Module Feedback

Should take approximately 3 minutes to complete

1	**I have a better understanding of the subject after completing this module.**	◯Strongly Agree ◯Agree ◯Not Sure ◯Disagree ◯Strongly Disagree
2	**The assessments to date were relevant to the work of the module.**	◯Strongly Agree ◯Agree ◯Not Sure ◯Disagree ◯Strongly Disagree
3	**I achieved the learning outcomes for this module.**	◯Strongly Agree ◯Agree ◯Not Sure ◯Disagree ◯Strongly Disagree
4	**The teaching on this module supported my learning.**	◯Strongly Agree ◯Agree ◯Not Sure ◯Disagree ◯Strongly Disagree
5	**Overall I am satisfied with this module.**	◯Strongly Agree ◯Agree ◯Not Sure ◯Disagree ◯Strongly Disagree

Your comments are very important and valued by lecturers. Please ensure that neither the language nor content will cause personal offense to any individual lecturer.

6 **Identify up to three aspects of the module that most helped your learning**

7 **Suggest up to three changes to the module that would enhance your learning.**

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COMP2009J
Computer Networks

IP Addressing
&
IP Routing

Last Week

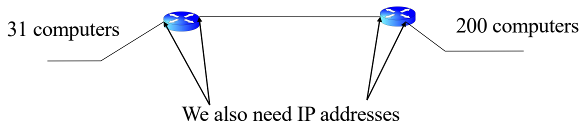
- What is IP Addressing?
  - an **End-to-End** addressing
- Need to identify network addresses
  - Class System - old
  - CIDR – new
    - Using a Netmask (two equivalent notations: Full or Slash)
- In a routing table:
  - We could aggregate routing entries
    - To reduce the size of the routing time (save memory)
    - To quicken the check for prefix match (save execution time)
  - We match an IP address to the **longest prefix**

Today

- Subnet design
  - If we are given an IP prefix, how do we split it our infrastructure
- Some problems with IPv4
- IP Forwarding & Routing

Subnet Design

- You are a network designer!
- You have the IP address range 192.168.0.0/23
  - 11000000 10101000 00000000 00000000
- You have to assign network addresses to 2 departments
  - Department A has 31 computers
  - Department B has 200 computers



Subnet Design

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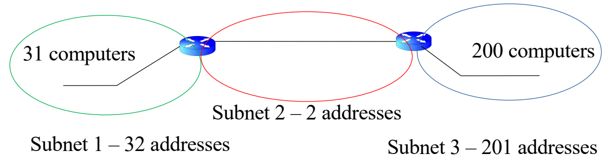
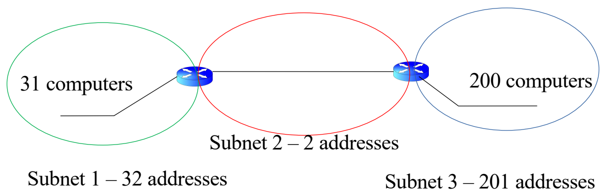


Assigned IP Range: 192.168.0.0/23

Subnet Design

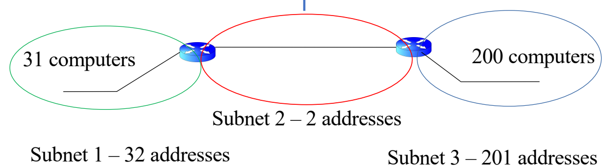
- 3 subnets – Take the largest first
  - 201 addresses requires 8 bits for host addresses
    - 7 bits = 128 addresses, 126 valid host addresses
    - 8 bits = 256 addresses, 254 valid host addresses



Assigned IP Range: 192.168.0.0/23

Subnet Design

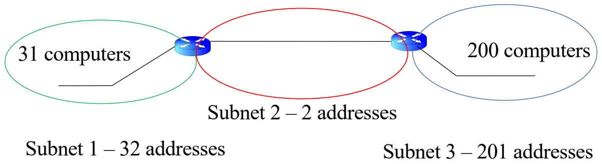
- 3 subnets – Take the largest first
  - 201 addresses requires 8 bits for host addresses
    - 7 bits = 128 addresses, 126 valid host addresses
    - 8 bits = 256 addresses, 254 valid host addresses
  - 192.168.0.0 → 192.168.0.255
  - 192.168.0.0/24
    - 11000000 10101000 00000000 00000000



Assigned IP Range: 192.168.0.0/23
Subnet 3: 192.168.0.0/24

Subnet Design

- 3 subnets
  - 32 addresses requires 6 bits for host addresses
    - 5 bits = 32 addresses, 30 valid host addresses
    - 6 bits = 64 addresses, 62 valid host addresses



Assigned IP Range: 192.168.0.0/23
Subnet 3: 192.168.0.0/24

Subnet Design

- 3 subnets
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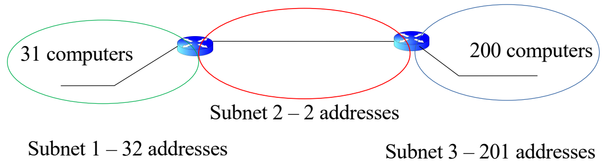
    - 5 bits = 32 addresses, 30 valid host addresses
    - 6 bits = 64 addresses, 62 valid host addresses
  - 192.168.0.0 → 192.168.0.255 ---- already used



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Subnet 3: 192.168.0.0/24

Subnet Design

- 3 subnets
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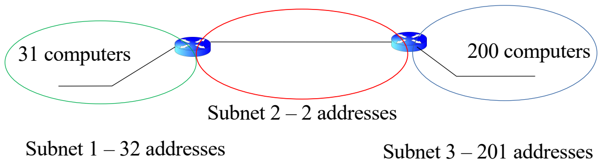
  - 192.168.1.0



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Subnet 3: 192.168.0.0/24

Subnet Design

- 3 subnets
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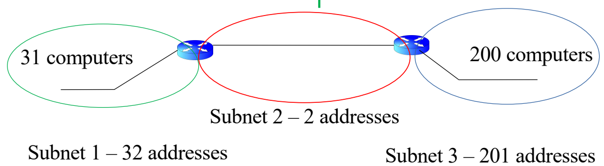
  - 192.168.1.0 → 192.168.1.63
  - 192.168.1.0/26

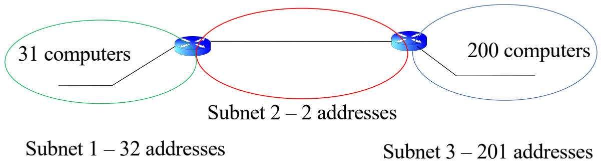
11000000 10101000 00000001 00000000



Assigned IP Range: 192.168.0.0/23
Subnet 3: 192.168.0.0/24
Subnet 1: 192.168.1.0/26

Subnet Design

- 3 subnets
  - 2 addresses requires 2 bits for host addresses
    - 1 bit = 2 addresses, 0 valid host addresses
    - 2 bits = 4 addresses, 2 valid host addresses



Assigned IP Range: 192.168.0.0/23
Subnet 3: 192.168.0.0/24
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Subnet Design

- 3 subnets
  - 2 addresses requires 2 bits for host addresses
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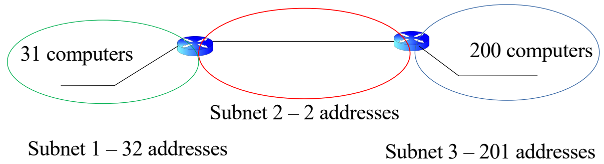
  - 192.168.0.0 → 192.168.1.63 ----- already used



Assigned IP Range: 192.168.0.0/23
Subnet 3: 192.168.0.0/24
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Subnet Design

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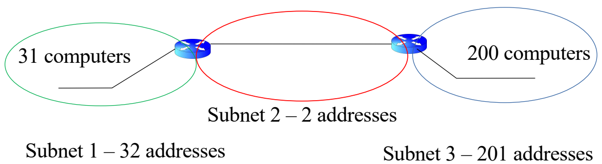
    - 2 bits = 4 addresses, 2 valid host addresses
  - 192.168.1.64

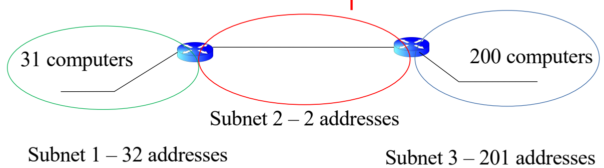


Assigned IP Range: 192.168.0.0/23
Subnet 3: 192.168.0.0/24
Subnet 1: 192.168.1.0/26

Subnet Design

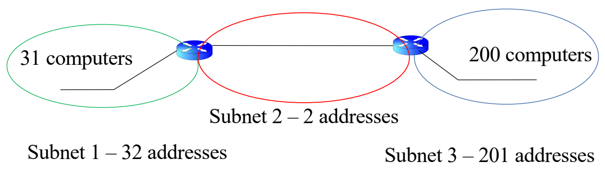
- 3 subnets
  - 2 addresses requires 2 bits for host addresses
    - 1 bit = 2 addresses, 0 valid host addresses
    - 2 bits = 4 addresses, 2 valid host addresses
  - 192.168.1.64 → 192.168.1.67
  - 192.168.1.64/30

11000000 10101000 00000001 01000000

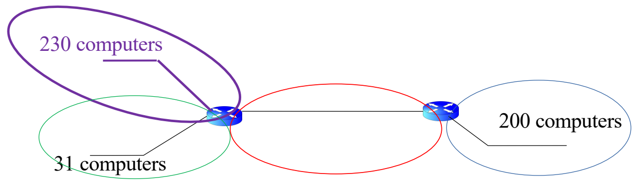


Subnet Design

- Subnet 1: 192.168.1.0/26
- Subnet 2: 192.168.1.64/30
- Subnet 3: 192.168.0.0/24



Can We Add More Computers?



Assigned IP Range: 192.168.0.0/23

/23 means 512 Existing addresses

We have in total: 230 + 31+ 200 = 561 computers

So, based only on the number of available IP addresses, it is clear that we cannot add 230 new computers

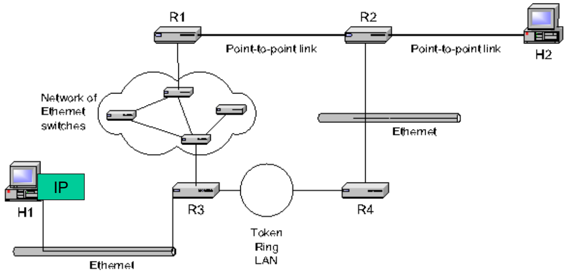
Problem with IPv4

- We are already running out of IP addresses
- Problem Fixes
  - NAT (Network Address Translation)
    - Allocates IP address freely to all internal devices
    - The outside networks only knows one IPv4 address (assigned by ISP) for a whole internal network
    - Need a device for translating messages between internal and external IPs
  - IPv6:
    - the IPv6 address space is **128**-bits (**2^{128}**) in size

IP Forwarding

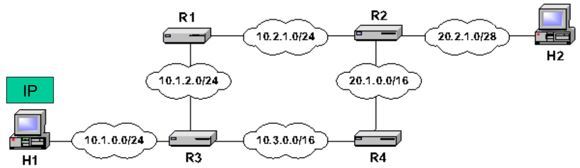
Delivery of an IP datagram

- View at the data link layer layer:
  - Internetwork is a collection of LANs or point-to-point links or switched networks that are connected by routers



Delivery of an IP datagram

- View at the IP layer:
  - An IP network is a logical entity with a network number
  - We represent an IP network as a "cloud"
  - The IP delivery service takes the view of clouds, and ignores the data link layer view



Principles of end-to-end delivery of datagrams

To successfully deliver an IP datagram:

1. The network prefix of an IP destination address must correspond to a unique data link layer network
2. Routers and hosts that have a common network prefix must be able to exchange IP datagrams using a data link protocol
3. Every data link layer network must be connected to at least one other data link layer network via a router

Routing tables

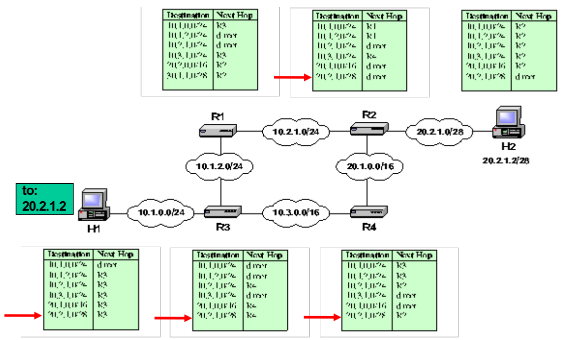
- Each router and each host keeps a **routing table** which tells the router how to process an outgoing packet
- Main columns:
  1. **Destination address:** where is the IP datagram going to?
     a. Network Address
     b. Netmask
  2. **Next hop:** how to send the IP datagram?
  3. **Interface:** what is the output port?
- Next hop and interface column can often be summarized as one column
- Routing tables are set so that datagrams gets closer to the its destination

Routing table of a Host or Router

IP datagrams can be directly delivered ("direct") or is sent to a router (e.g., "R2" or "R4")

Destination	Next Hop	interface
10.1.0.0/24	direct	eth0
10.1.2.0/24	direct	eth0
10.2.1.0/24	R2	wlan0
10.3.1.0/24	direct	eth0
20.1.0.0/16	R4	eth1
20.2.1.0/28	R4	eth1

Delivery with routing tables



Delivery of IP datagrams

- There are two distinct processes to delivering IP datagrams:
  1. **Forwarding:** How to pass a packet from an input interface to the output interface?
  2. **Routing:** How to find and setup the routing tables?

- Forwarding must be done as fast as possible:
  - on routers, is often done with support of hardware
  - on PCs, is done in kernel of the operating system
- Routing is less time-critical
  - On a PC, routing is done as a background process

Type of routing table entries

- **Network route**
  - Destination addresses is a network address (e.g., 10.0.2.0/24)
  - Most entries are network routes
- **Host route**
  - Destination address is an interface address (e.g., 10.0.1.2/32)
  - Used to specify a separate route for certain hosts
- **Default route**
  - Used when no network or host route matches
  - The router that is listed as the next hop of the default route is the **default gateway (for Cisco: "gateway of last resort)**
- **Loopback address**
  - Routing table for the loopback address (127.0.0.1)
  - The next hop lists the loopback (lo0) interface as outgoing interface

Routing table lookup

- When a router or host needs to transmit an IP datagram, it performs a r **Routing Table Lookup**
- **Routing table lookup:** Use the IP destination address as a key to search the routing table.
- Result of the lookup is the IP address of a next hop router, and/or the name of a network interface

Routing table lookup: Longest Prefix Match

- **Longest Prefix Match:** Search for the routing table entry that has the longest match with the prefix of the destination IP address

1. Search for a match on all 32 bits
2. Search for a match for 31 bits

.....

32. Search for a match on 0 bits

Host route, loopback entry
→ 32-bit prefix match

Default route is represented as 0.0.0.0/0
→ 0-bit prefix match

128.143.71.21

Destination address	Next hop
10.0.0.0/8	R1
128.143.0.0/16	R2
128.143.64.0/20	R3
128.143.192.0/20	R3
128.143.71.0/24	R4
128.143.71.55/32	R3
default	R5

The longest prefix match for 128.143.71.21 is for 24 bits with entry 128.143.71.0/24
Datagram will be sent to R4

Route Aggregation

- Longest prefix match algorithm permits to aggregate prefixes with identical next hop address to a single entry
- This contributes significantly to reducing the size of routing tables of Internet routers

Destination	Next Hop
10.1.0.0/24	R3
10.1.2.0/24	direct
10.2.1.0/24	direct
10.3.1.0/24	R3
192.168.0.0/24	R2
192.168.1.0/24	R2
……	…
192.168.255.0/24	R2

Destination	Next Hop
10.1.0.0/24	R3
10.1.2.0/24	direct
10.2.1.0/24	direct
10.3.1.0/24	R3
192.168.0.0/16	R2

How do routing tables get updated?

- **Adding an interface:**
  - Configuring an interface eth2 with 10.0.2.3/24 adds a routing table entry

Destination	Interface
10.0.2.0/24	eth2

- **Adding a default gateway:**
  - Configuring 10.0.2.1 as the default gateway adds the entry

Destination	Next Hop
0.0.0.0/0	10.0.2.1

- Two ways to configure routing tables
- **Static configuration** of network routes or host routes
- **Dynamic update** of routing tables through routing protocols
- Test reachability of a host:
  - Ping: ICMP echo request