National University of Computer & Emerging Sciences

CS 3001 - COMPUTER NETWORKS

Lecture 17

Chapter 4

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Office Hours: 02:30 pm till 06:00 pm (Every Tuesday & Thursday)

Default HOP Limit (IPv6) Or TTL (IPv4) Values

Default TTL and Hop Limit values vary between different operating systems, here are the defaults for a few:

- Linux kernel 2.4 (circa 2001): 255 for TCP, UDP and ICMP
- Linux kernel 4.10 (2015): 64 for TCP, UDP and ICMP
- Windows XP (2001): 128 for TCP, UDP and ICMP
- Windows 10 (2015): 128 for TCP, UDP and ICMP
- Windows Server 2008: 128 for TCP, UDP and ICMP
- Windows Server 2019 (2018): 128 for TCP, UDP and ICMP
- MacOS (2001): 64 for TCP, UDP and ICMP

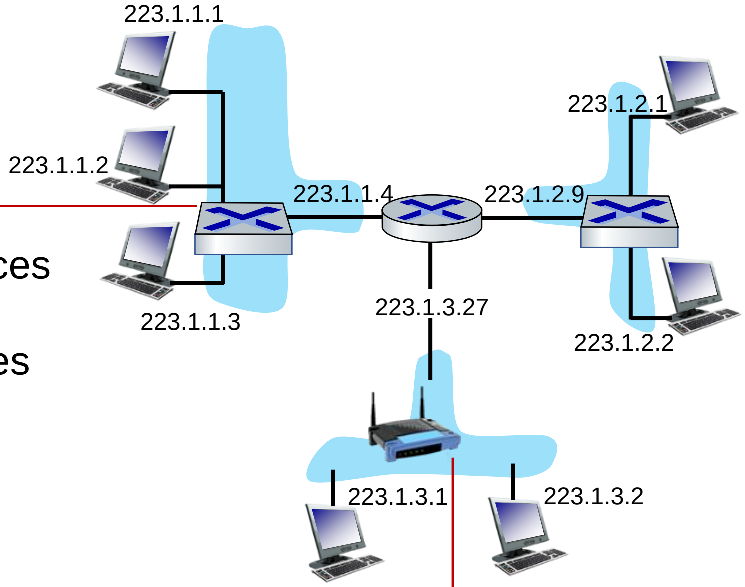
As you can see, the TTL or Hop Limit seen in packets from a host could, in part, be used to identify the operating system in use on that host.

IP addressing: introduction

Q: how are interfaces actually connected?

A: we'll learn about that in chapters 6, 7

A: wired Ethernet interfaces connected by Ethernet switches

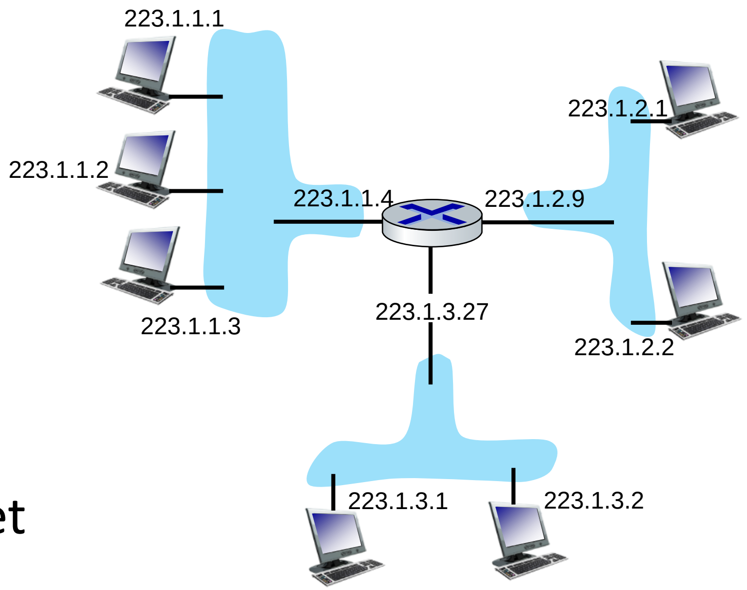


For now: don't need to worry about how one interface is connected to another (with no intervening router)

A: wireless WiFi interfaces connected by WiFi base station

Subnets

- *What's a subnet ?*
  - device interfaces that can physically reach each other without passing through an intervening router
- IP addresses have structure:
  - subnet part: devices in same subnet have common high order bits
  - host part: remaining low order bits

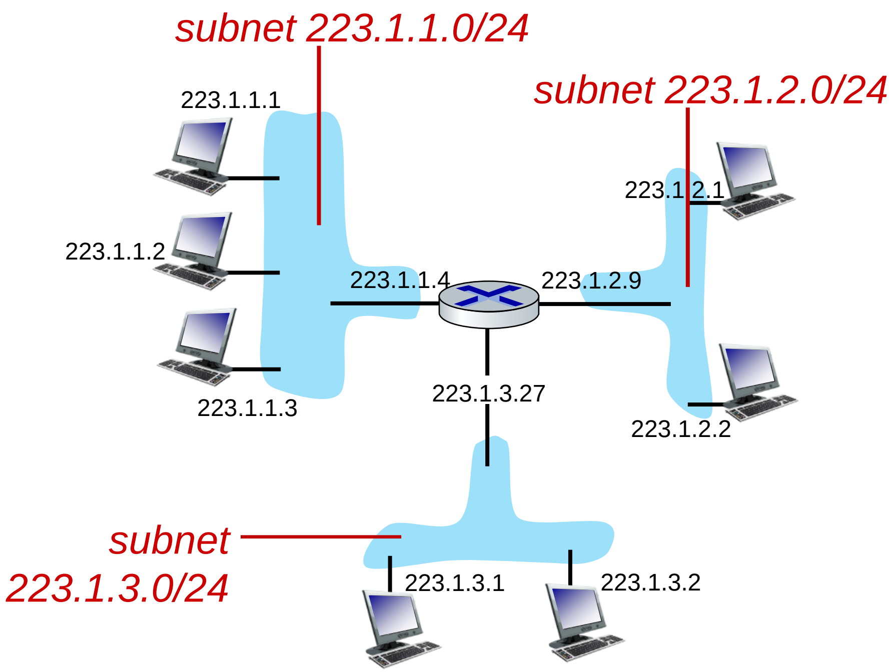


network consisting of 3 subnets

Subnets

Recipe for defining subnets:

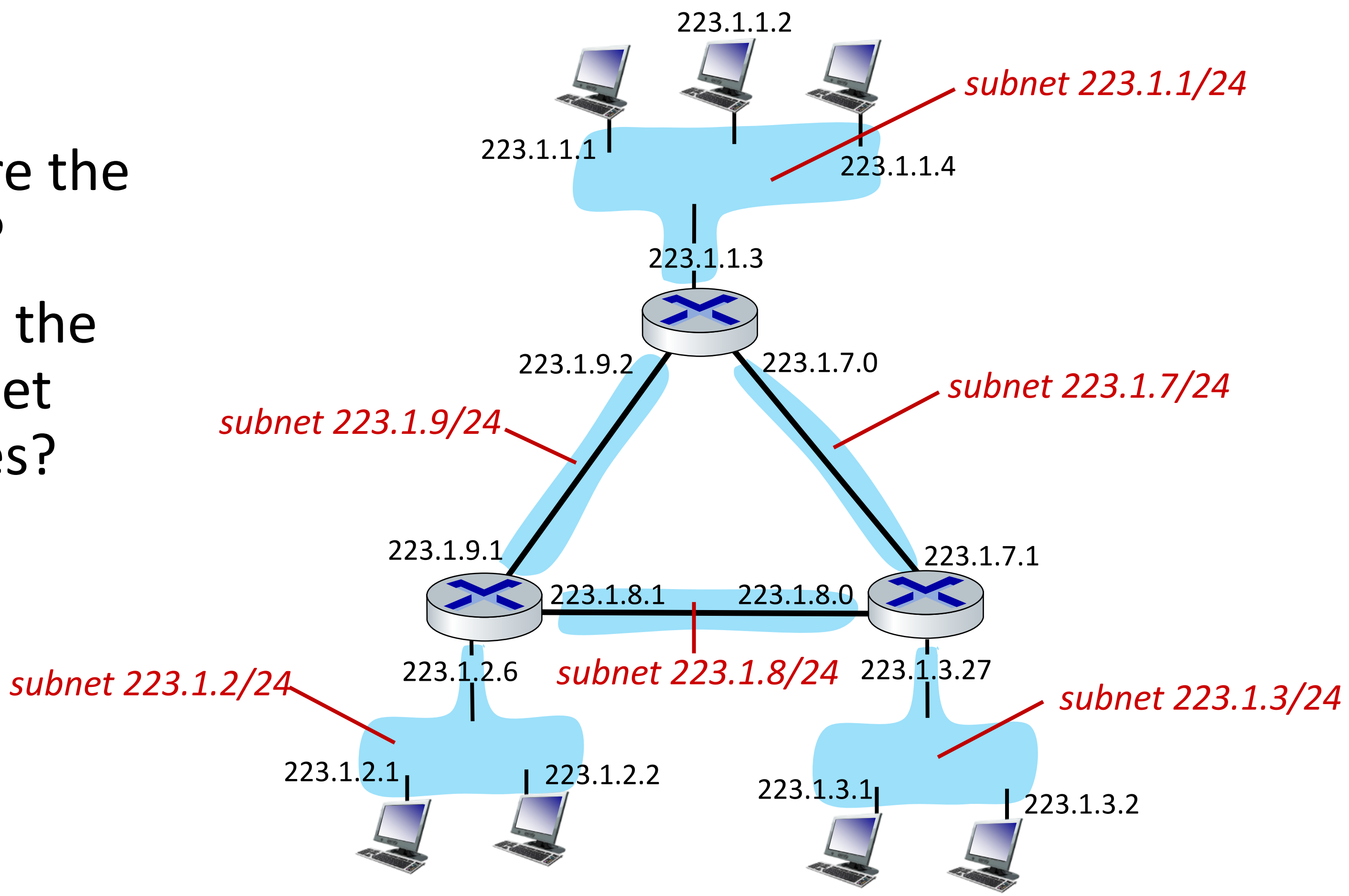
- detach each interface from its host or router, creating "islands" of isolated networks
- each isolated network is called a *subnet*



subnet mask: /24
(high-order 24 bits: subnet part of IP address)

Subnets

- where are the subnets?
- what are the /24 subnet addresses?



Subnetting

- Subnetting is the process of dividing a network (within a single IP network address space) into smaller sized networks called subnets

- It is transparent to the outside world, i.e. the outside world can only see one network and a single net ID, but internally, there can be multiple subnets, each having an ID similar to the parent network's net ID called subnet ID or network prefix or simply prefix

- Thus the tables in the routers of the internet are not affected, i.e. they don't need to have entries for any of the subnet, just the entry of the original (parent network) i.e., while only internal router of the corresponding network needs to have the subnet entries in it's tables

- IP addresses in Class A, B & C have two levels of hierarchy, i.e. *IP address = (net ID, host ID)* Subnetting creates another level of hierarchy, i.e. *IP address = (net ID, subnet ID, host ID)* Again, this subnet ID is transparent to the outside world, i.e. they will still see IP address = (net ID, host ID). Delivery of incoming IP packets from the internet to this network involves three steps now: *delivery to the site router*, *delivery to the subnet router*, *delivery to the end host*

Subnet Mask (SM)

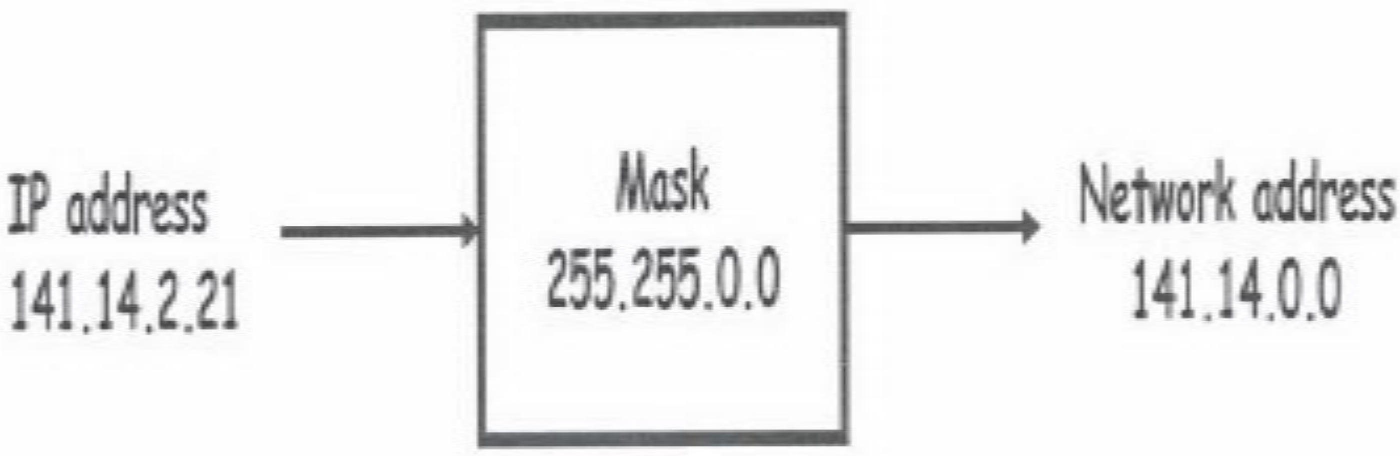
- Masking is the process of extracting the network address / net ID (if no subnetting is done) or subnet ID (if subnetting is done) from an IP address
- SM is a 32 bit **pattern / sequence** (not address) which has a **"1" in every network ID** & a **"1" in every subnet ID** (if any) bit **location** and a **"0" in every host ID bit location**.
- Subnet masking is performed (both at the host & the router) by applying "bit-wise-AND" operation between the IP Address & the subnet mask

- **Default masks (No subnetting)**: for Class A is 255.0.0.0, for Class B is 255.255.0.0, for Class C is 255.255.255.0, so from outer world (Global), subnet mask of unsubnetted network address 128.125.0.0 is 255.255.0.0 (since it is class B.)
- After subnetting network 128.125.0.0 network into 8 equal subnets, subnet mask will be 255.255.224.0 (visible only internally, invisible to the outside world.)
- All devices on the same subnet **must** have the same subnet mask. Furthermore, devices on different subnets **may** have the same subnet masks, but will have different subnet IDs
- When a host performs a **logical AND** between it's IP address & the subnet mask, it gets the net ID / subnet ID
- The network's internal router will have in it's **forwarding table 3 entry columns, i.e. i) subnet IDs of all the subnets, ii) their subnet masks & iii) their corresponding interfaces**
- **Question**: When a packet arrives at this router from the outside world for a host in one of the subnets, how does this router determine that the destination host resides on which subnet?
- **Answer**: The router performs a logical AND between the destination IP address it received and all the subnet masks in it's forwarding table. The result will be the subnet ID of one of the attached subnets. The router can now forward the incoming packet to this subnet.

Important Point: Net ID / Network Address of parent network (unsubnetted network) & first subnet may be the same, but their subnet masks will be different.

Subnet Mask (SM)

- Example 1: Class B network without subnetting
  - 141.14.2.21 10001101.00001110.00000010.00010101
  - 255.255.0.0 11111111.11111111.00000000.00000000
  - "Bit-wise and" 10001101.00001110.00000000.00000000



Examples of Classless IP Addressing

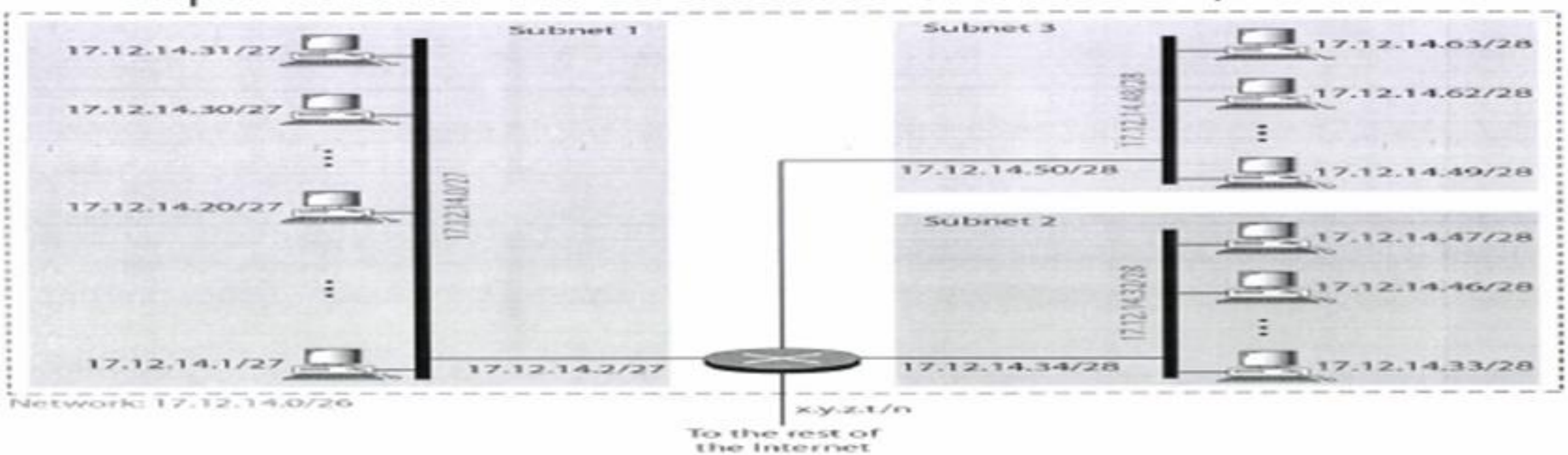
Example of Classless IP Addressing

- An ISP gets a block of IP addresses. The Block is 200.23.16.0/20 . The size of the block is $2^{12} = 4096$. The ISP has 8 customers (organizations), each requiring a "block" of size 512

ISP's block	11001000	00010111	00010000	00000000	200.23.16.0/20
Organization 0	11001000	00010111	00010000	00000000	200.23.16.0/23
Organization 1	11001000	00010111	00010010	00000000	200.23.18.0/23
Organization 2	11001000	00010111	00010100	00000000	200.23.20.0/23
...	.....			....	....
Organization 7	11001000	00010111	00011110	00000000	200.23.30.0/23

Example of Classless IP Addressing

- Organization was assigned a block 17.12. 14 .0/26 (Size of block is 64).Organization has three departments. Three subnets of sizes 32, 16 and 16



Difference between Classful, CIDR, FLSM & VLSM in IP Addressing

These four terms can be categorized into two categories:

- ***Classful and CIDR*** — these have to do with the size of networks as they are assigned from IANA (a sub function of ICANN).
- ***FLSM and VLSM*** — (i.e. Fixed Length Subnet mask & Variable Length Subnet Mask.) These have to do with how the administrator allocate your IP space within your networks (assignment by the local network administrator.)

"FLSM & VLSM refer to how IP address space is assigned within each organization (by their **local network administrator**.) Classful and CIDR refer to how IP address space is allocated (**by ICANN - IANA**.)"

Summary

- Classful addressing is ICANN assigning IP space from Class A, B, or C blocks (legacy) & local administrator can then apply FLSM (if required)
- Classless is ICANN assigning IP space in any size block, as required (modern standard) and local administrator can then apply FLSM or VLSM (if required)
- CIDR is simply classless, but VLSM already applied by ICANN and then assigned to an organization.
- FLSM mandates that every IP subnet within your deployment be the same size (legacy).
- VLSM allows IP subnets within your deployment to be of different sizes (modern standard.)

Fixed Length Subnet Mask (FLSM) – Example Video (Watch First)

- For revision of FLSM discussed in the Class, please watch and review my video shared via Google Classroom. (Please watch the complete video, where I explain & solve an example of FLSM in detail.)

Variable Length Subnet Mask (VLSM) – Example Video (Watch Second)

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Very Important topic of Computer Networks !!!!!!!

IP addresses: how to get one?

That's actually two questions:

1. Q: How does a *host* get IP address within its network (host part of address)?
2. Q: How does a *network* get IP address for itself (network part of address)

How does *host* get IP address?

- hard-coded by sysadmin in config file (e.g., /etc/rc.config in UNIX)
- DHCP: Dynamic Host Configuration Protocol: dynamically get address from as server
  - "plug-and-play"

DHCP: Dynamic Host Configuration Protocol

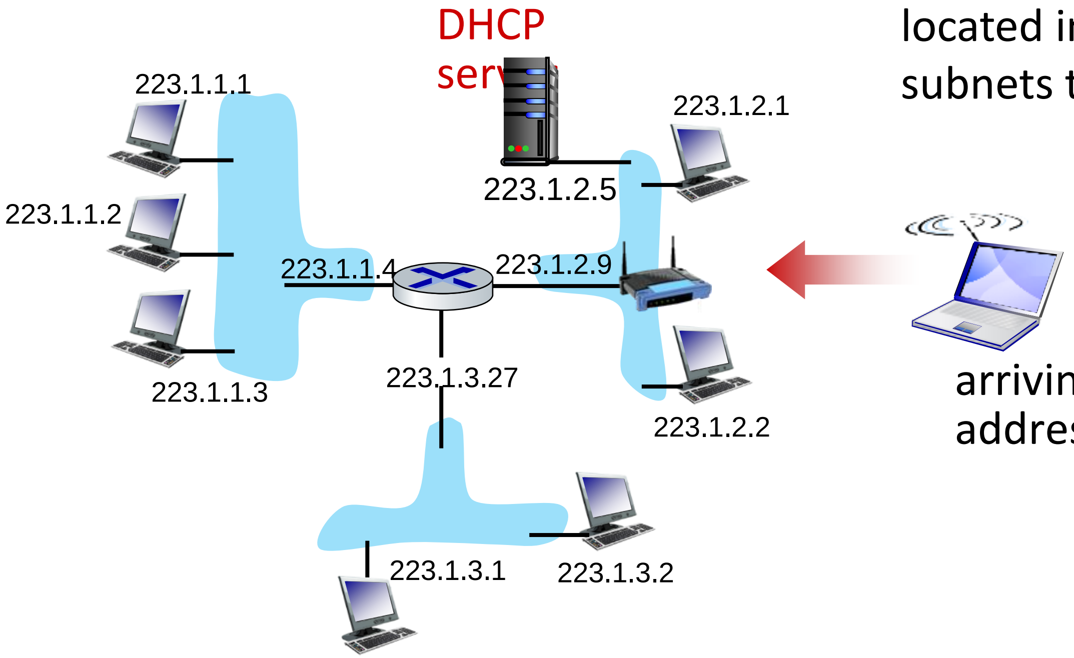
goal: host *dynamically* obtains IP address from network server when it "joins" network

- can renew its lease on address in use
- allows reuse of addresses (only hold address while connected/on)
- support for mobile users who join/leave network
  - App layer protocol used by the Network Layer
  - DHCP uses UDP at the Transport Layer

DHCP overview: (DHCP Summary)

- host broadcasts DHCP discover msg [optional]
- DHCP server(s) responds with DHCP offer msg [optional]
- host requests IP address: DHCP request msg
- DHCP server sends address: DHCP ack msg

DHCP client-server scenario

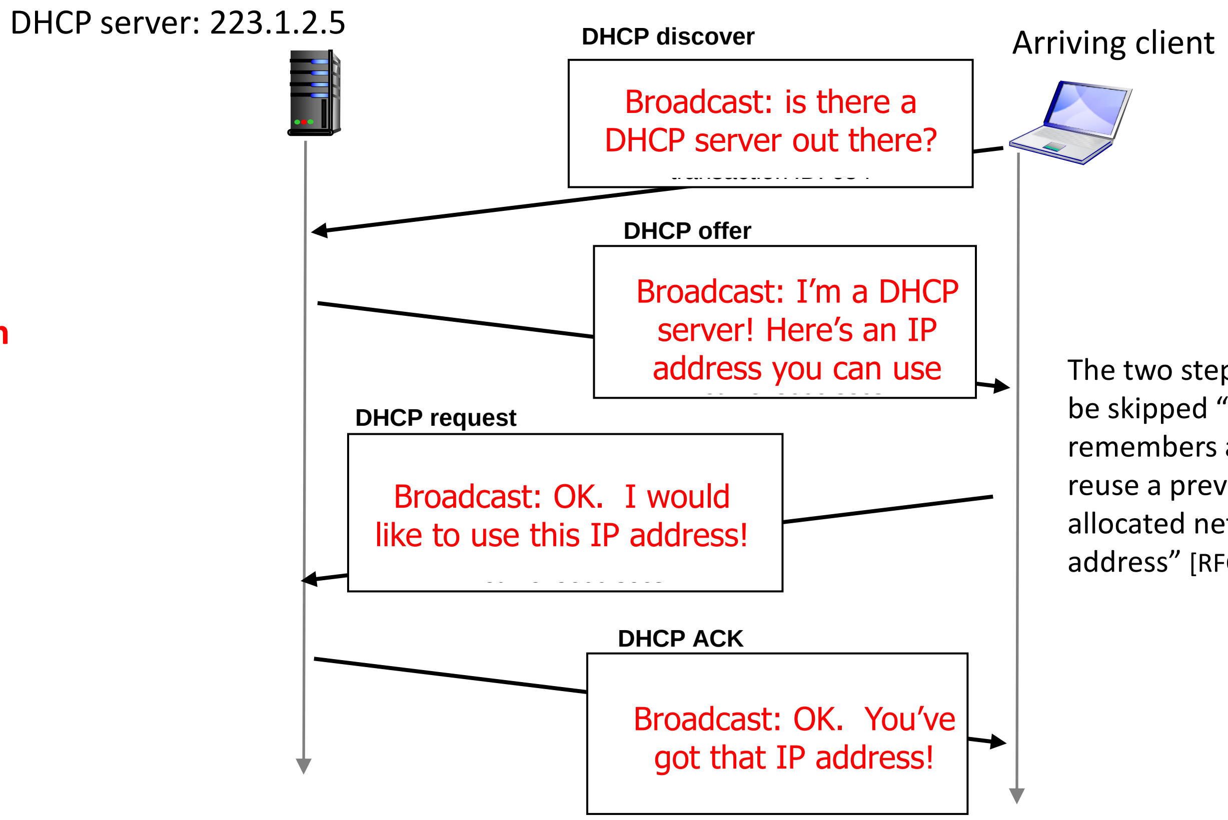


Typically, DHCP server will be co-located in router, serving all subnets to which router is attached

arriving DHCP client needs address in this network

DHCP client-server scenario

- **Port 67 & 68 are standard ports in DHCP Protocol for DHCP Server & DHCP Client respectively**



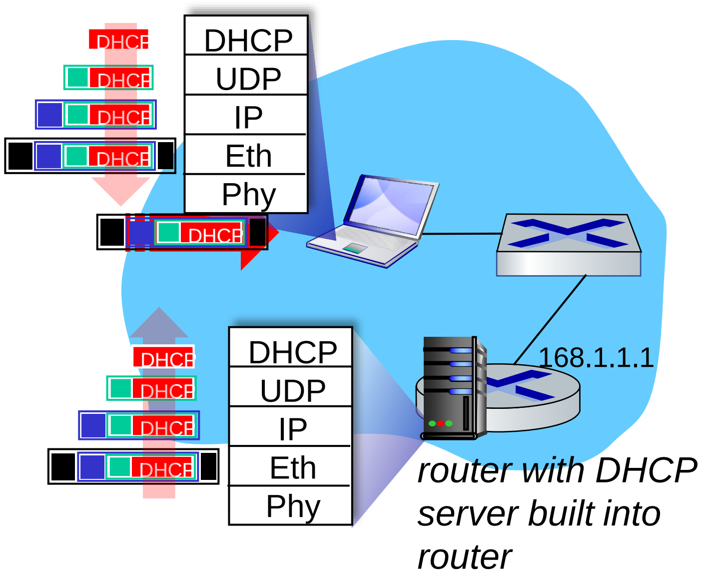
The two steps above can be skipped "if a client remembers and wishes to reuse a previously allocated network address" [RFC 2131]

DHCP: more than IP addresses

DHCP can return more than just allocated IP address on subnet:

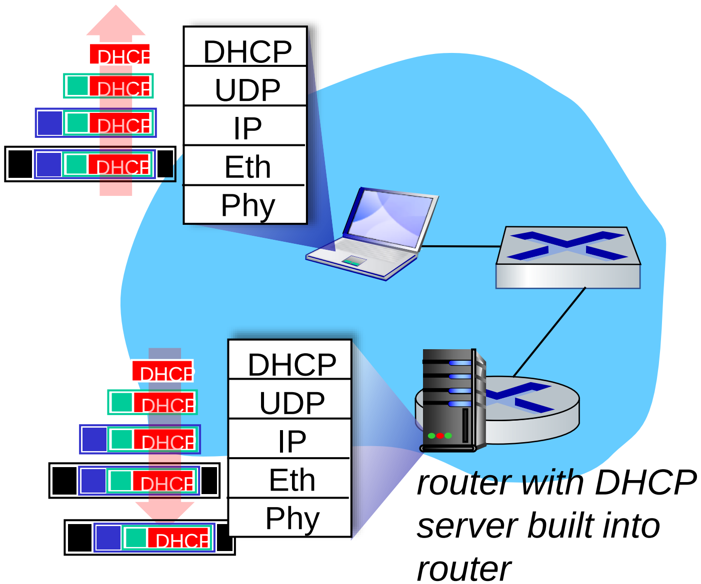
- address of first-hop router for client
- name and IP address of DNS sever
- network mask (indicating network versus host portion of address)

DHCP: example



- Connecting laptop will use DHCP to get IP address, address of first-hop router, address of DNS server.
- DHCP REQUEST message encapsulated in UDP, encapsulated in IP, encapsulated in Ethernet
- Ethernet frame broadcast (dest: FFFFFFFFFFFF) on LAN, received at router running DHCP server
- Ethernet de-mux'ed to IP de-mux'ed, UDP de-mux'ed to DHCP

DHCP: example



- DCP server formulates DHCP ACK containing client's IP address, IP address of first-hop router for client, name & IP address of DNS server
- encapsulated DHCP server reply forwarded to client, de-muxing up to DHCP at client
- client now knows its IP address, name and IP address of DNS server, IP address of its first-hop router

IP addresses: how to get one?

Q: how does *network* get subnet part of IP address?

A: gets allocated portion of its provider ISP's address space

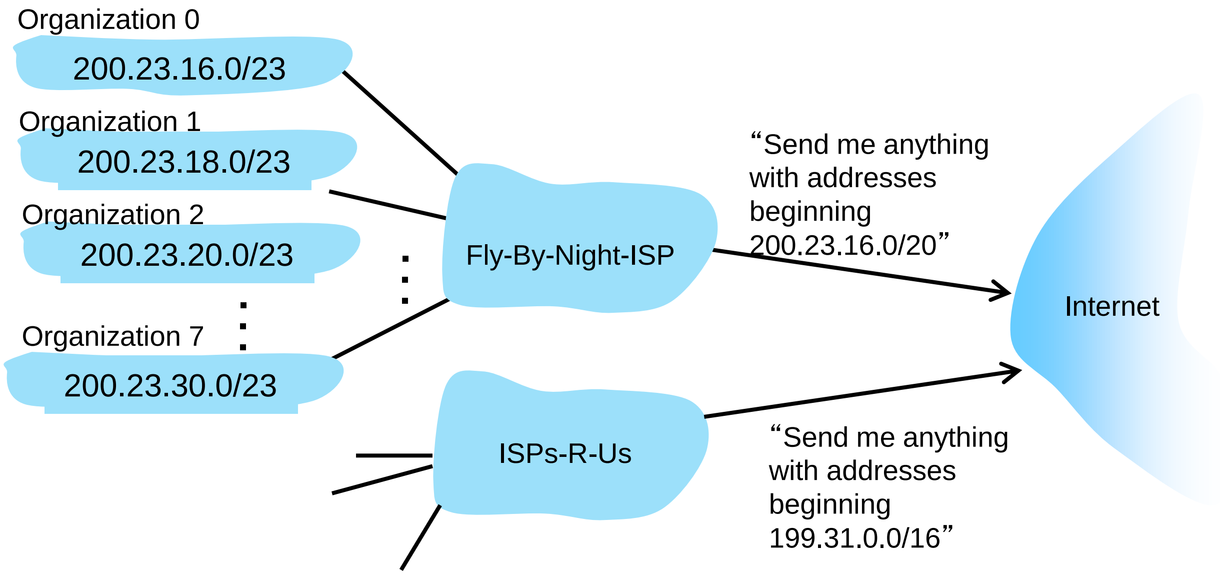
ISP's block	11001000 00010111 00010000 00000000	200.23.16.0/20

ISP can then allocate out its address space in 8 blocks:

Organization 0	11001000 00010111 00010000 00000000	200.23.16.0/23
Organization 1	11001000 00010111 00010010 00000000	200.23.18.0/23
Organization 2	11001000 00010111 00010100 00000000	200.23.20.0/23
...	….. ….	….
Organization 7	11001000 00010111 00011110 00000000	200.23.30.0/23

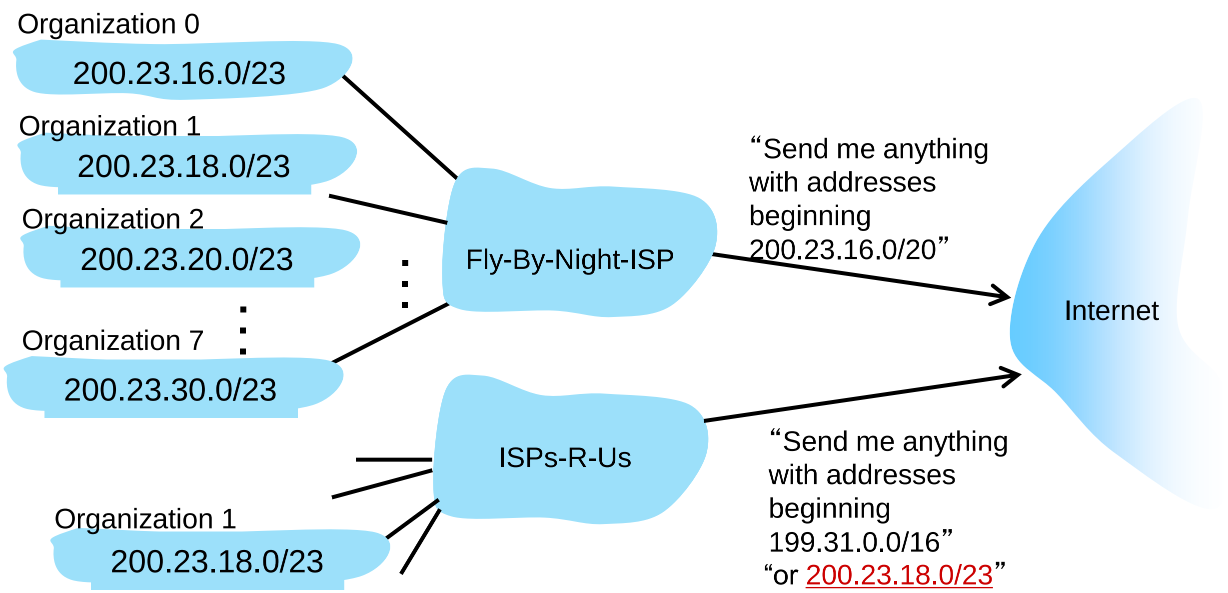
Hierarchical addressing: route aggregation
(Route Summarization / Address Aggregation)

hierarchical addressing allows efficient advertisement of routing information:



Hierarchical addressing: more specific routes

- Organization 1 moves from Fly-By-Night-ISP to ISPs-R-Us
- ISPs-R-Us now advertises a more specific route to Organization 1



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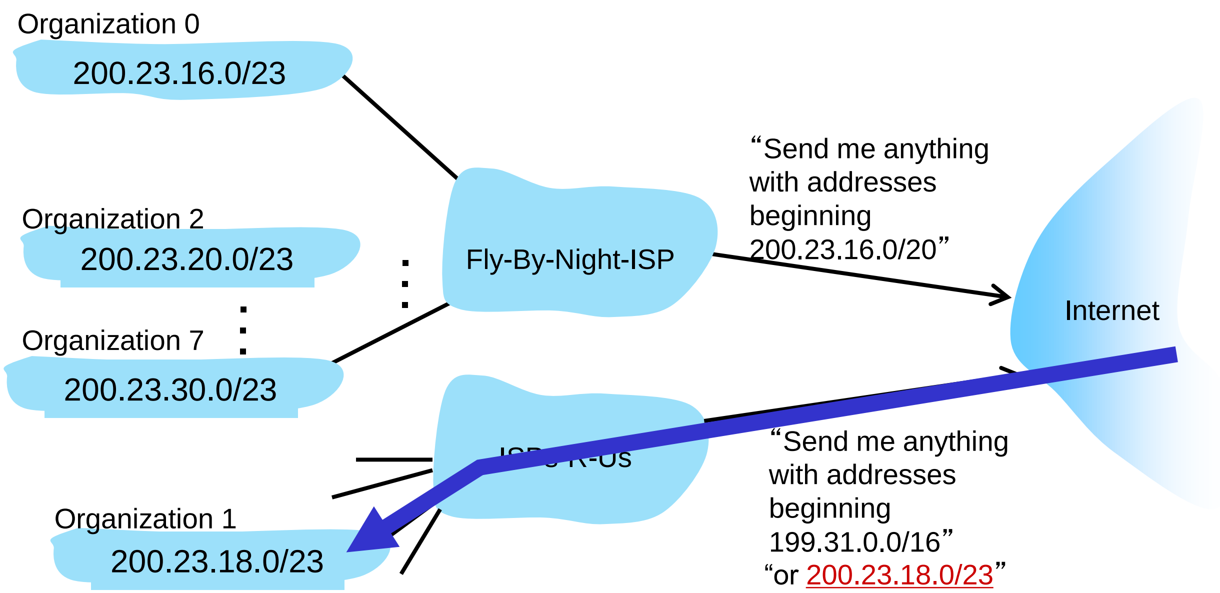

Hierarchical addressing: route aggregation (Route Summarization / Address Aggregation)

- As was shown in the previous Figure, the ISP Fly-By-Night advertises to the outside world that it should be sent any datagrams whose first 20 address bits match 200.23.16.0/20.

- The rest of the world need not know that within the address block 200.23.16.0/20 there are in fact eight other organizations, each with their own subnets.

- This ability to use a single prefix to advertise multiple networks is often referred to as address aggregation (also route aggregation or route summarization or loosely can be called supernetting).

- This works extremely well when addresses are allocated in blocks to ISPs and then from ISPs to client organizations.

Hierarchical addressing: route aggregation (Route Summarization / Address Aggregation)

What if the addresses are not allocated in such a hierarchical manner?

- For example , what would happen if ISP Fly-By-Night acquires ISPs-R-Us and then has Organization 1 connect to the Internet through its subsidiary ISPs-R-Us?

- As was shown in the Figure, ISPs-R-Us owns the address block 199.31.0.0/16 but Organization 1's IP addresses are unfortunately outside of this address block.

- What should be done here?

Hierarchical addressing: route aggregation (Route Summarization / Address Aggregation)

Proposed Solutions

- **Organization 1 could renumber all of its routers and hosts to have addresses within the ISPs-R-Us address block.**

  - It's a costly solution.
  - Organization 1 might well be reassigned to another subsidiary in the future.

- **Organization 1 keeps its IP addresses in 200.23.18.0/23 and ISPs-R-Us advertises the block of addresses for Organization 1 (in addition to its own block of addresses.)**

  - When routers in the Internet see the address block 200.23.16.0/20 (from Fly-By-Night) and 200.23.18.0/23 (from ISPs-R-Us), and want to route to an address in the block 200.23.18.0/23, they will use longest prefix matching and route towards ISPs-R-Us as it advertises the longest (most specific) address prefix that matches the destination address.

Longest prefix matching

longest prefix match

when looking for forwarding table entry for given destination address, use *longest* address prefix that matches destination address.

Destination Address Range	Link interface
11001000 00010111 00010*** ********	0
11001000 00010111 00011000 ********	1
11001000 00010111 00011*** ********	2
otherwise	3

examples:

11001000 00010111 00010110 10100001 which interface?

11001000 00010111 00011000 10101010 which interface?

Longest prefix matching

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when looking for forwarding table entry for given destination address, use *longest* address prefix that matches destination address.

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otherwise	3

match!

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match!

examples:

11001000	00010111	00010110	10100001	which interface?
11001000	00010111	00011000	10101010	which interface?

Route Summarization / Address Aggregation

- For revision of Route Summarization / Address Aggregation (Supernetting) discussed in the Class, please watch and review my video shared via Google Classroom. (Please watch the complete video, where I explain & solve an example for this in detail.)

Important topic of Computer Networks !!!!!!!

IP addressing: last words ...

Q: how does an ISP get block of addresses?

A: ICANN: Internet Corporation for Assigned Names and Numbers http://www.icann.org/

- allocates IP addresses, through 5 regional registries (RRs) (who may then allocate to local registries)
- manages DNS root zone, including delegation of individual TLD (.com, .edu , …) management

Q: are there enough 32-bit IP addresses?

- ICANN allocated last chunk of IPv4 addresses to RRs in 2011
- NAT (next) helps IPv4 address space exhaustion
- IPv6 has 128-bit address space

"Who the hell knew how much address space we needed?" Vint Cerf (reflecting on decision to make IPv4 address 32 bits long)

Quiz 3 - Chapter 3

- Quiz 3 for Chapter 3 taken during the lecture time