of (net IP address, subnet mask, outgoing line) triplets
- When a packet comes in:
  - its destination address is first extracted
  - The routing table is scanned entry by entry to find a match
    - It is possible to find multiple matches (entries), the one having the longest mask is used (i.e. between /20 entry and /24 entry, /24 is used)
  - The packet is forwarded on the outgoing line
- Commercial VLSI chipsets for routers have been developed using this new algorithm, in order to speed up the address matching process

CIDR practical example (1)

- Addresses are available at 194.24.0.0
- Suppose that:
  - Cambridge needs 2048 addresses and it is assigned 194.24.0.0 through 194.24.7.255 with mask 255.255.248.0
  - Oxford asks for 4096 addresses and it is assigned 194.24.16.0 through 194.24.31.255 with mask 255.255.240.0
  - Edinburgh asks for 1024 addresses and it is assigned 194.24.8.0 through 194.24.11.255 with mask 255.255.252.0

University	First address	Last address	How many	Written as
Cambridge	194.24.0.0	194.24.7.255	2048	194.24.0.0/21
Edinburgh	194.24.8.0	194.24.11.255	1024	194.24.8.0/22
(Available)	194.24.12.0	194.24.15.255	1024	194.24.12/22
Oxford	194.24.16.0	194.24.31.255	4096	194.24.16.0/20

CIDR practical example (2)

- The routing tables all over the world will update to contain the following entries:
  - C: 11000010 00011000 00000000 00000000 with mask 11111111 11111111 11111000 00000000
  - E: 11000010 00011000 00001000 00000000 with mask 11111111 11111111 11111100 00000000
  - O: 11000010 00011000 00010000 00000000 with mask 11111111 11111111 11110000 00000000
- Packet coming for destination 194.24.17.4 or in binary: 11000010 00011000 00010001 00000100
  - First it is ANDed with Cambridge mask
    - 11000010 000110000 00010000 00000000, this value doesn't match the Cambridge base address

CIDR practical example (3)

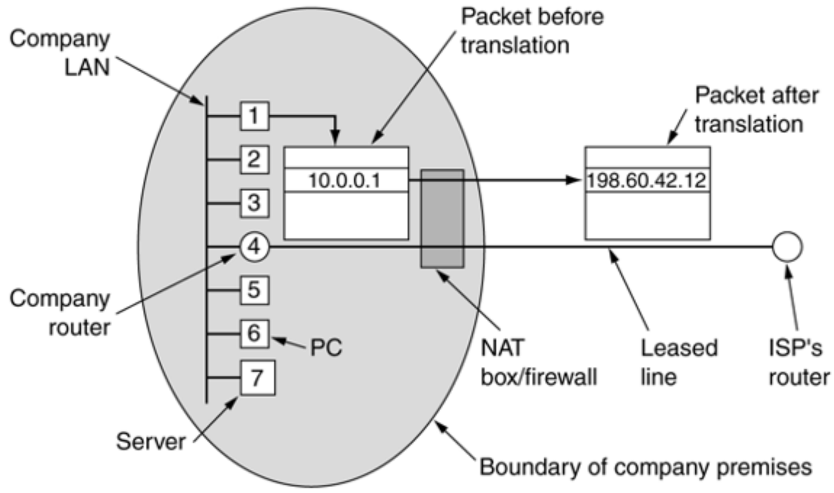
- The original address is ANDed with Edinburgh mask:
  - 11000010 000110000 00010000 00000000, this value doesn't match the Edinburgh base address
- Next original address is ANDed with Oxford mask:
  - 11000010 000110000 00010000 00000000, this does match the Oxford base address

- If no other matches are found, then the packet will be forwarded on the outside line corresponding to the Oxford entry.

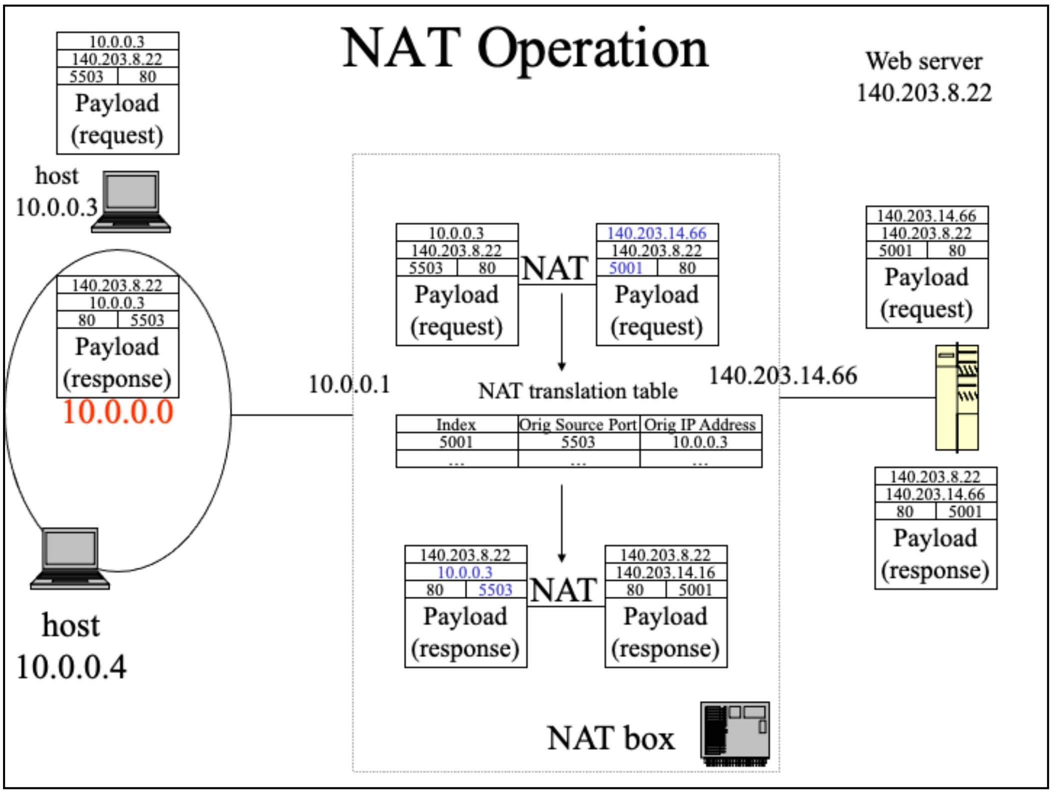
NAT (**N**etwork **A**ddress **T**ranslation)

- It comes into play whenever a need for more hosts than real IP addresses are available (i.e. an ISP may have a class B address, having a 65,534 possible hosts, but has more customers than that)
- NAT (RFC 3022) – basic idea is to assign each company a single IP address (or a small number of them) for Internet traffic. Within company, every computer gets a unique IP address, which is used for routing internal traffic; when a packet exits the company and goes to the ISP, an address translation takes place
- To make this thing possible, three ranges of IP addresses have been declared as private, companies can use them internally as they wish; the only rule is that no packets containing these addresses may appear on the internet itself

NAT



- 10.0.0.0 – 10.255.255.255/8 (16,777,216 hosts)
- 172.16.0.0 – 172.31.255.255/12 (1, 048,576 hosts)
- 192.168.0.0 – 192.168.255.255 (65,536 hosts)


NAT Operation
Web server
140.203.8.22
10.0.0.3
140.203.8.22
5503 80
Payload
(request)
host
10.0.0.3
140.203.8.22
10.0.0.3
80 5503
Payload
(response)
10.0.0.0
host
10.0.0.4
10.0.0.1
10.0.0.3
140.203.8.22
5503 80
Payload
(request)
NAT
140.203.14.66
140.203.8.22
5001 80
Payload
(request)
NAT translation table
Index | Orig Source Port | Orig IP Address
5001 | 5503 | 10.0.0.3
… | … | …
140.203.8.22
10.0.0.3
80 5503
Payload
(response)
NAT
140.203.8.22
140.203.14.16
80 5001
Payload
(response)
NAT box
140.203.14.66
140.203.14.66
140.203.8.22
5001 80
Payload
(request)
140.203.8.22
140.203.14.66
80 5001
Payload
(response)

NAT problems

- Violates the architecture of IP model, which states that every host worldwide should be identified by a unique IP
- Changes the Internet from a connectionless network in a kind of connection-oriented network
- Violates the most elementary rule of protocol layering, that layer k should not make any assumption of what layer k+1 put in the payload
- Will not work with any protocols on the Internet (beside TCP or UDP)
- Some applications insert IP addresses in the text (payload); the receiver will extract these addresses and use them; NAT will not work with those applications since it doesn’t know about this insertion (i.e. MS Messenger)

Internet Control Protocols

- ICMP (Internet Control Message Protocol)
- ARP (Address Resolution Protocol)
- RARP (Reverse Address Resolution Protocol)
- BOOTP (BOOTstrap Protocol, alternative to RARP)
- DHCP (Dynamic Host Configuration Protocol)

ICMP

- Used to report something unexpected; each ICMP message is encapsulated in an IP packet
- Used to test the internet

Message type	Description
Destination unreachable	Packet could not be delivered
Time exceeded	Time to live field hit 0
Parameter problem	Invalid header field
Source quench	Choke packet
Redirect	Teach a router about geography
Echo request	Ask a machine if it is alive
Echo reply	Yes, I am alive
Timestamp request	Same as Echo request, but with timestamp
Timestamp reply	Same as Echo reply, but with timestamp

Timestamp request and Timestamp reply – are similar with echo messages, except that the arrival time of the message and the departure time of the reply are recoded in the reply; it is used me measure network performance

Destination unreachable – is used when the subnet or a router can’t locate the destination or when a packet with DF bit set can’t be delivered because a “small packet” network stands in the way

Time exceeded – is sent when a packet is dropped because its counter reached zero; this event is a symptom that packets are looping, there is an enormous congestion or the timer values were set to low

Parameter problem – indicates that an illegal value has been detected in a header field; this message indicates a bug in the sender’s IP software or possible in the transited routers

Source quench – message formerly used to slow down stations that were sending too many packets; it is not used anymore, because when congestion occurs, those packets tend to throw more fuel into the fire; congestion control is done now in the transport layer

Redirect – is used when a router notices that a packets seem to be routed wrong. It is used by the router to tell the sending host about the probable error

Echo and Echo reply – are used to see if a given destination is reachable and alive; upon receiving the echo message, the receiving station is suppose to answer with the echo reply message

Timestamp request and Timestamp reply – are similar with echo messages, except that the arrival time of the message and the departure time of the reply are recoded in the reply; it is used me measure network performance

ARP and RARP

- ARP is a network layer (3) protocol and is required to allow a sending station gather address information used in forming a layer 2 frame complete with destination and source MAC addresses
- Although ARP is a layer 3 protocol it does not use an IP header, it has its own packet format and is a broadcast on the local LAN within the data field of a layer 2 (Ethernet) frame without needing to be routed.
- The Ethernet Type field uses the value 0x**0806** to indicate an ARP request and 0x**0835** to indicate an ARP response.
- If a station does not know its IP address it may send out a RARP (Reverse Address Resolution Protocol) request read by a RARP server which has a table of hardware addresses and IP addresses. The RARP uses the same packet format as the ARP
- Most hosts on a network will send out a **Gratuitous ARP** when they are initializing their IP stack. This Gratuitous ARP is an ARP request for their own IP address and is used to check for a duplicate IP address. If there is a duplicate address then the stack does not complete initialization.
- RFC 826 describes ARP in detail, while RFC 903 describes RARP.

Every router maintains a table listing IP addresses and respective hardware addresses (e.g. MAC addresses) of devices that exist on the network. This table is called an ARP cache and is referenced by the router when it is looking up a hardware address of a device for which it knows the IP address and needs to forward a datagram to it. If no hardware address is found in the ARP cache then an ARP broadcast is sent on to the adjacent media (ARP only applies to the connecting wire). This broadcast is read by every station including the destination station. The destination station sends back an ARP reply with its hardware address so that the IP datagram can now be forwarded to it by the router.

ARP packet format

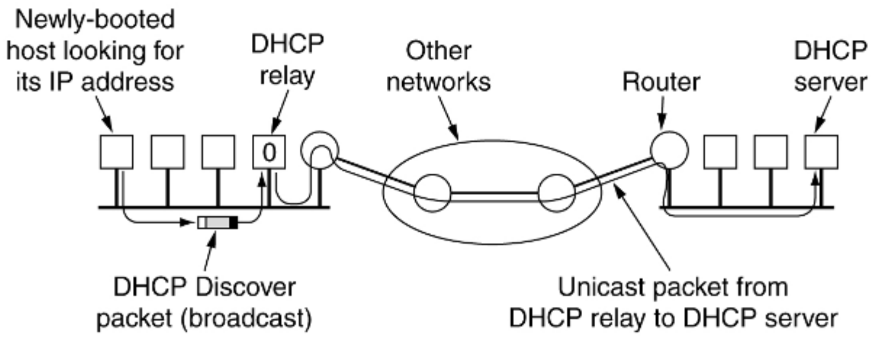
HARDWARE TYPE	PROTOCOL TYPE	LENGTH OF HARDWARE ADDRESS	LENGTH OF PROTOCOL ADDRESS	OPERATION CODE	SOURCE HARDWARE ADDRESS	SOURCE PROTOCOL ADDRESS	DESTINATION HARDWARE ADDRESS	DESTINATION PROTOCOL ADDRESS
2 BYTES	2 BYTES	1 BYTE	1 BYTE	2 BYTES				

- Hardware Type – (i.e. this is 1 for Ethernet).
- Protocol Type - the protocol used at the network layer (i.e. IP).
- Length of Hardware Address - this is the length in bytes, so it would be 6 for Ethernet.
- Length of Protocol Address - for TCP/IP the value is 4 bytes.
- Operation Code - this code indicates whether the packet is an ARP Request, ARP Response, RARP Request or RARP Response.
- Source Hardware Address - hardware address of the source node.
- Source Protocol Address - layer 3 address of the source node.
- Destination Hardware Address - used in a RARP request, the response carries both the destination's hardware and layer 3 addresses.
- Destination Protocol Address - used in an ARP request, the response carries both the destination's hardware and layer 3 addresses.

RARP, BOOTP and DHCP

- Given an data-link address (i.e. Ethernet address) what is the corresponding net address (IP address)
  - RARP
    - Is using a broadcasting destination address of all 1s (it is not forwarded by the routers), so a RARP server needs to be in each network
  - BOOTP
    - Is using UDP messages, so they will be forwarded over routers
    - It is specifically designed for diskless stations, so it provides additional information, such as IP of the file server holding the operating system image, etc…
    - It requires manual configuration of the tables mapping the IP addresses with Ethernet addresses
  - DHCP (Dynamic Host Configuration Protocol)
    - Special server that allows automatic and manual IP assignment
    - It may require a DHCP relay agent on the local networks, so the DISCOVER packet would be forwarded outside the local LAN
    - RFC 2131 and RFC2132

DHCP operation



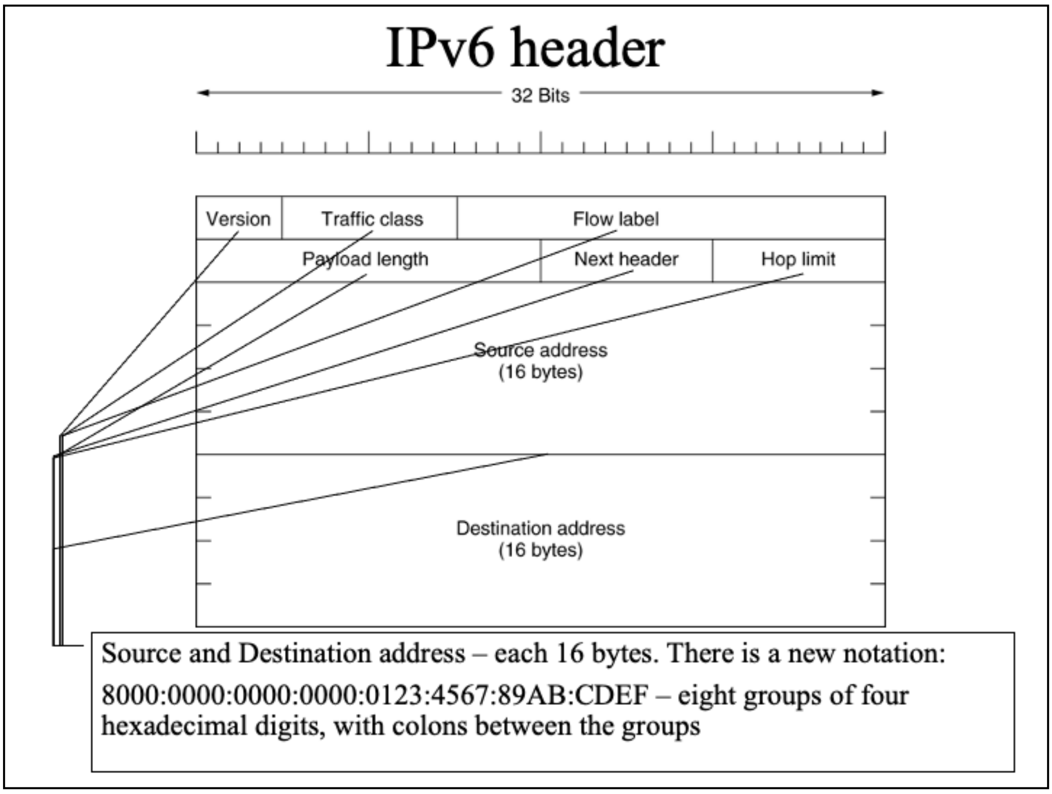
- DHCP relay agent intercepts all broadcast DISCOVER packets and forwards them as unicast packets to DHCP server
- DHCP relay agent needs to know the IP address of the DHCP server

IPv6

- CIDR and NAT may "buy" a few more years, but the days of IPv4 are numbered (shortage problem)
- 1990, IETF started to work on IPv6, with the following goals:
  - Support billion of hosts
  - Reduce the size of the routing tables
  - Simplify the protocol, to allow routers to process faster
  - Provide better security (auth and privacy) than IPv4
  - Pay more attention to type of service (for real time data)
  - Aid multicasting (by allowing scopes to be specified)
  - Make roaming possible without change of address
  - Allow protocol expansion
  - Permit the old and new protocols to coexist for years

IPv6 features

- 16 bytes IP addresses
- Header simplification (contains only 7 fields versus 13 fields in IPv4)
- Better support for options;
  - the way options are represented is different, making it simple for the routers to skip over options not intended for them; this feature speeds up processing in the routers
- Improved security features – authentication and privacy are key features of the new protocol.
- Better handling of quality of service



Version - is always 6 for IPv6 or 4 for IPv4; routers will be able to examine this field and process the packet accordingly

Traffic class – is used to distinguish between packets with different real time delivery requirements

Flow label – experimental field, used to allow a source and a destination to setup a pseudo-connection with particular properties and requirements; i.e. a stream of packets on a certain source host to a certain destination host may have stringent delay requirements, thus need reserved bandwidth. The flow can be setup in advance and given an identifier. When a packet with a non zero flow label gets to a router, the router will lookup his tables to determine what kind of special treatment it requires. In effect, the flow label is an attempt to have it both ways: the flexibility of a datagram subnet and the guarantees of a virtual circuit subnet. Many flows could be active at the same time between two given IP addresses.

Payload length – how many bytes follow the 40byte header of the packet. The 40 bytes header is not counted anymore in the length of the packet.

Next header – there can be optional (extra) headers for the given packet. This field tells which (if any) of the currently supported six extension headers follow this header; if this header is the last IP header, the *next header* field tells which transport protocol handler (TCP, UDP, etc..) to pass the packet to

Hop limit – used to keep packets from living forever; it is practically the same time to live field as in IPv4 header

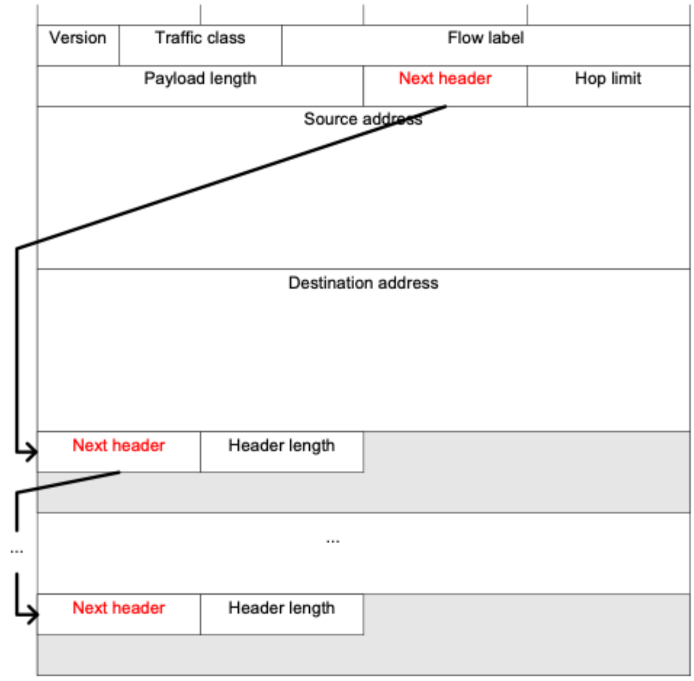
Source and Destination address – each 16 bytes. There is a new notation:

8000:0000:0000:0000:0123:4567:89AB:CDEF – eight groups of four hexadecimal digits, with colons between the groups

IPv4 versus IPv6

- *Protocol* filed – was taken out because the next header field tells what follows the last IP header (i.e. UDP or TCP segment)
- *Fragmentation* fields were removed
  - IPV6 hosts are expected to dynamically determine the datagram size to use.
  - The minimum has been raised from 576 to 1280 to allow 1024 bytes of data and many headers
  - If an IPV6 host sends a too large packet, the routers will issue an error message; this message tells the host to break up all future packets to that destination
- *Checksum* field – not existing because calculating it greatly reduces performance. However, since transport layer have their own checksum, it is not making sense to do it twice

IPv6 extension headers



IPv6 extension headers

Extension header	Description
Hop-by-hop options	Miscellaneous information for routers
Destination options	Additional information for the destination
Routing	Loose list of routers to visit
Fragmentation	Management of datagram fragments
Authentication	Verification of the sender's identity
Encrypted security payload	Information about the encrypted contents

Encrypted security payload – header that makes possible to encrypt the content of a packet so that only the intended recipient can read it; these headers use cryptographic techniques to accomplish their mission

They are optional, if exist, they should appear after the fixed 8 bytes header, preferably in the listed order

Hop by hop options - it is used to carry information that all the headers along the path must examine. One option has been defined so far: support for datagrams that exceeds 64K; when used, the *payload length* field in the main header is set to zero

Destination options - intended for fields that may be interpreted only at the destination host

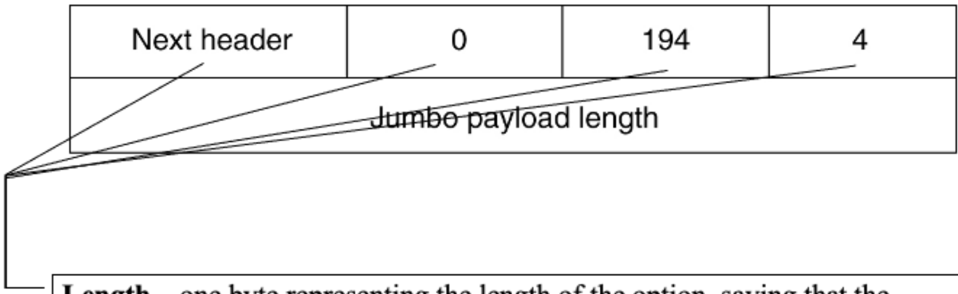
Routing header – lists one or more routers that must be visited prior to reaching the destination

Fragmentation – deals with fragmentation, similarly with IPv4; this header holds the datagram identifier, fragment number and a bit telling whether more fragments will follow; in IPv6 only the source host can fragment the packet (unlike IPv4)

Authentication – header that provides a mechanism so the receiving station is sure of who sent the packet (who is the source)

Encrypted security payload – header that makes possible to encrypt the content of a packet so that only the intended recipient can read it; these headers use cryptographic techniques to accomplish their mission

Hop by hop extension header



Length – one byte representing the length of the option, saying that the option value is represented on 4 bytes. It is followed by 4 bytes containing the option value; sizes less than 65536 bytes are not permitted and the routers will issue an error message if happens.

- Datagrams using this header are called **jumbograms**
- Their use is important for supercomputers that must transfer gigabytes of data, in an efficient way, over Internet

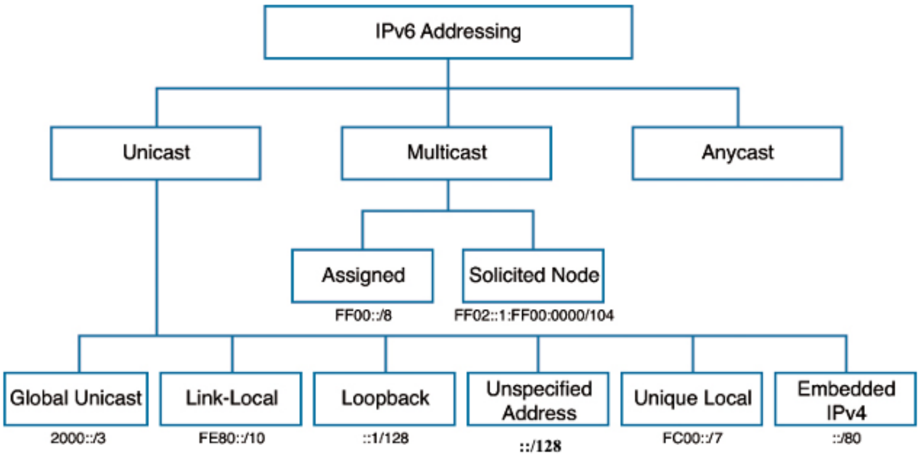
Next header – byte that shows what kind of header is next

Header length – how long the hop-by-hop header is in bytes, excluding the first 8 bytes that are mandatory

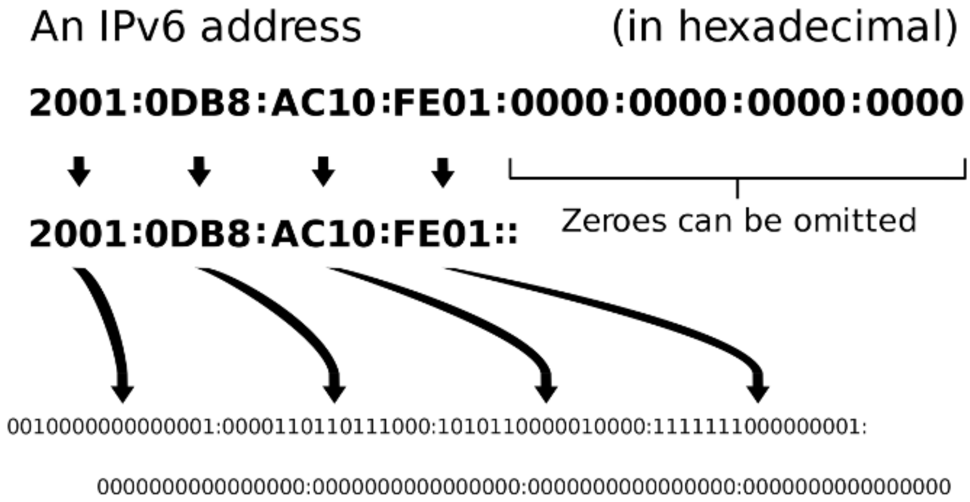
Type – for this case is code 194 showing that this option defines the datagram size

Length – one byte representing the length of the option, saying that the option value is represented on 4 bytes. It is followed by 4 bytes containing the option value; sizes less than 65536 bytes are not permitted and the routers will issue an error message if happens.

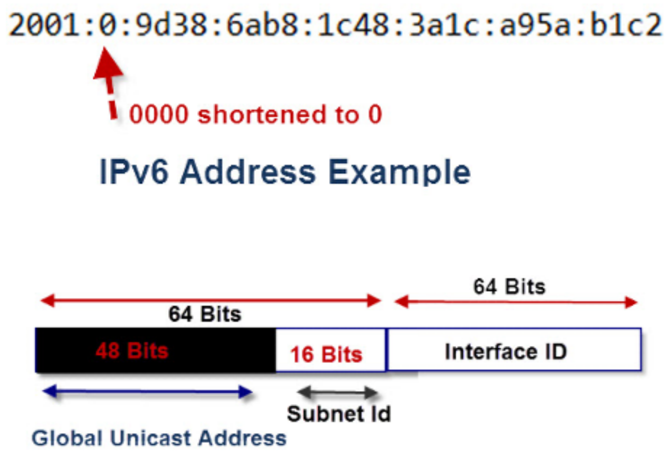
IPv6 Address Types



IPv6 Address Example

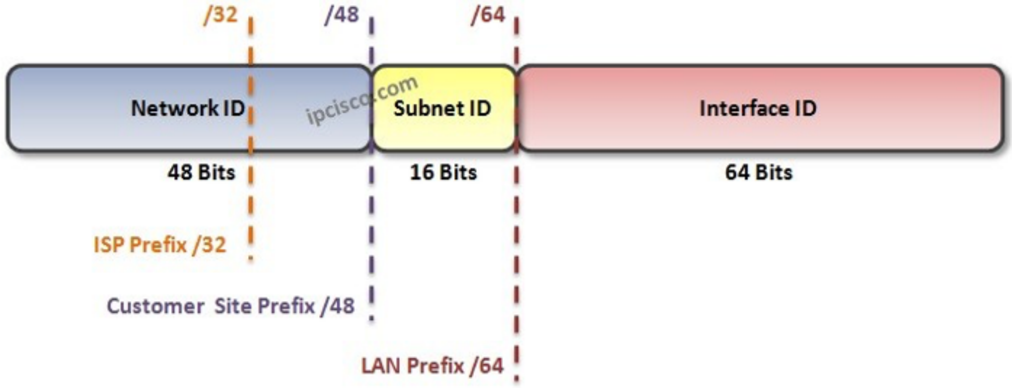


IPv6 Address Structure



IPv6 Address Structure

IPv6 End User Allocation



Common IPv6 Allocations

Prefix	/52 Subnets	/56 Subnets	/60 Subnets	/64 Subnets
/48	16	256	4096	65536
/52		16	256	4096
/56			16	256
/60				16
/64				1

Common IPv6 Subnet Prefixes