# CSCD 330
# Network Programming
## Spring 2017

## Lecture 15
## Network Layer
## IP Addressing

Reading: Chapter 4

# Network Layer

- 4. 1 Introduction
- 4.2 Virtual circuit and datagram networks
- 4.3 What's inside a router
- 4.4 IP: Internet Protocol
  - Datagram format
  - Fragmentation
  - IPv4 addressing
- 4.5 Routing algorithms
  - Link state
  - Distance Vector
  - Hierarchical routing
- 4.6 Routing in the Internet
  - RIP
  - OSPF
  - BGP
- 4.7 Broadcast and multicast routing

# Introduction

- Last time, began the network layer
- Provides a best effort service most of the time
- Alternate model, ATM, Frame-relay tries to create a virtual circuit on top of the best effort datagram environment
- Talked about router functions
- Today, get into addressing …

# IP Version 4 Header

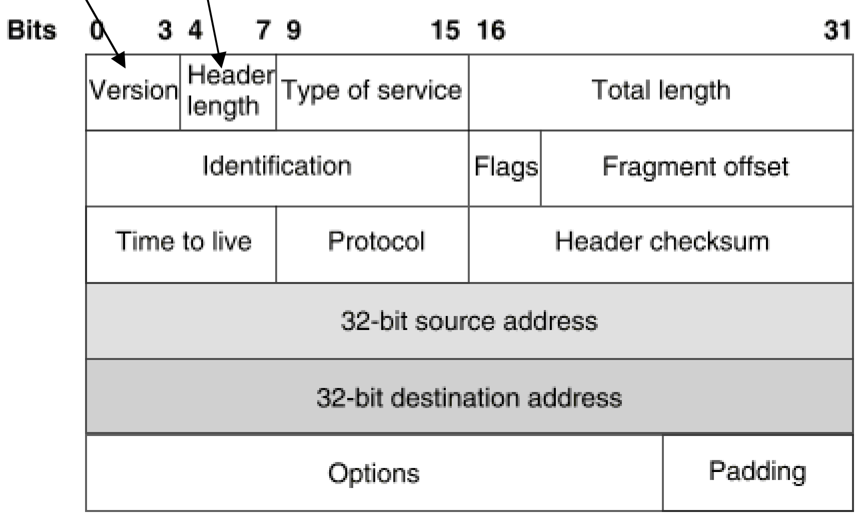
- IPv4 Frame Header
  - Designed to handle addressing and routing challenges
  - Think about trying to route through a network where …
    - Physical network varies – different capacity of links
    - Maximize efficiency – means minimize redundancy
    - Account for both uncertain and certain delivery
    - Handle errors
  - Explains the IP packet header …

# IPv4 Header

- Fields Explained
  - Version – IPv4 or IPv6 - will contain 4 or 6
    - Header Length – Length in 32 bit words (4  bytes)

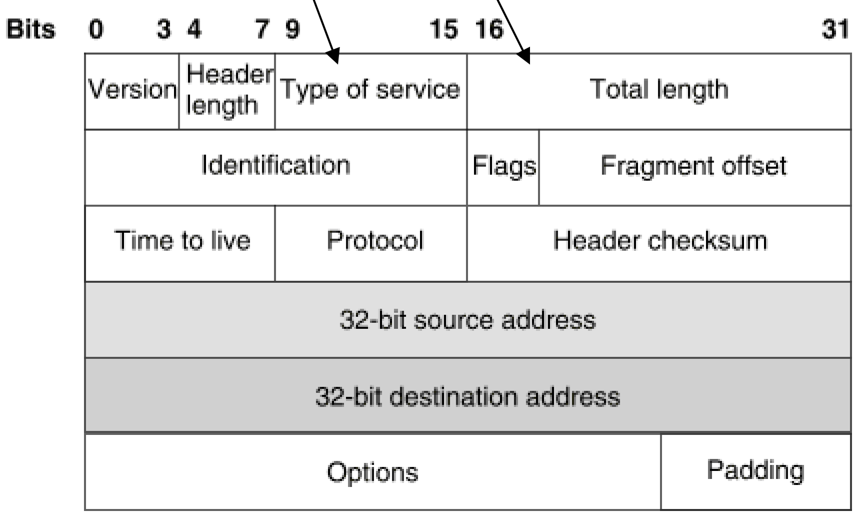
      Most of the time its 5 – for 20 bytes of header,

      but it can vary due to options



# IPv4 Header

- Type of Service – Application dependent – applications can say to treat packets differently
  - Length – Maximum length packet in bytes
    - 16 bits so, packets can be 65,535 bytes long

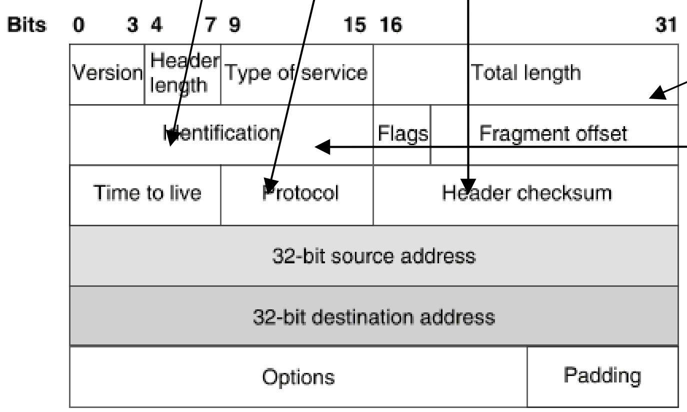


# IPv4 Header

- Time to Live (TTL) – Used to be a time, now its more a hop count – don't want packets circulating through network forever
  - Routers decrease this by 1, default 64
- Protocol – Upper layer protocol, TCP or UDP or ICMP
- Checksum – Only of the IP Header!

  Computed by adding header as 16 bit words using ones complement arithmetic and then taking the one's complement of the result, Routers compute it too.

  At destination, compare it to value stored in this field and if different discard the packet




Line Two Deals with Fragments

Fragment offset – 13 bits, in bytes/8

Fragment Identification – 16 bits, identifier set by sender

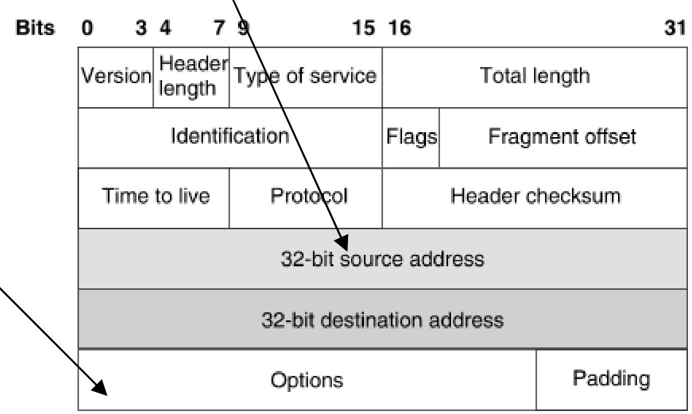
Flags – 3 bits, indicates fragments

# IPv4 Header

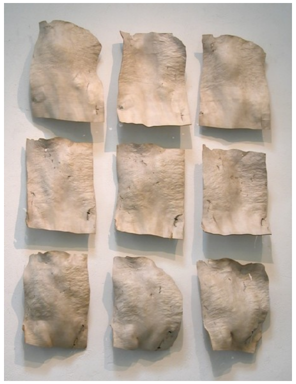
- Source Address 32 bits long
- Destination Address 32 bits long

  Gives us $2^{32}$ addresses or over 4 billion addresses

- Options field – used sometimes



# Fragmentation



- One design decision helped Internet remain flexible
  - Able to accommodate multiple network technologies – Packet Fragmentation
  - Packets can be divided so can pass through links of different sizes
  - Some typical maximum packet sizes
    - Ethernet – 1500 bytes long
    - FDDI – 4500 bytes long
    - Point to point (PPP) – 532 bytes long

# Fragmentation

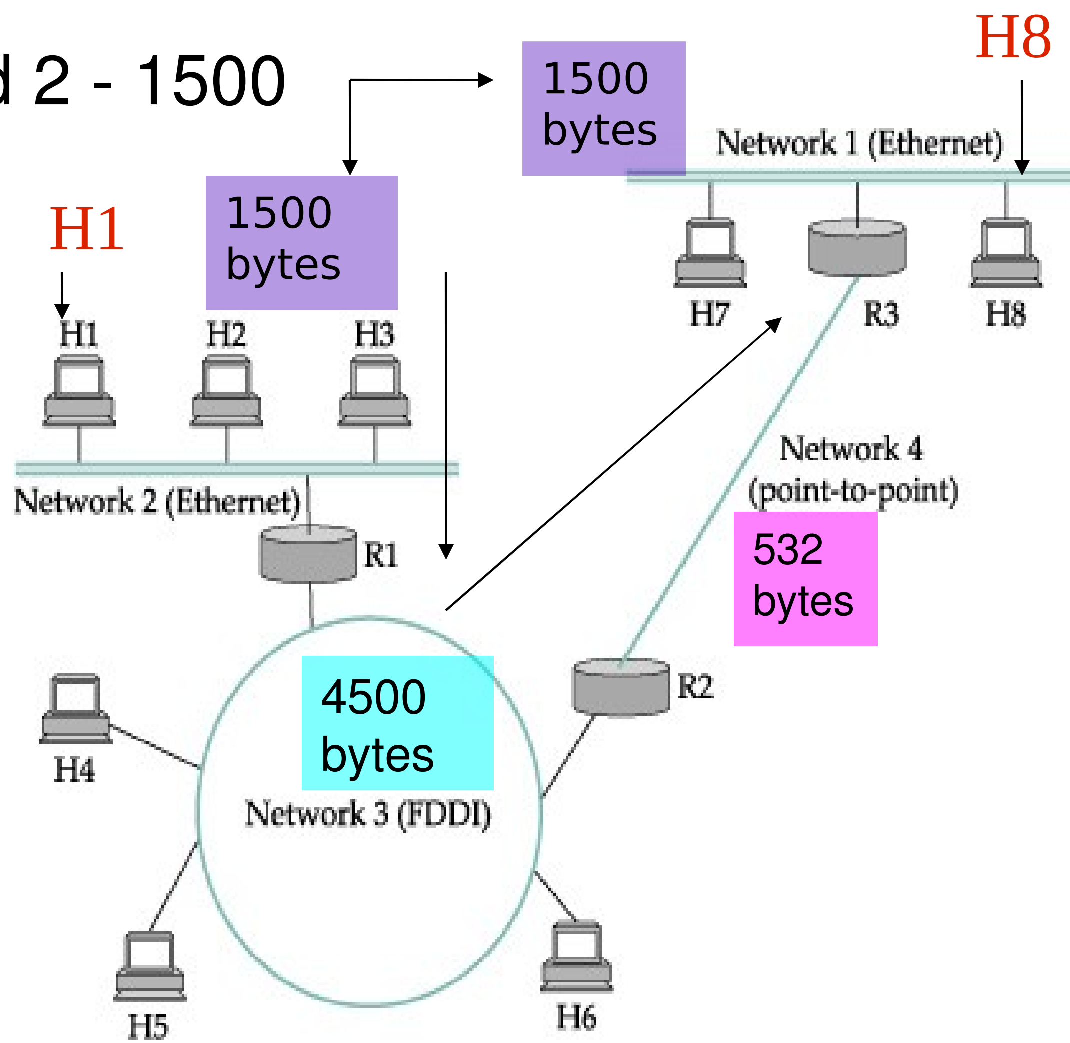
- Every network sets its MTU
  - Maximum Transmission Unit
    - Largest Frame Size of Data link layer
  - Previous slides shows -> MTU varies with link type
    - IP packets need to adjust to that frame size
  - Think of squeezing packets through different sized pipes
  - If MTU along the way, is smaller than IP packet size on your network
    - Datagram must fit within payload of link layer frame so …
    - Fragmentation occurs **in router** – when datagram size > than network MTU it must travel over

# Example Fragmentation Links

- MTU's
- Ethernet, Networks 1 and 2 - 1500
- FDDI, Network 3 – 4500
- PPP, Network 4 - 532

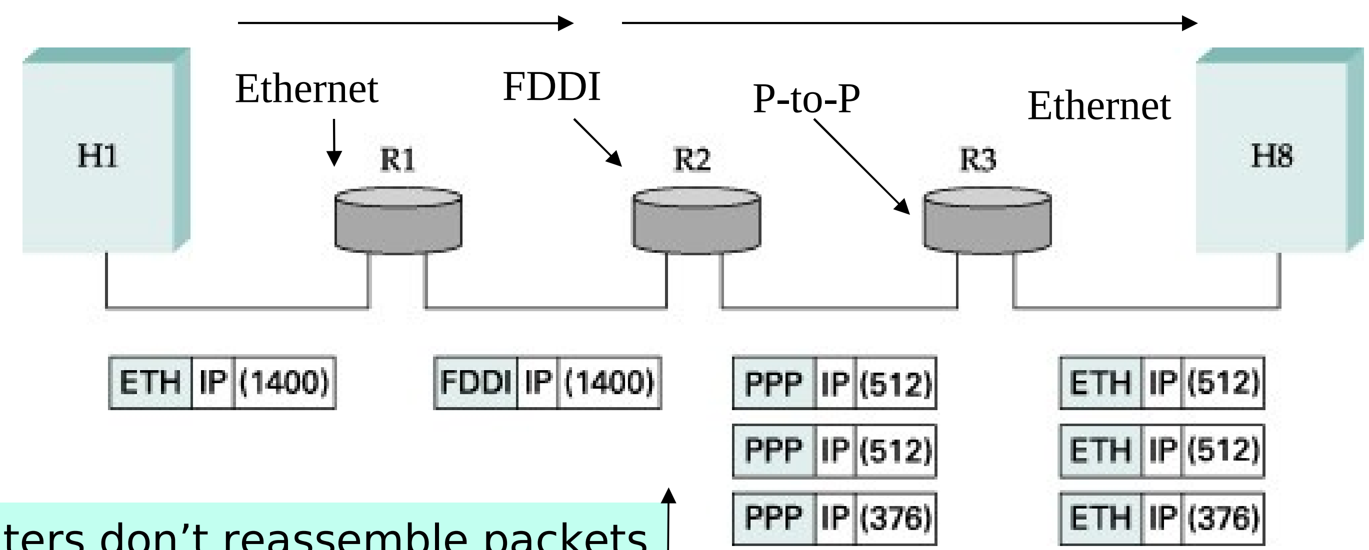
- H1 sends datagram to H8, **1400** bytes data and **20** bytes header …. **1420** total

Do we Need to fragment?



# Fragmentation: Example Network

- Ethernet R1 and FDDI R2 – No fragmentation needed
  - Why is that?
- PPP R3 – Fragmentation is needed




Routers don't reassemble packets
Host does packet reassembly

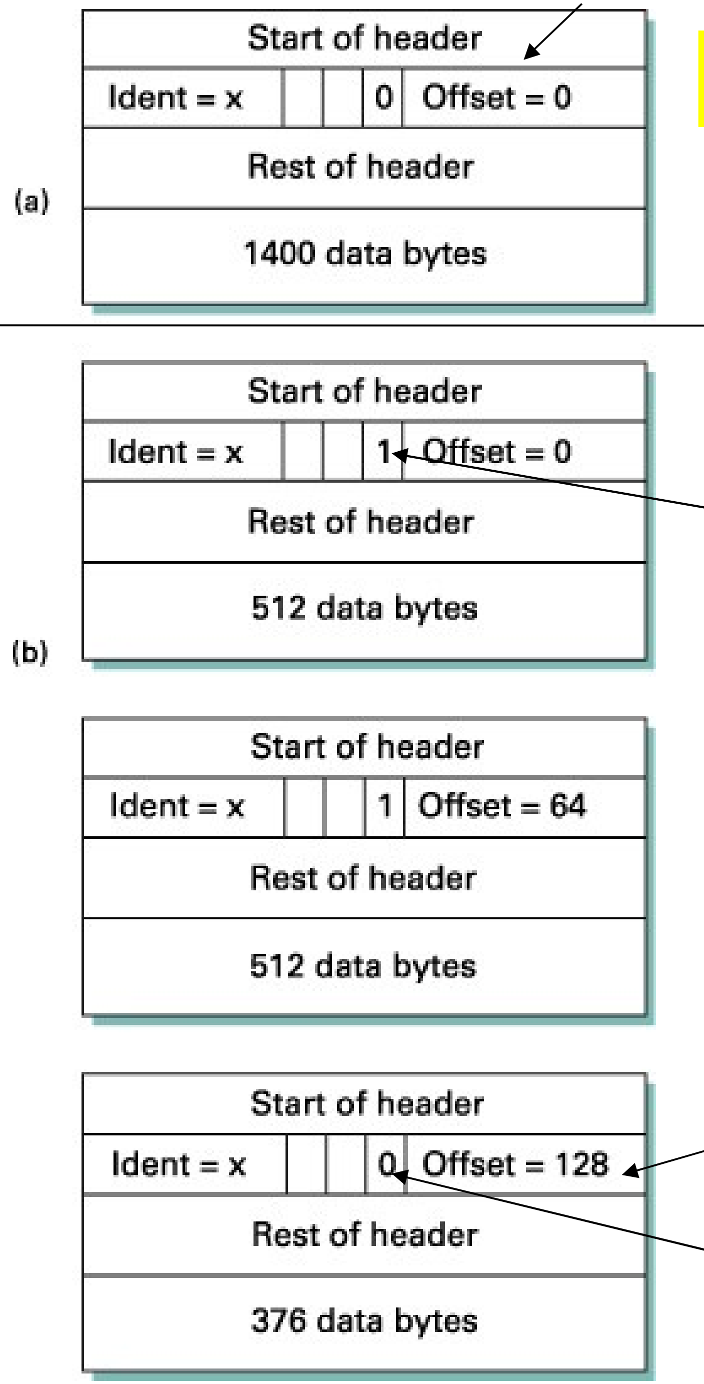
## Original Packet

Bytes
1400

512

512

376




**Example of fragment**

512 bytes of data + 20 bytes of header, why this size?

Flag = 1 for more fragments follow

Offset is in groups of 8 bytes

512/8 = 64

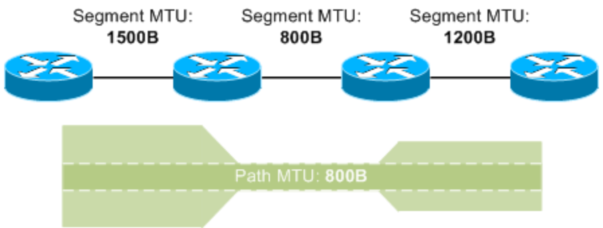
Offset = 2 x 64 = 128

Flag = 0, no more fragments

# Fragments  Reassembly

- IF all fragments don't arrive,
  - What do you do?
  - Discards ones that have arrived
  - Packet will need to be resent
  - Consequently, fragments can waste resources
    - Not recommended !!!
    - Hosts encouraged to perform MTU path discovery
    - Avoid fragments if possible

# Fragmentation Discouraged




- To avoid fragmentation, hosts commonly use path MTU discovery to find smallest MTU along path
- Path MTU discovery involves sending various size datagrams until they do not require fragmentation along the path
- Most links use MTU >= 1500 bytes today
- Nice short summary of MTU Path discovery
  http://packetlife.net/blog/2008/aug/18/path-mtu-discovery/


Network Addressing

# Addressing Global Level

- Look at how IP level performs addressing of packets ...
- Ethernet address scheme is flat

  MAC address doesn't provide for much structure or hierarchy

  00:13:02:BA:43:56
- IP address is divided into Two parts
  - **Host** and **network** part
  - Addresses are also hierarchical
    - Allows network to scale
    - Routing tables only need network number
    - Local delivery inside a network doesn't involve router at all

# Forwarding in General

- Forwarding Datagrams
  - Source host sends datagram to destination host
  - Passes through possibly several routers
    - Router, "Is Source on Same Network as Destination?"
    - Compares network part of destination with network part of address for each of its interfaces
      - **If match**, destination on same physical network
        - » Packet can be delivered
      - **If no match**, sends datagram to next router
        - » Router chosen is "next hop" router
        - » Found via forwarding table


# IP Addresses

# IP Addressing An Evolution

- IP Addresses and Grouping together to form networks
  - Didn't happen by accident
  - Evolving process
  - First attempt
    - Divide addresses into rigid categories
  - Then, more flexible way of addressing
    - Subnetting
  - Still working on it … IPV6 is in the works

# IP Addresses RFC 1166

- Each host on Internet has unique 32 bit IP address
- Each address has two parts: netid and hostid
- hostid simply the number of the host on that network
- netid unique - Administered by
  - American Registry for Internet Numbers (ARIN) or
  - Reseaux IP Europeens (RIPE) or
  - Asia Pacific Network Information Centre (APNIC)
- Each host has Separate address
- Dotted-Decimal Notation
- IP address of 10000000 10000111 01000100 00000101

  is 128. 135. 68. 5

  Called Dotted-decimal notation

  Each part is an octet, 8 bits

# Classful Addressing

- Classful addressing, formally adopted as part of the Internet Protocol (IP) in RFC 791, 1981
  - Internet's first major addressing scheme
- There were three address classes to chose from:
  - A, B, or C, corresponding to 8-bit, 16-bit, or 24-bit network prefixes
  - No other prefix lengths were allowed
  - Not very flexible to needs of organizations

# Classful Addresses

**Class A**

Starts with 0

| 1 bit | 7 bits | 24 bits |
|---|---|---|
| 0 | netid | hostid |

- 128 networks with up to ~16 million hosts

**1.0.0.0 to 127.255.255.255**

**Class B**

Starts with 2

| 2 bits | | 14 bits | 16 bits |
|---|---|---|---|
| 1 | 0 | netid | hostid |

- 16,384 networks with up to ~65,000 hosts

**128.0.0.0 to 191.255.255.255**

**Class C**

Starts with 3

| 3 bits | | | 21 bits | 8 bits |
|---|---|---|---|---|
| 1 | 1 | 0 | netid | hostid |

- ~2 million networks with up to 256 hosts

**192.0.0.0 to 223.255.255.255**

# Classful Address Examples

- Upon installing a new Internet connection, network engineer
  - Requested a Class A, B, or C network, depending on expected size of the installed network
  - For example
  - U.S. Department of Defense
    - Large network, got a  Class A network
  - University of Maryland,
    - Mid-sized network, got a Class B network
  - Small consulting firm
    - Small network, got a Class C network

# Problems with Classful Addressing

- Soon became apparent that classful addressing was inadequate
- For example, a reasonably sized company
  - Class C, with 254 IP addresses, would be too small
- Next larger choice would be a
  - Class B, providing 65,534 IP addresses, too big
  - Unlikely that thousands of hosts would be located on a single Ethernet LAN
- How could we fix this?

# Subnetting to the Rescue

- What many network engineers desired was
  - Ability to take Class B and break its 65,534 addresses into 100-200 smaller networks of 200-300 addresses each
- These smaller networks became known as Subnets, and a standard scheme called subnetting was formalized in RFC 950
- Was in 1985 … around 25 + years ago

RFC that describes how it works

http://www.faqs.org/rfcs/rfc950.html

# Subnets and Subnet Masks

- Subnetting splits host field
  - Subnet + host fields, creates a three-part address
    - Network + Subnet + host

  - **Network field** remains unchanged,
  - You start with the **Classful** classification, then borrow bits from host to make your subnets

# Subnets and Subnet Masks

- When subnet created, engineer also creates subnet mask,
- 32 bits long, dotted decimal format, like IP address
    - Purpose: Lets routers identify portion IP address that's related to network
    - Each bit is either 1 to identify bit positions in the network and subnet fields, or 0 to identify bit positions in host field
    - Then, the mask is AND'd with IP Address

      255 = What is this value in binary?

      11111111 by the way

# Subnet Mask

- Want only the network portion of the address

  Network part – so **and network part + 1's** to

  preserve the network part

- The host part will be zero'd out

  Host part – so **and host part + 0's**

  to zero out this part

- Routers only care about the network part of the IP Address
- Mask then, is composed of all 1's for the network portion and 0's for the host.
- See some examples ...

# Example: Subnet Mask

- Example 1.:  Say 16 bits of  network address
- 191.70.55.130
- 10111111.10000110.00110111.10000010
- What would the mask look like?

- Example 2: Say 24 bits of network address
- 192.168.5.10
- 11000000.10101000.00000101.00001010
- What would the mask look like?

# Example Apply a Subnet Mask

- IP Address: 187.199.127.5

  Subnet mask: 255.255.255.0

- Anding two together gives us

  Network part: 187.199.127

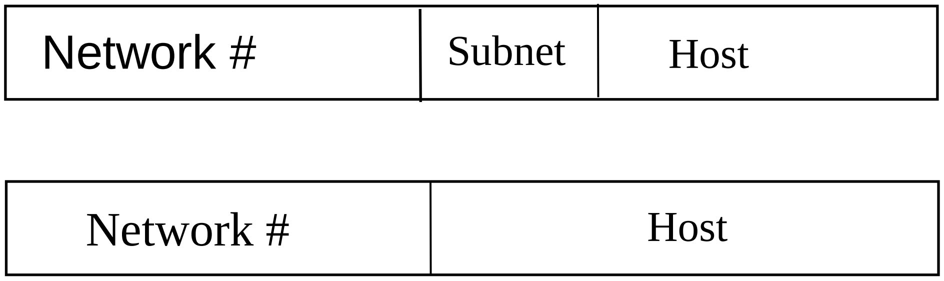
- Network Class: B – 16 bits of address
- Network ID: 187.199
- Sub-network ID: 127
- Router needs above, host is ignored by router

# Subnetting Creates Hierarchy

- Idea with subnetting, take one IP address
  - Partition it into several IP addresses
    - Each refers to an actual physical network
- Assume that subnets are geographically close to one another
  - Because … distant routers only have one IP address for entire set of subnets
  - So sending packets to these subnets through one IP number should route packets in the same general direction

# Subnetting Creates Hierarchy

- Subnetting creates another level of hierarchy within IP addresses
  - Now there is a subnet part too, since borrow bits from host



# Addressing Problems not Over

- By 1990, the Internet was facing serious growing pains …
  - Two most severe problems were
    - **Explosion of routing table size**
    - **Looming exhaustion of Class B networks**
  - Popularity of Internet triggered flood of new networks, and each network included in routing tables
  - Routers were running out of memory, and spending too much time doing address lookup

# **Classless** Interdomain Routing (CIDR)

- Internet Engineering Task Force (IETF), proposed
  - Solution known as classless routing, supernetting, or CIDR
  - This addressing scheme currently used
- CIDR based on already successful practice of subnetting
- Supernetting allows subnet boundary to move to the left, into the network part
  - Groups of neighboring **classful** networks are combined into single routing table entries
    - Size of routing tables reduced through summarization

# CIDR Example

- Introduced CIDR notation of network
  **192.0.2.0/18**
  - /18 says that the first 18 bits are network part of address and 14 bits are available for host addresses
- The network part is called the prefix

- Assume that a site requires a network address with 1000 addresses
- **How many bits of network address gives us 1000 hosts?**
  - See following slide for table
- With CIDR, network is assigned a continuous block of 1024 addresses with a 22-bit long prefix

# CIDR  Prefix Size vs. Network Size

| CIDR Block Prefix | # of Host Addresses |
|---|---|
| /27 | 32 hosts |
| /26 | 64 hosts |
| /25 | 128 hosts |
| /24 | 256 hosts |
| /23 | 512 hosts |
| /22 | 1,024 hosts |
| /21 | 2,048 hosts |
| /20 | 4,096 hosts |
| /19 | 8,192 hosts |
| /18 | 16,384 hosts |
| /17 | 32,768 hosts |
| /16 | 65,536 hosts |
| /15 | 131,072 hosts |
| /14 | 262,144 hosts |
| /13 | 524,288 hosts |

# CIDR Network Size / Number of Network Bits

- CIDR networks referencing Class C networks

  /n = number of network bits

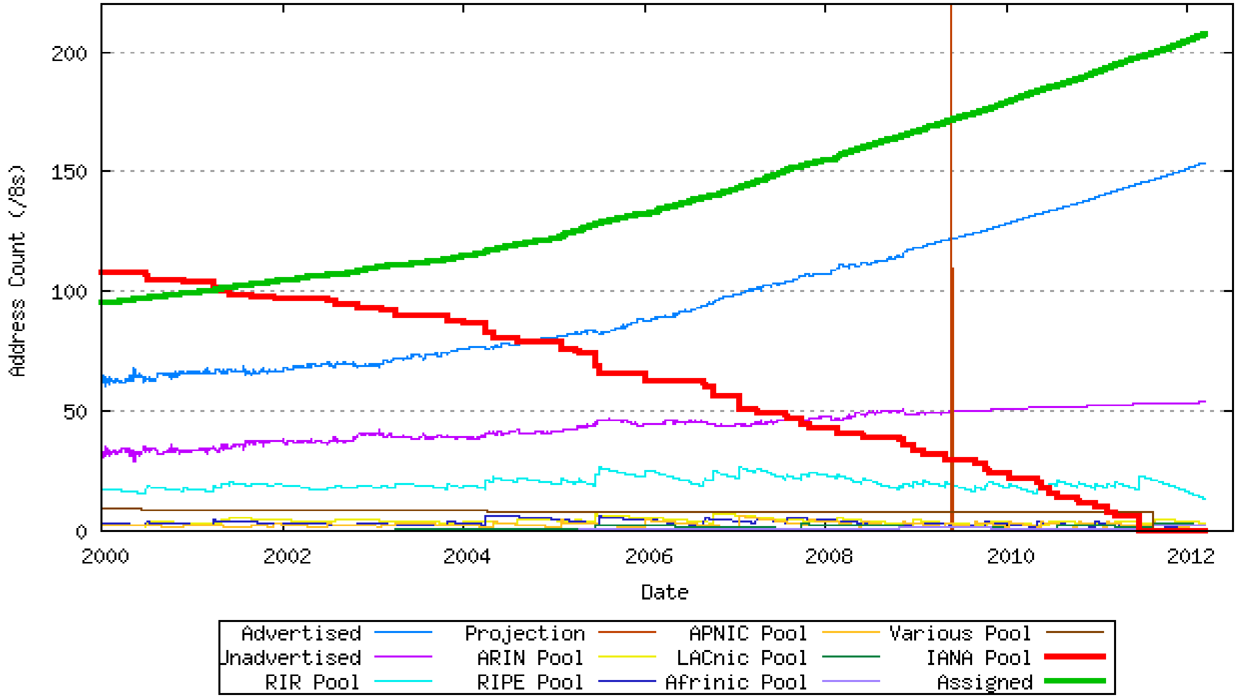
| CIDR Block Prefix # | Equivalent Class C | # of Host Addresses |
|---|---|---|
| /27 | 1/8th of a Class C | 32 hosts |
| /26 | 1/4th of a Class C | 64 hosts |
| /25 | 1/2 of a Class C | 128 hosts |
| /24 | 1 Class C | 256 hosts |
| /23 | 2 Class C | 512 hosts |
| /22 | 4 Class C | 1,024 hosts |
| /21 | 8 Class C | 2,048 hosts |
| /20 | 16 Class C | 4,096 hosts |
| /19 | 32 Class C | 8,192 hosts |
| /18 | 64 Class C | 16,384 hosts |
| /17 | 128 Class C | 32,768 hosts |
| /16 | 256 Class C | 65,536 hosts |

# Ipv4 Address Exhaustion

- Depletion of IPv4 allocation pool a concern since late 1980s when Internet started dramatic growth
- Anticipated shortage driving factor in creating and adopting several technologies
  1. Classless Inter-Domain Routing (CIDR)
     methods in 1993
  1. Network address translation (NAT) and
  2. Internet Protocol, IPv6, in 1998

# Ipv4 Address Exhaustion

- Predictions of exhaustion date of unallocated IANA pool seem to converge to between January 2011 and January 2012,
- When did we run out?     Did this in Nov, 2011.



# Ipv4 Address Exhaustion

- Predicted that until exhaustion there will be no significant demand for Ipv6
- David Conrad, the general manager of IANA, acknowledges:

  "I suspect we are actually beyond a reasonable time frame where there won't be some disruption. Now it's more a question of how much."

http://en.wikipedia.org/wiki/IPv4_address_exhaustion


Stop here for now

# CIDR and Subnetting

- To understand CIDR, begin with **defaults** for classful addressing
- Each Class has a DEFAULT subnet mask
  - The picture below shows the 3 Network Classes with their respective default subnet mask:

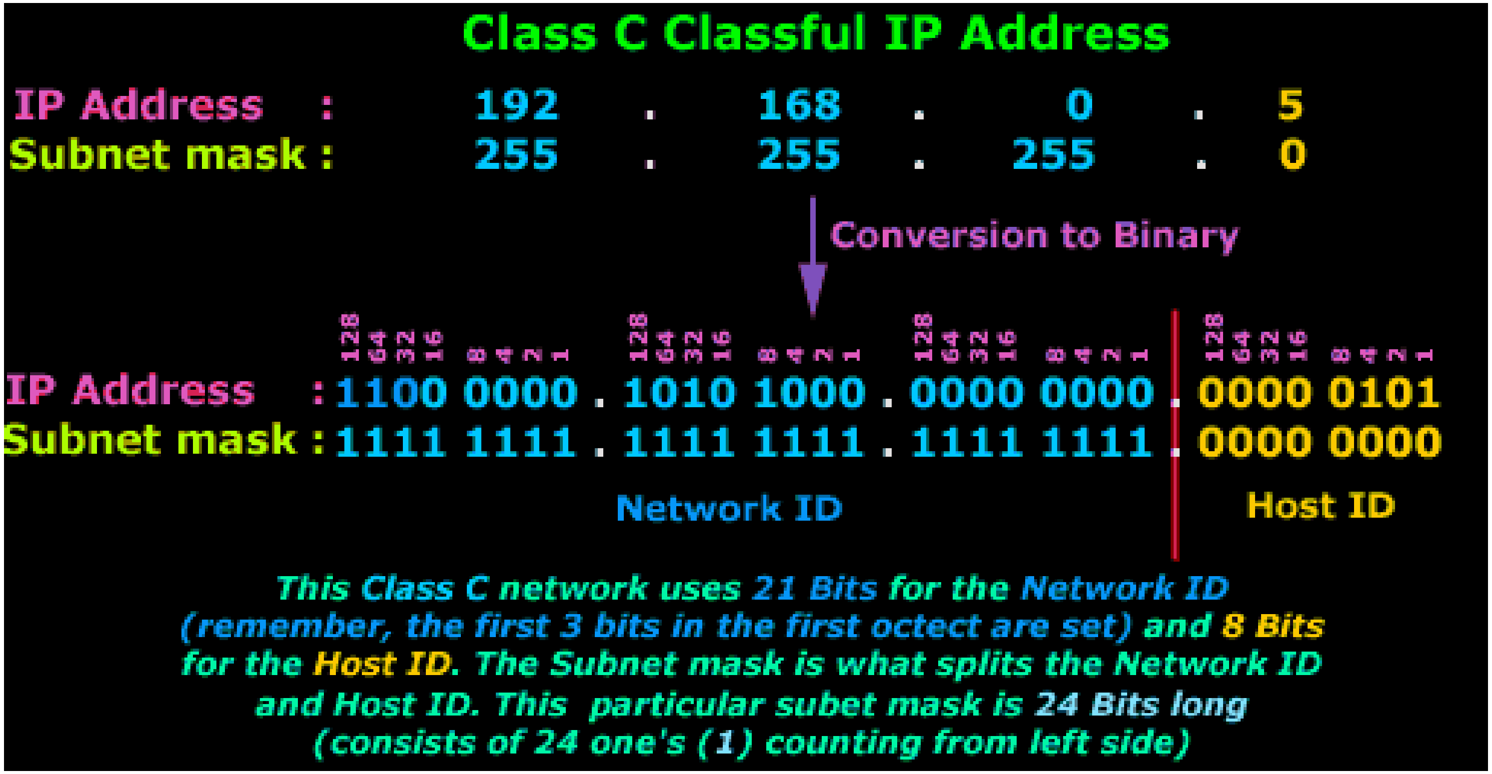
**Network Classes with their respective Default Subnet Masks**

| CLASS TYPE | NETWORK RANGE | DEFAULT SUBNET MASK |
|---|---|---|
| Class A | 1.0.0.0 to 127.255.255.255 | 255.0.0.0 |
| Class B | 128.0.0.0 to 191.255.255.255 | 255.255.0.0 |
| Class C | 192.0.0.0 to 223.255.255.255 | 255.255.255.0 |

*Here you can see each Network Class with its range of IP Addresses followed by the default subnet mask for the particular Class. Remmeber that we can modify the default subnet mask to meet our needs*

# Default Subnet Masks

- We can see in the picture below,
- IP Address is in Binary and Mask is 24 bits



# Subnet Masks for CIDR Addresses

- To create subnetworks from the standard network sizes, must borrow bits to create more networks
- Here we use bits from host, must change network mask
  - Suppose we want to create eight subnetworks in the 192.168.18.0 address space.
  - How many bits from the host do we need ?

| | | | | |
|---|---|---|---|---|
| | 192 | . 168 | .18 | .0 |
| | 11000000 | 10101000 | 00010010 | 00000000 |
| Netmask | 11111111 | 11111111 | 11111111 | 00000000 |

# Subnet Masks for CIDR Addresses

- How many bits for 8 subnets?

| | | | | |
|---|---|---|---|---|
| 192 | . 168 | .18 | .0 | How many hosts on each network ? |
| 11000000 | 10101000 | 00010010 | 00000000 | |
| 11111111 | 11111111 | 11111111 | 11100000 | Netmask |

We just add 3 bits to the length of the 24-bit subnet mask.

Why 3 bits? Binary, because $2^3 = 8$.

So now we have a /27, or 255.255.255.224, subnet mask

How many hosts can we have on each network?

# Subnet Masks for CIDR Addresses

- How many hosts?
  - Each subnet is limited to $2^5 = 32$ hosts
  - 5 host bits left for creating host addresses

  - But, each subnet is actually limited to 30 hosts
  - Why is that?
  - Need 1 address for base network address
  - Need 1 address used as broadcast address of the subnetwork

# Subnet Masks for CIDR Addresses

- Using the /27 mask gives us eight subnets, but we also need to know their numbers if we're going to build a network diagram or a routing table
- Eight possible values of the 3-bit subnets are:
  - 000 0
  - 001 1
  - 010 2
  - 011 3
  - 100 4
  - 101 5
  - 110 6
  - 111 7

# Subnet Masks for CIDR Addresses

- Starting subnetwork number
- 000 0
- 001 32
- 010 64
- 011 96 (64+32)
- 100 128
- 101 160 (128+32)
- 110 192 (128+64)
- 111 224 (128+64+32)

- Subnetworks are
- 192.168.18.0/27
- 192.168.18.32/27
- 192.168.18.64/27
- 192.168.18.96/27
- 192.168.18.128/27
- 192.168.18.160/27
- 192.168.18.192/27
- 192.168.18.224/27

# CIDR and Subnets Created Flexible Network Size

- Helped with running out of address space
  - Blocks of addresses can be assigned to networks as small as 32 hosts
  - **Or,** over 500,000 hosts
  - Allows for address assignments that much more closely fit an organization's specific needs
- A single high-level route entry can represent many lower-level routes in the global routing tables

# Example of Subnetting

- This will be the lab this week!!!
- How to figure out your broadcast address …

https://www.countryipblocks.net/identifying-the-network-and-broadcast-address-of-a-subnet

- URLs for Subnet Calculator

  http://www.subnetonline.com/pages/subnet-calculators/ip-subnet-calculator.php

  http://www.techzoom.net/tools/network-subnet-calculator.en

# Router Table Aggregation

# CIDR Also Helped with Route Aggregation

- Currently, big blocks of addresses assigned to large Internet Service Providers (ISPs)
- Re-allocate portions of their address blocks to their customers
  - Assigns its customers CIDR addresses from that block
    - Customers, smaller ISPs, and in turn re-allocate portions of their address block to their users
  - Yet  global routing tables for all these networks can be represented by single route entry

# CIDR Also Helped with Route Aggregation or Supernetting

- CIDR provides routing prefix aggregation, also known as **supernetting**
  - Example: Sixteen Contiguous /24 Networks
  - Aggregated and advertised as a single /20 route
    - If first 20 bits of their network addresses match!!
  - Two aligned contiguous /20s may then be aggregated to a /19, and so forth
  - Allows a significant reduction in the number of routes that have to be advertised

# CIDR Also Helped with Route Aggregation or Supernetting

- Example: Want to aggregate 8 network addresses between 131.0.0.0/16 and 131.7.0.0 /16

- Need subnet mask that makes all 8 network addresses appear to be on same single network
  - How many bits do we need to supernet 8 networks?
  - $2^3$ for 8 networks = 3 bits
  - /16 network has a subnet mask of 255.255.0.0
  - We **steal** 3 bits from network portion of subnet mask, we end up with the mask 255.248.0.0
  - Think of it as **Shortening** the mask

# Supernetting

http://www.2000trainers.com/cisco-ccna-05/ccna-classless-cidr-supernetting/

- So, range can now be designated as 131.0.0.0/13 This value aggregates all IP addresses between 131.0.0.1 and 131.7.255.254

| | | | | | | |
|---|---|---|---|---|---|---|
| /13 Subnet Mask | 11111111 | 11111 | 000 | 00000000 | 00000000 | |
| | Network | | | | | |
| 131.0.0.0 | 10000011 | 00000 | 000 | 00000000 | 00000000 | |
| 131.1.0.0 | 10000011 | 00000 | 001 | 00000000 | 00000000 | |
| 131.2.0.0 | 10000011 | 00000 | 010 | 00000000 | 00000000 | |
| 131.3.0.0 | 10000011 | 00000 | 011 | 00000000 | 00000000 | |
| 131.4.0.0 | 10000011 | 00000 | 100 | 00000000 | 00000000 | |
| 131.5.0.0 | 10000011 | 00000 | 101 | 00000000 | 00000000 | |
| 131.6.0.0 | 10000011 | 00000 | 110 | 00000000 | 00000000 | |
| 131.7.0.0 | 10000011 | 00000 | 111 | 00000000 | 00000000 | |
| Network ID | 10000011 | 00000 | 000 | 00000000 | 00000000 | = 131.0.0.0/13 |

# Reserved Addresses

Two Reserved Addresses

- 127.0.0.1 – What is this called?
- 0.0.0.0 – Also reserved

Can we route to these normally?

Blocks of Private Addresses

- 10.0.0.0/8   (10.0.0.0 to 10.255.255.255)
- 172.16.0.0/12 (172.16.0.0 to 172.31.255.255)
- 192.168.0.0/16 (192.168.0.0 to 192.168.255.255)
- 169.254.0.0/16 (169.254.0.0 to 169.254.255.255)

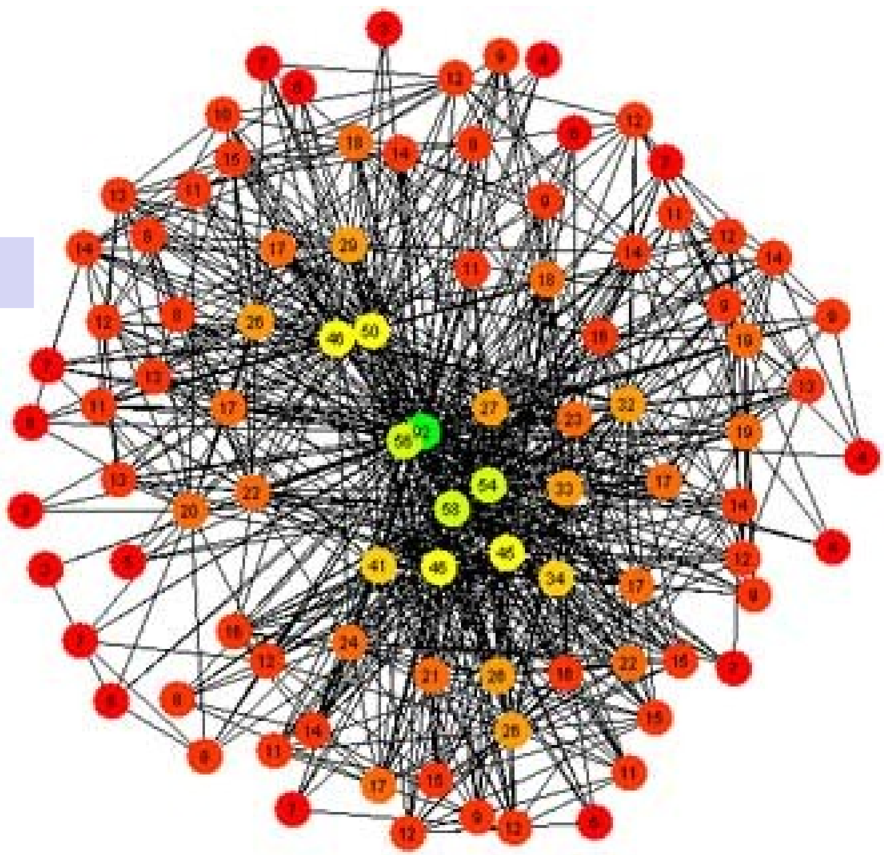
Small companies use: 172.16.0.0

Home users use:        192.168.0.0

# References

- Packet Fragmentation
  http://www.cisco.com/en/US/tech/tk827/tk369/technologies_white_paper09186a00800d6979.shtml
- Subnetting
  http://microcomputer-network.net/calculate-subnet-mask
- More Subnetting
  http://learn-networking.com/network-design/how-to-subnet-a-network
- Subnetting Made Easy
  http://www.techexams.net/forums/ccna-ccent/38772-subnetting-made-easy.html
- Calculators
  http://jodies.de/ipcalc
  http://www.aboutmyip.com/AboutMyXApp/SubnetCalculator.jsp

Routing?



Next ….

Read: Continue with Chapter 4

**Lab this week is on subnetting**


# Network Addressing

# Subnet Mask

- Want only the network portion of the address
  Network part – so **and network part + 1's** to
  preserve the network part
- The host part will be zero'd out
  Host part – so **and host part + 0's**
  to zero out this part
- Routers only care about the network part of the IP Address
- Mask then, is composed of all 1's for the network portion and 0's for the host.
- See some examples ...

# Reserved Addresses

## Two Reserved Addresses

- 127.0.0.1 – What is this called?
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Can we route to these normally?

## Blocks of Private Addresses

- 10.0.0.0/8   (10.0.0.0 to 10.255.255.255)
- 172.16.0.0/12 (172.16.0.0 to 172.31.255.255)
- 192.168.0.0/16 (192.168.0.0 to 192.168.255.255)
- 169.254.0.0/16 (169.254.0.0 to 169.254.255.255)

Small companies use: 172.16.0.0

Home users use:      192.168.0.0