CS3103: Computer Networks Practice

Introduction to CS3103 and LAB

Course Introduction
Lab Equipments and Procedures
Internet Today
Layering - Recap Activity
Networking Concepts with A Simple Example
IP Foundations and Subnet- Revision

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Your dream team for the semester

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Course Timetable

- Lecture: Tue 02pm-04pm, **LT13**
  - **Topics:** [refer Canvas -> Home -> Course Weekly Schedule]
- Labs @ COM1-B1-02
  - Total 12 sessions
  - Wed, Thu, Fri: 10-12, 12-2, 2-4 and 4-6pm
  - **[Starts from Week 3]**
- Consultation:

  By prior arrangement

EXPERIMENT LIST in ORDER

- 10 Experiments [Week 3 to Week 13]
- [with one break - no LAB week]

[refer Canvas -> Syllabus -> Course Weekly Schedule]

Course Tools

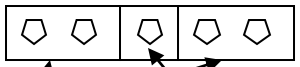
- Canvas
  - All contents, Assignment submissions & Announcements
- Discord forum. [Join @...]
  - All discussions, clarifications on assignments, labs, grading scheme, feedback, comments
    - https://discord.gg/Er3YdhhA92

Lab Equipments

Detail in "LABS-INTRO.PDF" manual in CANVAS

Each bench's setup is as follows:

Patch Panel Mounted on Partition



4 10BaseT socket to patch panel in the 19" rack

Telephone socket

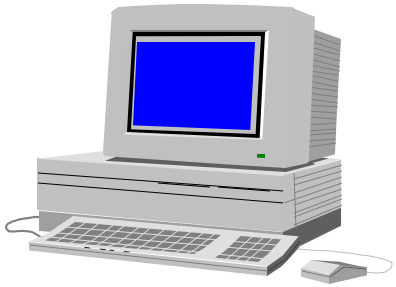
IP Phone

Cisco 2906S 24-port switch

Cisco 2900 Series router

pc1

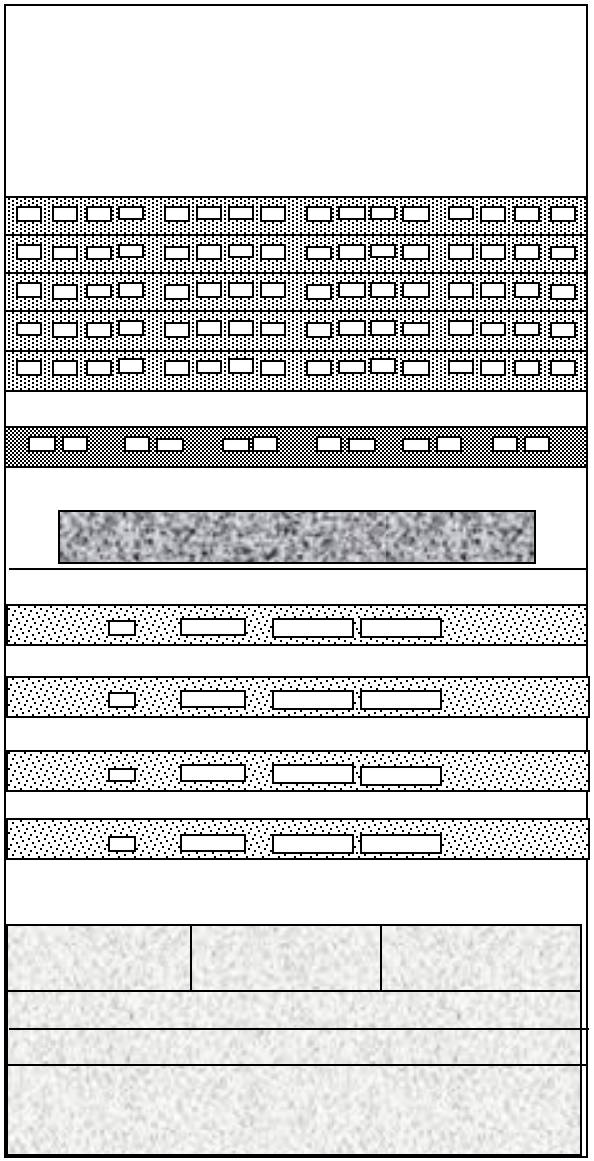
pc2



pcs

- Fast Ethernet (1 Gbps) card – UTP, Fiber (1 Gbps)
- Dual boot: Windows and Linux

Lab Equipments – Central Facility



UTP Patch Panel

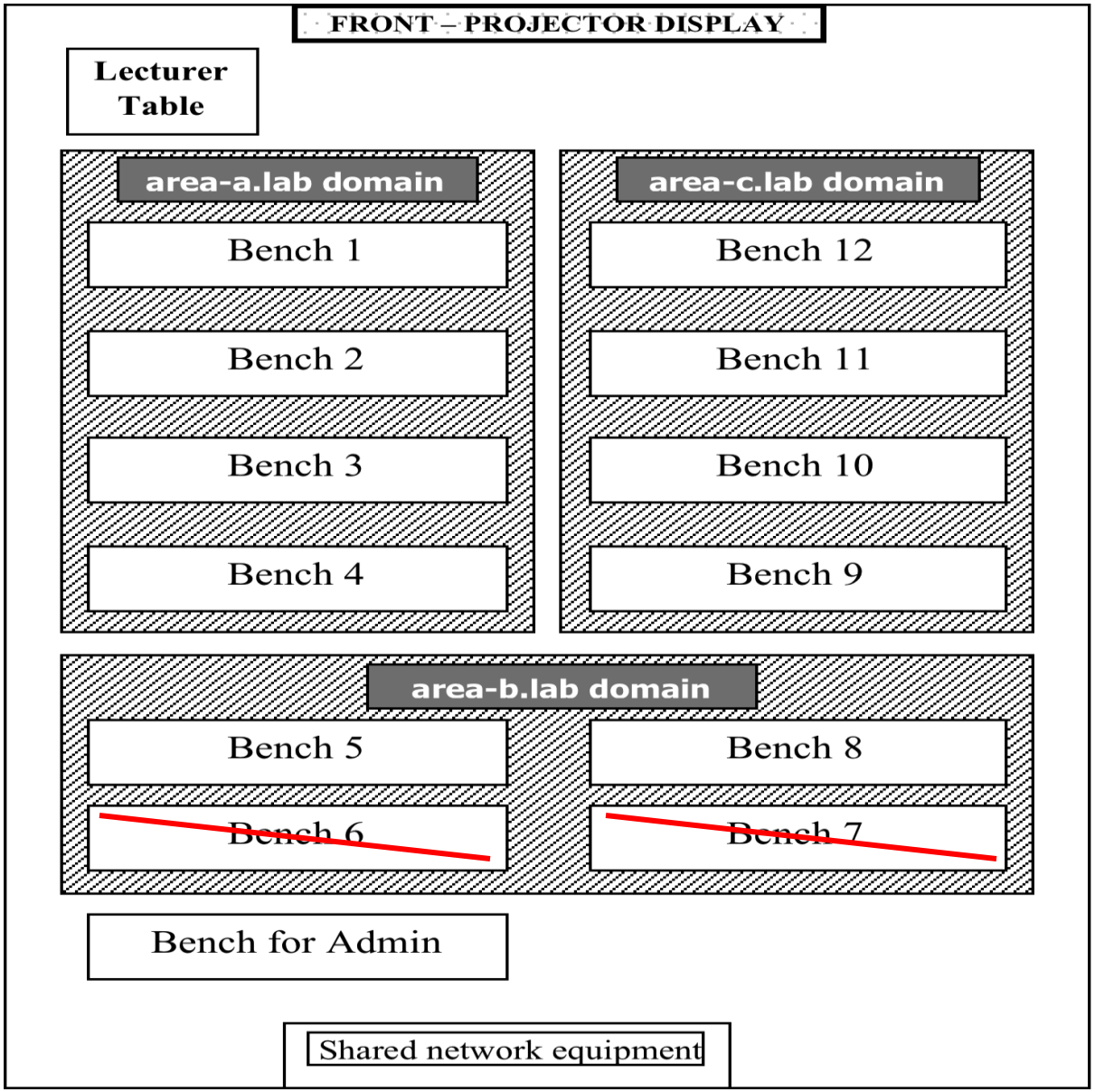
Fibre Patch Panel

Siemens Hicom 112 IM

4 Cisco 2611 Router with 1 Ethernet port and 2 Serial Ports

Cisco Switch

Logical Lab Layout



For more details pls READ….

"LABS-INTRO.PDF" manual in CANVAS

Module Info: Assessment

- Credit Units: **4**

- Assessment Components [may have minor changes…. !, *depends on actual number of labs and quizzes used for final grading*]. Changes will be updated in **Canvas->Home->Assessment.**

- **PRACTICE [~37%]** (Changes based on number of labs. For eg. if 8 labs, then 8% will moved to Final Test)
  - Lab Sheet / Questionnaire (In Group of 2) : 25% [10 labs x 2.5]
  - Pre-lab Quiz or Post-lab Homework Quiz (Individual) : 12% [8 quizzes x 1.5]
- **PRACTICE [~30%]**
  - Assignment 1 (Individual) – Subnet Design: ~5%
  - Assignment 2 (Individual) – NW Tools [Submit to Canvas] : ~5%
  - Assignment 3 (Individual) – Client/Server Programming [Submit Code/Demo-Presentation to Canvas] : ~10%
  - Assignment 4 (In Group of 3 or 4) – BGP Network Design and Policies Configuration OR NW Application/Tool development [Submit Code/Demo-Presentation to Canvas] : ~10%
- **UNDERSTANDING CONCEPTS [~33%]**
  - Lecture Attendance: 3%
  - Lecture participation (VOX, PollEV): 5%
    - (Weekly participation is required in either PollEV or VOX)
  - Final Test: ~25%

Module Info: Policies

- **NO MAKEUP** LAB SESSIONS WILL BE ENTERTAINED
  - Be punctual for your lab session. ATTENDANCE will be taken [**Scan QR code**].
  - You should complete the lab on the same day of your registered lab/consultation session.

- Each Lab Session has the following components
  - **Prelab Quiz** – Monday 6pm to Wed 6am (36 hrs) on Canvas.
    [**OR** If the Quiz is not released by Monday 6pm in canvas, then it will be **Postlab Homework Quiz** – Friday 6pm to Mon 6am (50 hrs) on Canvas.]
  - Lab Worksheet/Questionnaire – submit at the end of the lab session

- Late comers to the lab will be penalized as follows:

15 mins	20% off the lab weightage for that expt
30 mins	50% off the lab weightage for that expt
45 mins	No credit for that lab experiment.

- YOU ARE EXPECTED TO ATTEND ALL **LECTURES**! ATTENDANCE will be taken [**Scan QR code**].

Labs Sessions – More Info….

- Print Lab Sheet --- From Canvas (It is not full recipe. Some info are just abstract.
  - We want you to figure-out the details and live with the hardware glitches!
  - That's reality. (Now you have us around!)
- Lab Questionnaire --- Will be distributed by TAs (what to fill?, how to fill? , etc… If you are not sure, pls ask.)
- Preparation --- Slides and Pre-Lab Readings (textbook & online) in Canvas (Some theories are covered in pre-requisite module)
- Please **communicate early and directly with me through telegram/email** if you have problems.

CS3103 - Text Book

Computer Networking: A Top-Down Approach: International Edition, 6/e

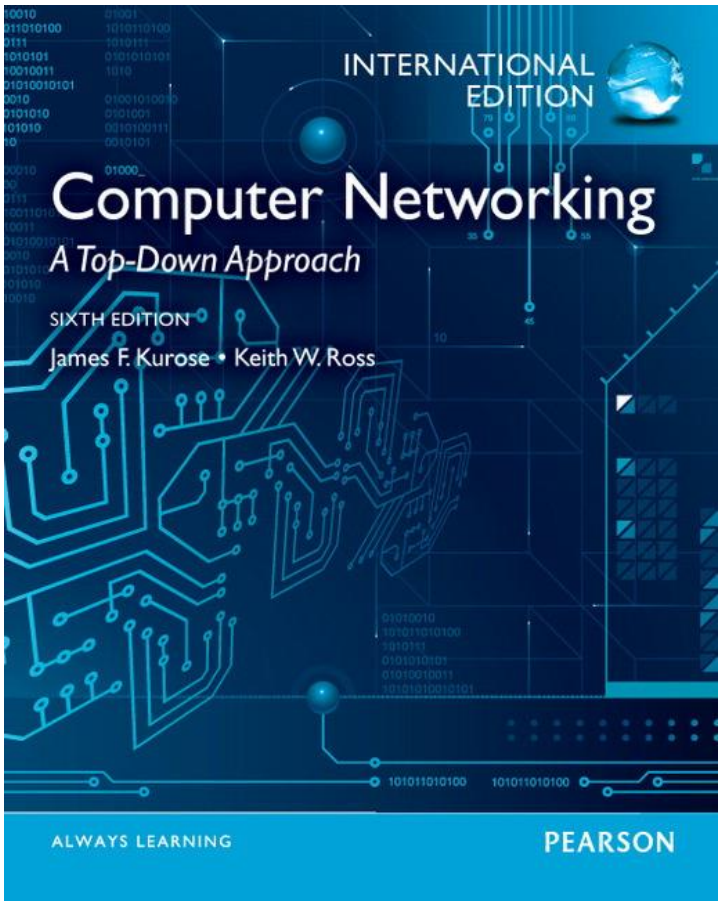
7/e or 8/e is also fine….

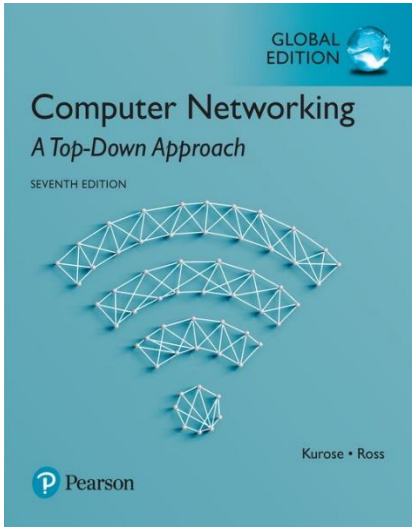
Author : KUROSE

ROSS

Publisher : Pearson

ISBN : 9780273768968





Available at **NUS Co-op @ Forum !!**

Right Infringements on NUS Course Materials

All course participants (including permitted guest students) who have access to the course materials on Canvas or any approved platforms by NUS for delivery of NUS modules are not allowed to re-distribute the contents in any forms to third parties without the explicit consent from the module instructors or authorized NUS officials

Topics Today

Internet Today
Layering - Recap Activity
Networking Concepts with A Simple Example
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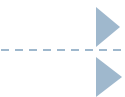
Internet Today

- How "Big" is the Internet?
- What is the right metric to use?
- What are the challenges?
- How fast Internet has grown?

The Internet

An *exciting* place

18 billion



18 billion

estimated* # of Internet connected devices in 2017

* Cisco Visual Networking Index 2017—2022

28.5 billion

estimated* # of Internet connected devices in **2022**

* Cisco Visual Networking Index 2017—2022

~4 exabytes

estimated* daily global IP traffic in 2017

* Cisco Visual Networking Index 2017—2022

A Visualization of the Space That Bytes on the Internet Would Occupy in Comparison to Real World Objects

bit.ly/inetsize

~13 exabytes

estimated* daily global IP traffic in **2022**

* Cisco Visual Networking Index 2017—2022

~75% of all IP traffic

estimated* percentage of **video traffic**

in 2017

* Cisco Visual Networking Index 2017—2022

Upstream		Downstream		Aggregate	
BitTorrent	18.37%	Netflix	35.15%	Netflix	32.72%
YouTube	13.13%	YouTube	17.53%	YouTube	17.31%
Netflix	10.33%	Amazon Video	4.26%	HTTP - OTHER	4.14%
SSL - OTHER	8.55%	HTTP - OTHER	4.19%	Amazon Video	3.96%
Google Cloud	6.98%	iTunes	2.91%	SSL - OTHER	3.12%
iCloud	5.98%	Hulu	2.68%	BitTorrent	2.85%
HTTP - OTHER	3.70%	SSL - OTHER	2.53%	iTunes	2.67%
Facebook	3.04%	Xbox One Games Download	2.18%	Hulu	2.47%
FaceTime	2.50%	Facebook	1.89%	Xbox One Games Download	2.15%
Skype	1.75%	BitTorrent	1.73%	Facebook	2.01%
	69.32%		74.33%		72.72%

sandvine

Table 1 - Top 10 Peak Period Applications - North America, Fixed Access

http://bit.ly/2Glwl8G

~82% of all IP traffic

estimated* percentage of **video traffic**

in 2022

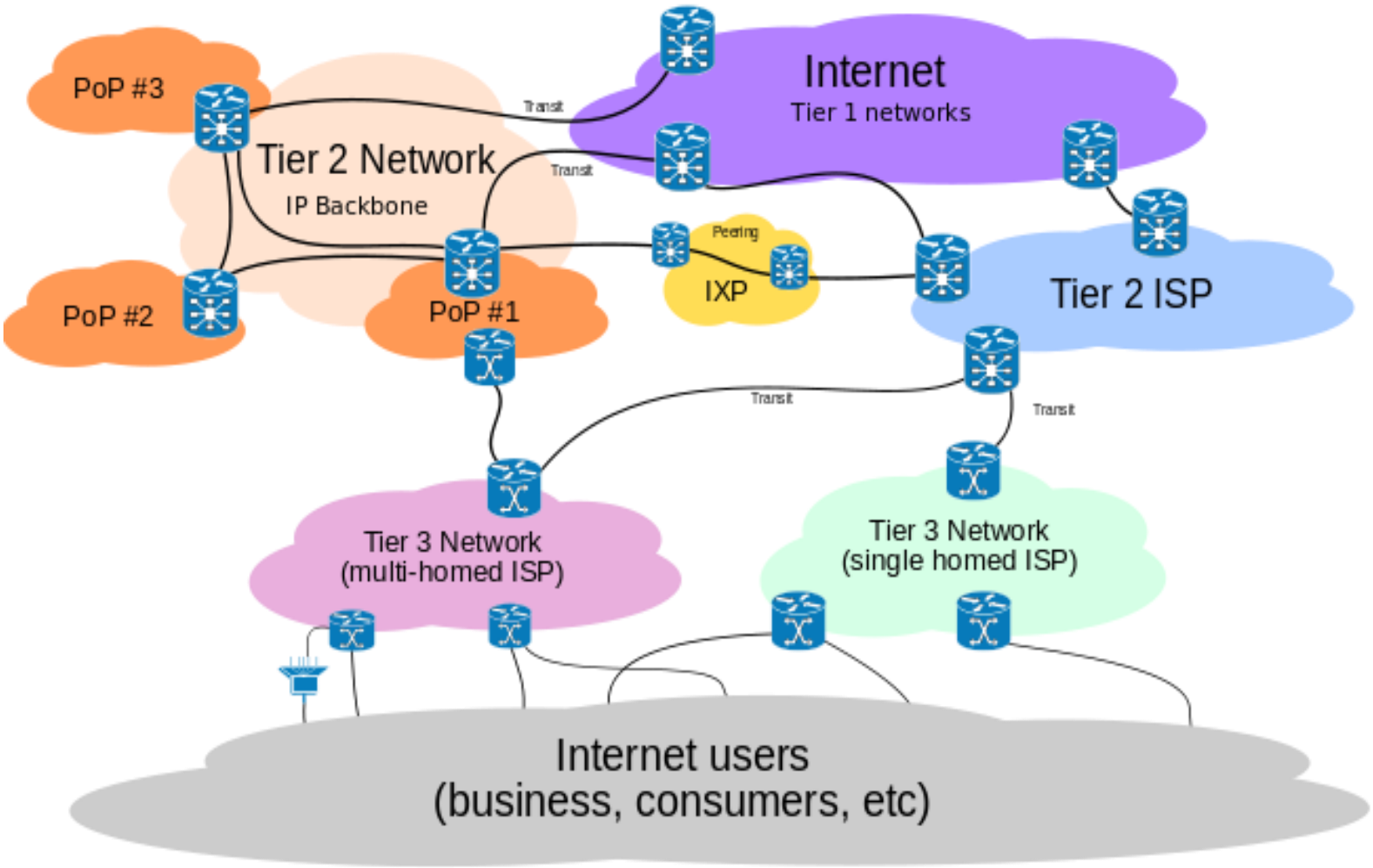
* Cisco Visual Networking Index 2017—2022

AI Era - 2025 and beyond

- The architecture is shifting - AI is reshaping infrastructure
  - 71% say their data centers can't scale AI
  - 88% plan to expand capacity to support AI workloads across on-prem, cloud, or both
  - Only 11% of data centers are fully optimized for AI workloads with advanced capabilities

This global study is based on a survey of 8,065 senior IT and business leaders responsible for networking strategy and infrastructure at organizations with 250 or more employees. The survey was conducted across 30 markets in December 2024 by Sandpiper Research & Insights, on behalf of Cisco.

Internet Today (Complex Architecture)

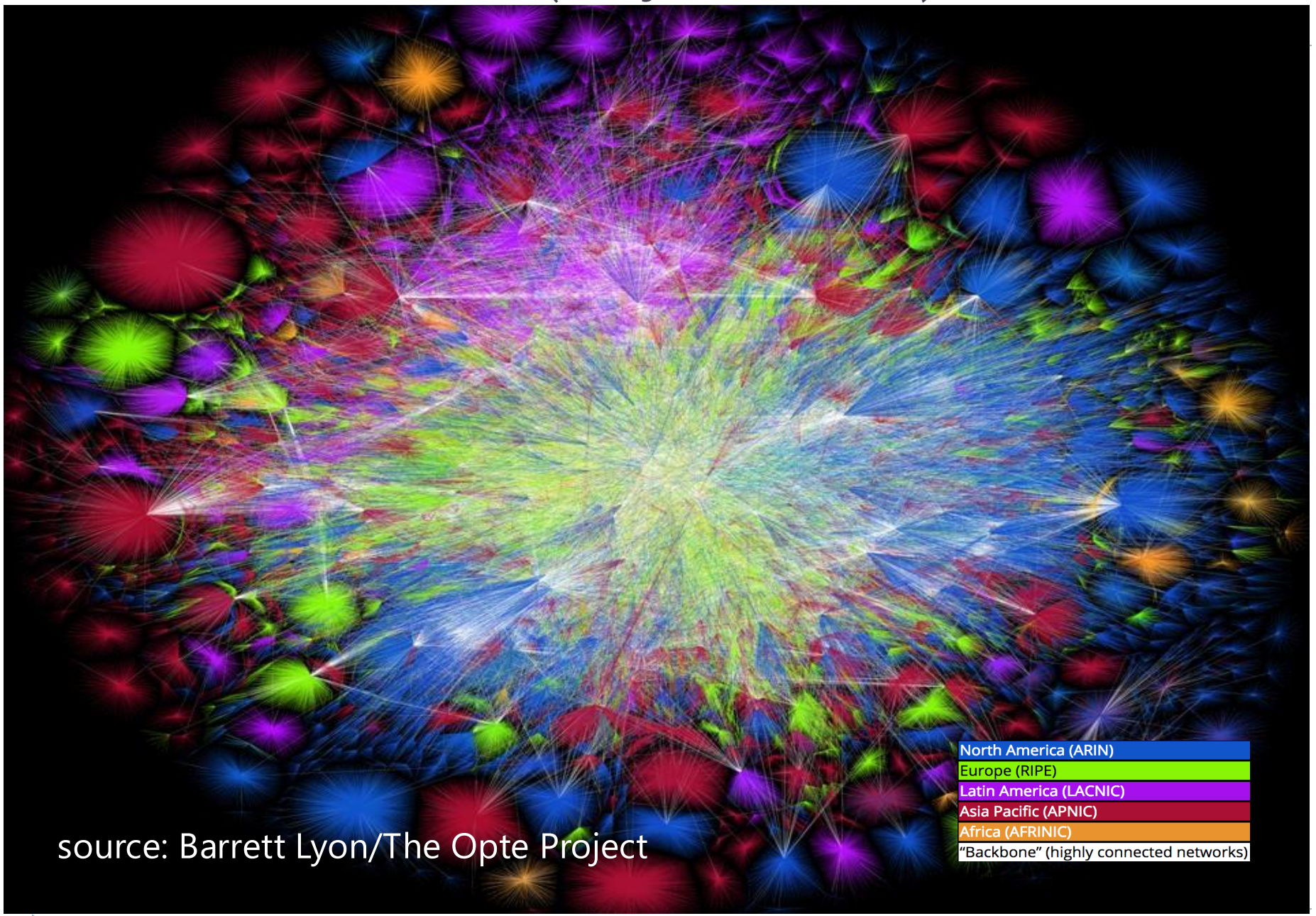


Source: wikipedia

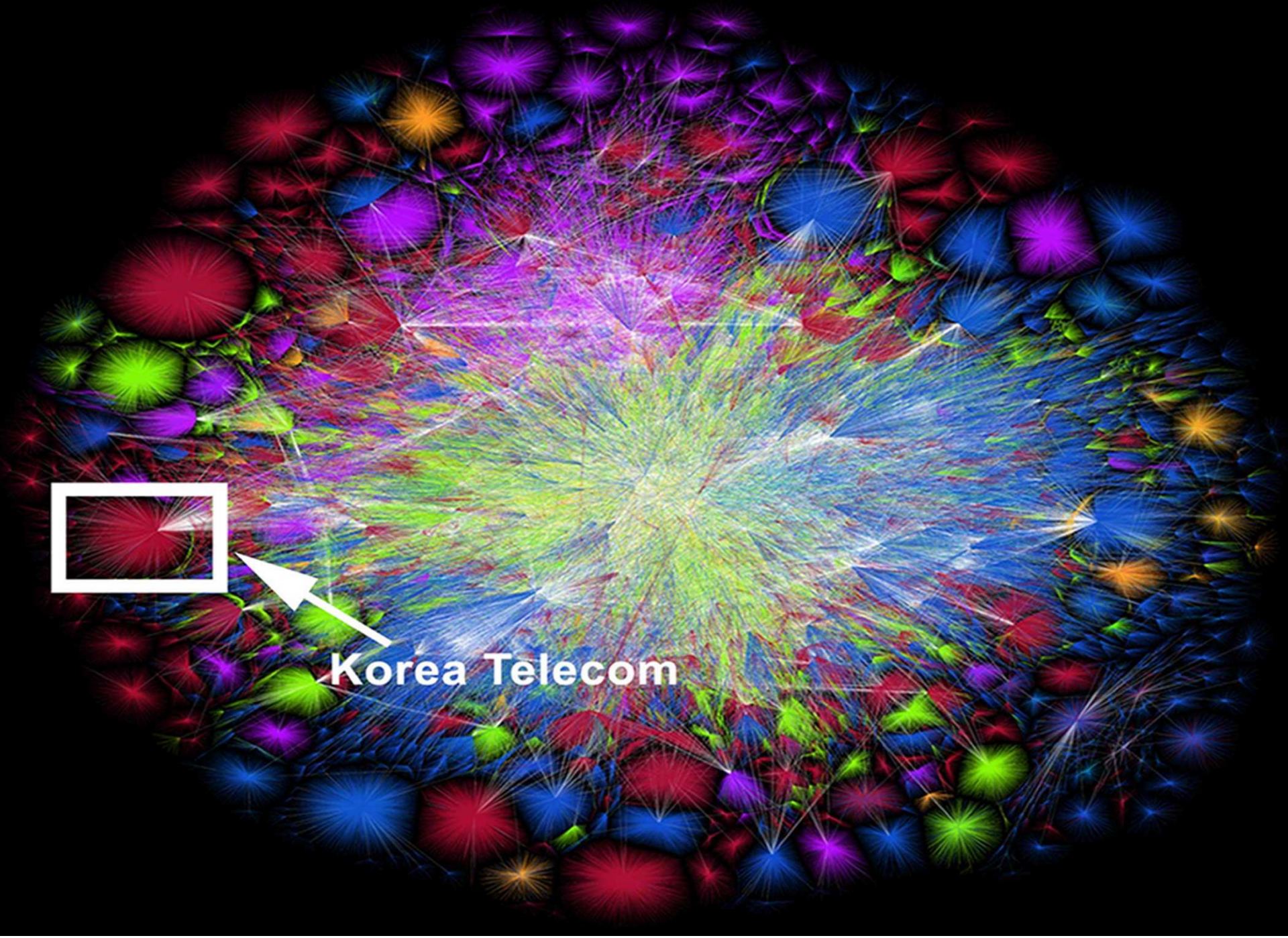
Q: What is the role of Singapore Open eXchange (SOX)?

Q: How many IXPs are there in Singapore?

Growth of Internet (**July 11, 2015**)

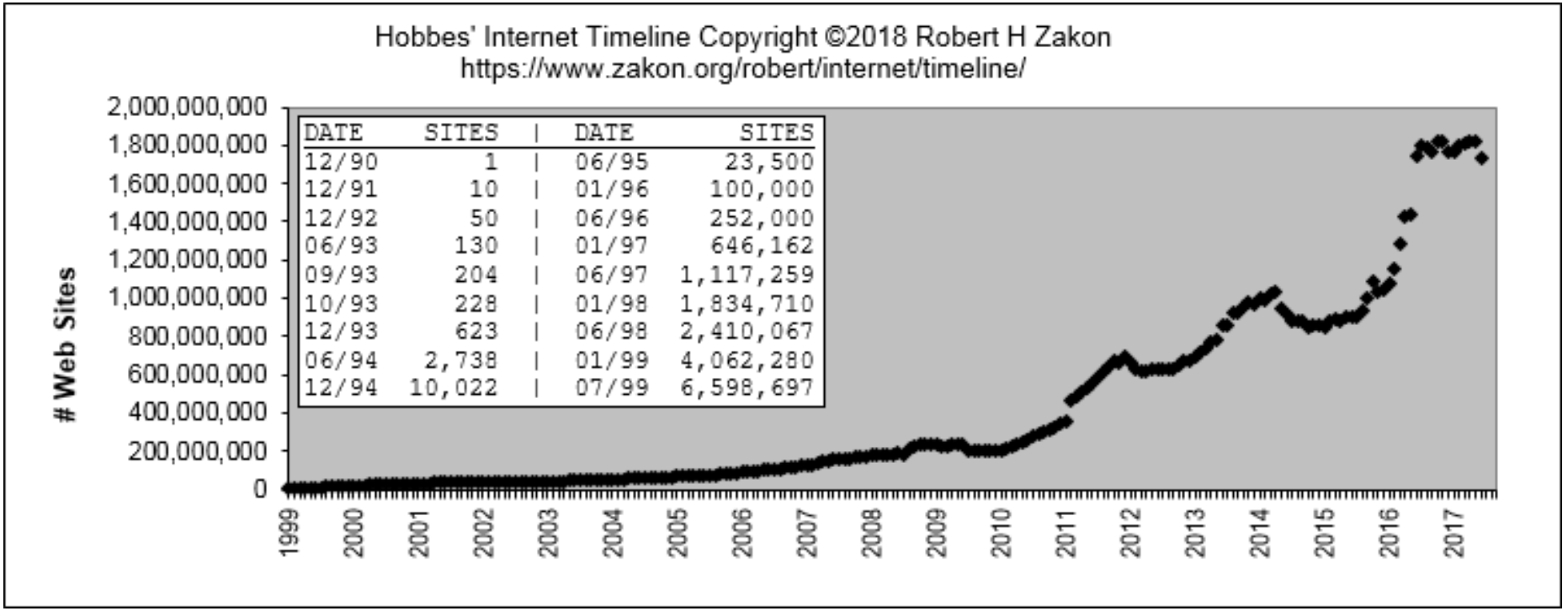


source: Barrett Lyon/The Opte Project


Korea Telecom

Growth of WWW Sites

For Your Reference



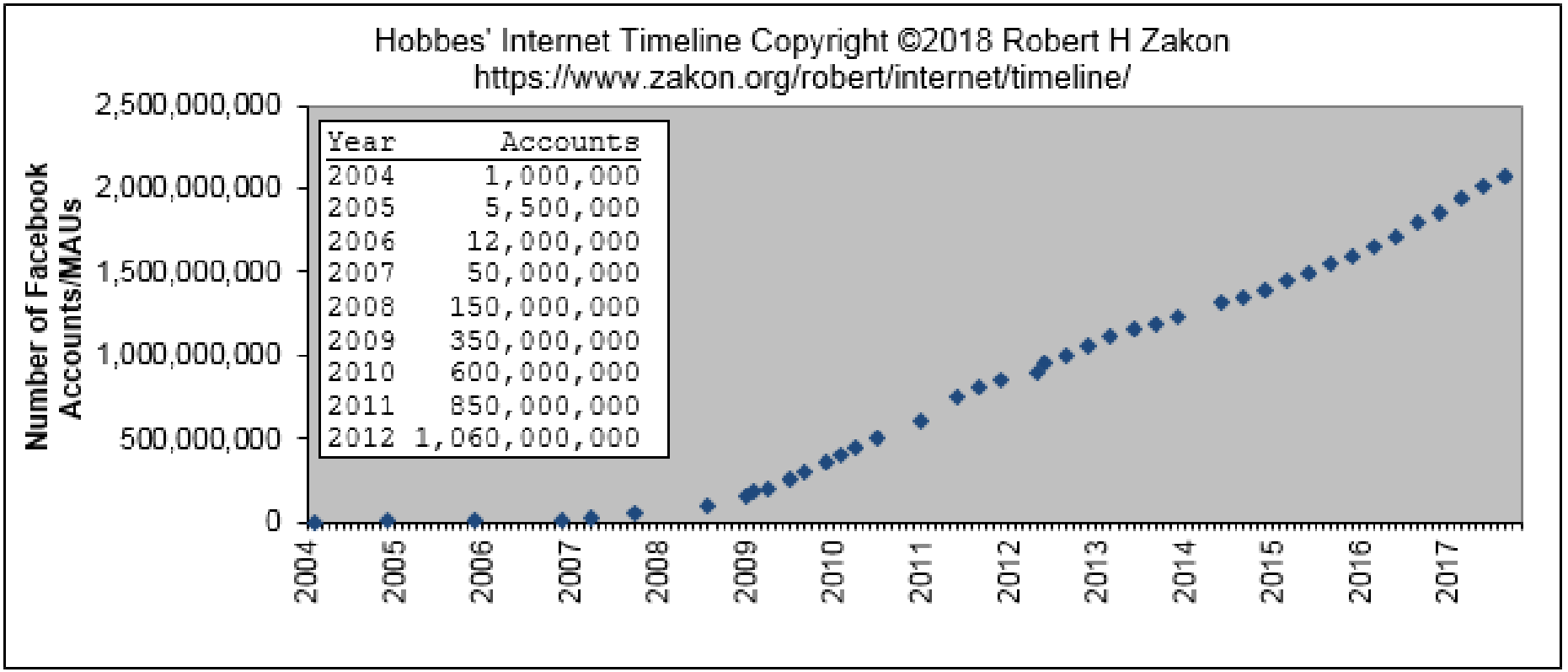
DATE	SITES	DATE	SITES
12/90	1	06/95	23,500
12/91	10	01/96	100,000
12/92	50	06/96	252,000
06/93	130	01/97	646,162
09/93	204	06/97	1,117,259
10/93	228	01/98	1,834,710
12/93	623	06/98	2,410,067
06/94	2,738	01/99	4,062,280
12/94	10,022	07/99	6,598,697

- to reach 50 million users
  - 74 years for telephone, 38 years for radio, 16 years for PC, 13 years for TV, 4 years for WWW.

Growth of Social Networks

For Your Reference

Eg. Facebook Accounts



Year	Accounts
2004	1,000,000
2005	5,500,000
2006	12,000,000
2007	50,000,000
2008	150,000,000
2009	350,000,000
2010	600,000,000
2011	850,000,000
2012	1,060,000,000

Course Theme & Philosophy

- Theme:

  "Design and Build Networks, Configure and Observe the Protocols in Action, Develop and Implement protocols and network applications."

- Philosophy:
  - Why the protocols are designed in this way, (the design philosophies)?
  - If the assumptions are different, should the design be changed?

Not just understanding the protocols and memorising structures!

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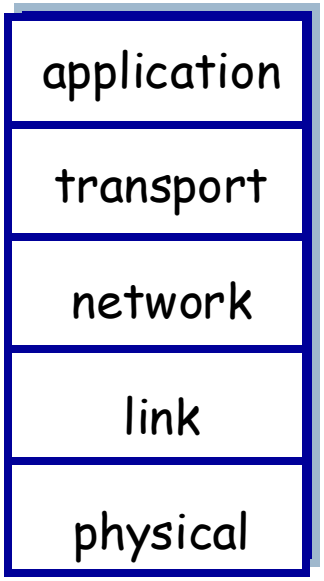
Internet protocol stack

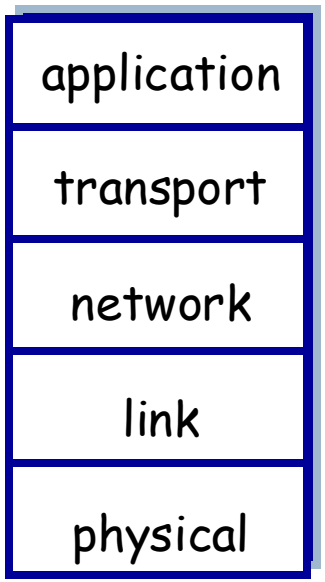
For Your Reference

- application: supporting network applications
  - FTP, SMTP, HTTP
- transport: process-process data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - Ethernet, 802.11 (WiFi), PPP
- physical: bits "on the wire"



Internet protocol stack (Identifiers)

For Your Reference



- application: SMTP (email address), HTTP (URL)
- transport: TCP/UDP (IP Addr + Port Number)
- network: Internet protocols – IPv4 (32 bits), IPv6 (128 bits)
- link: Ethernet/802.11 (WiFi) – 48 bits
- physical: bits "on the wire"

35

Layering - Recap Activity

- Match the protocols to layers - PollEV

https://pollev.com/banand

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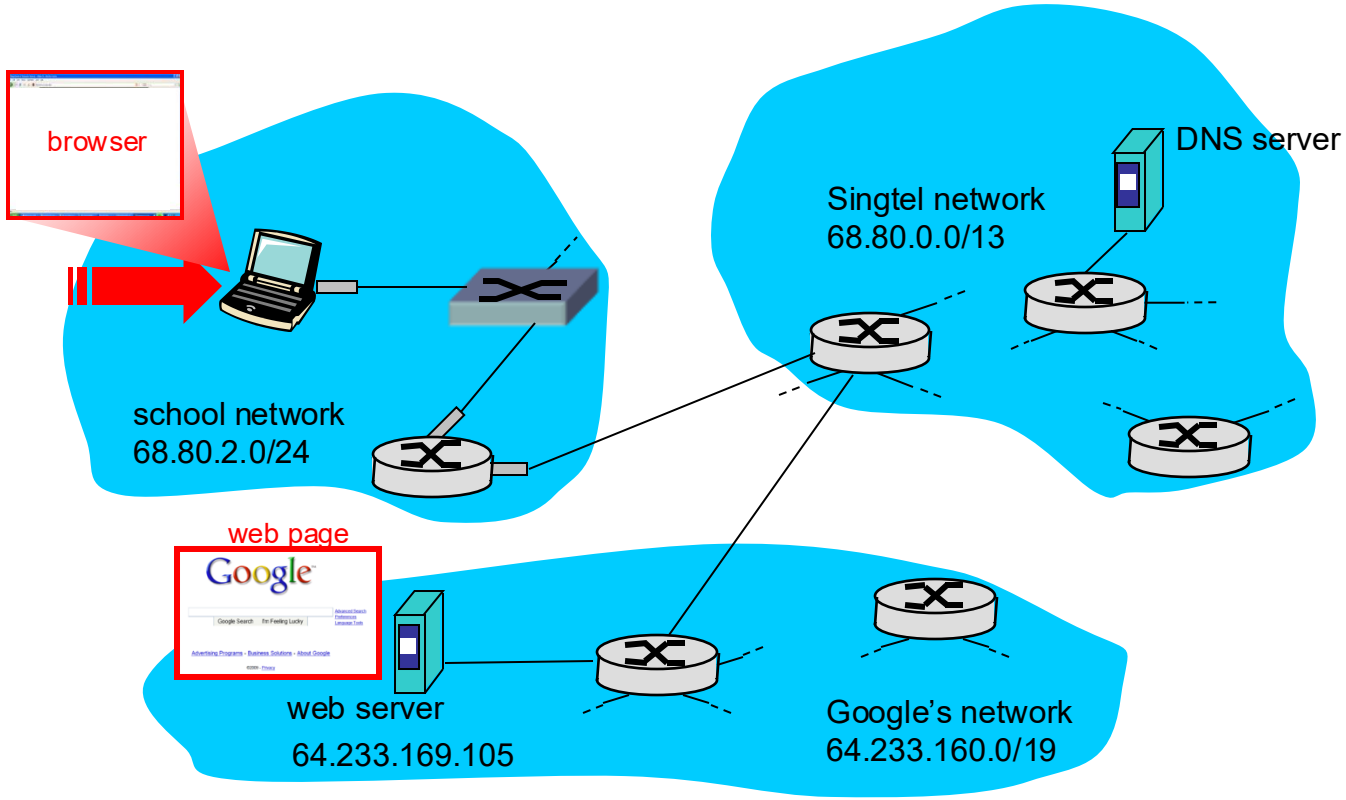
A day in the life: scenario

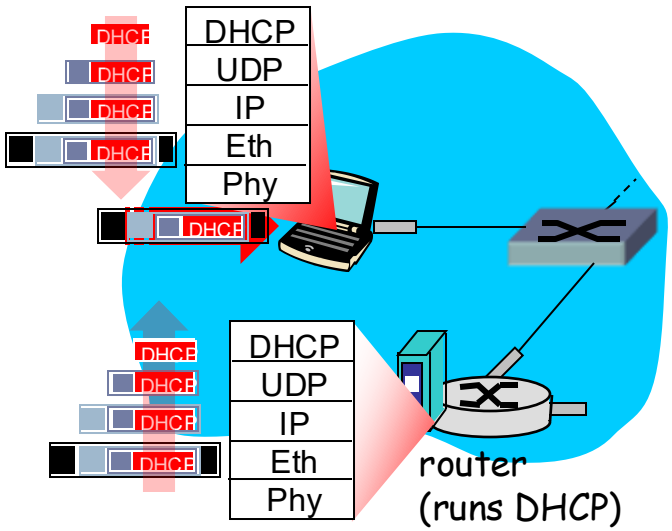
- Your laptop connects to the School Network…



Q: What actually happens in the network?
Q: What configurations are required for a Laptop to communicate in the Internet?

A day in the life… connecting to the Internet

- connecting laptop needs to get its own IP address, addr of first-hop router, addr of DNS server: use ***DHCP***



- DHCP request encapsulated in **UDP**, encapsulated in **IP**, encapsulated in **802.1** Ethernet

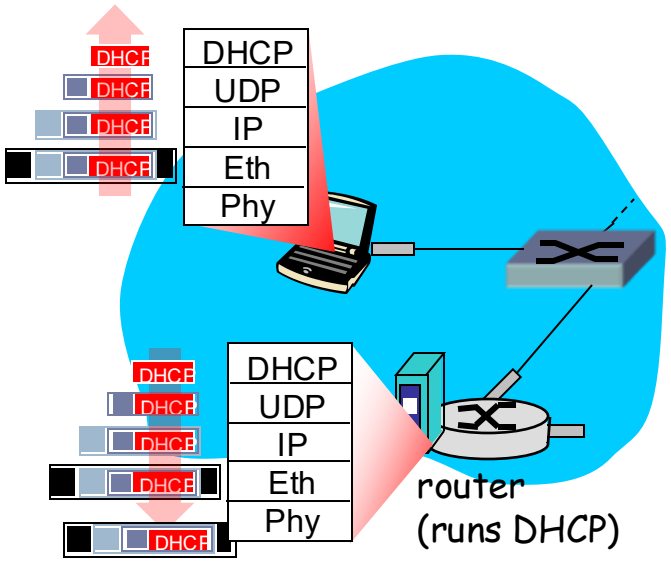
Q: How does the laptop know the IP address of DHCP Server?

- Ethernet frame broadcast (dest: FFFFFFFFFFFF) on LAN, received at router running **DHCP** server
- Ethernet demuxed to IP demuxed to UDP, UDP demuxed to DHCP

Q: How Ethernet knows it is an IP packet?
Q: How IP layer knows it is a UDP segment?
Q: How UDP layer knows it is a DHCP message?

A day in the life… connecting to the Internet

- DHCP server formulates ***DHCP ACK*** containing client's IP address, IP address of first-hop router for client, name & IP address of DNS server

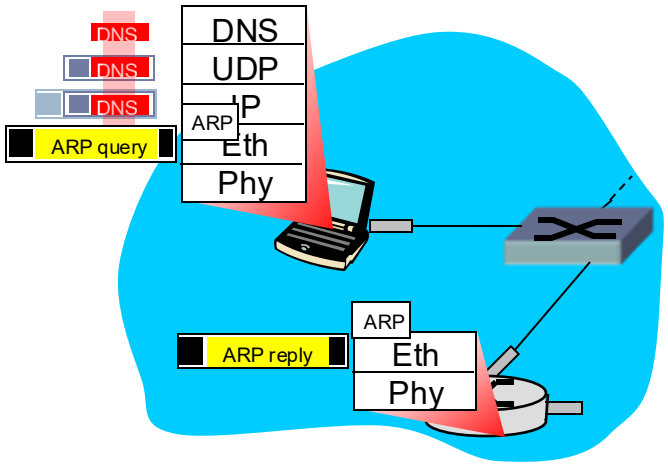


- encapsulation at DHCP server, frame forwarded (switch learning) through LAN, demultiplexing at client
- DHCP client receives DHCP ACK reply

Client now has IP address, knows name & addr of DNS server, IP address of its first-hop router

A day in the life… ARP (before DNS, before HTTP)

- before sending ***HTTP*** request, need IP address of **www.google.com**: ***DNS***



- DNS query created, encapsulated in UDP, encapsulated in IP, encapsulated in Eth.

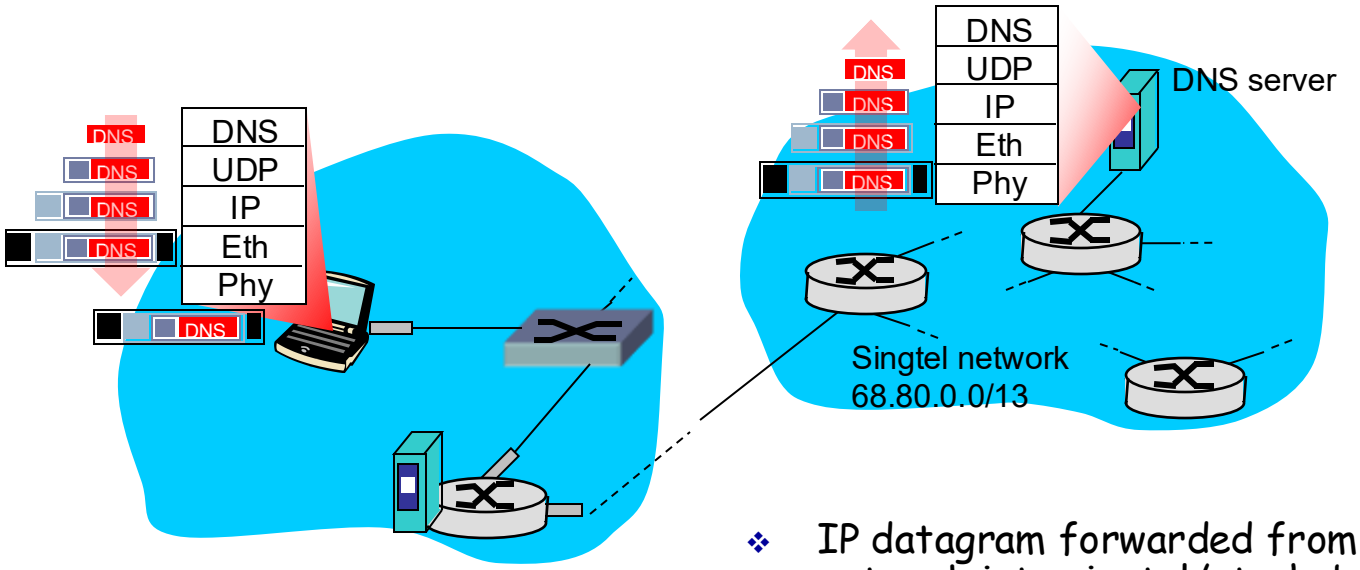
  Q: DNS Query should be sent to the gateway router. The Laptop knows IP address of the router. How does it get the MAC address?

- In order to send frame to router, need MAC address of router interface: **ARP**

- **ARP query** broadcast, received by router, which replies with **ARP reply** giving MAC address of router interface

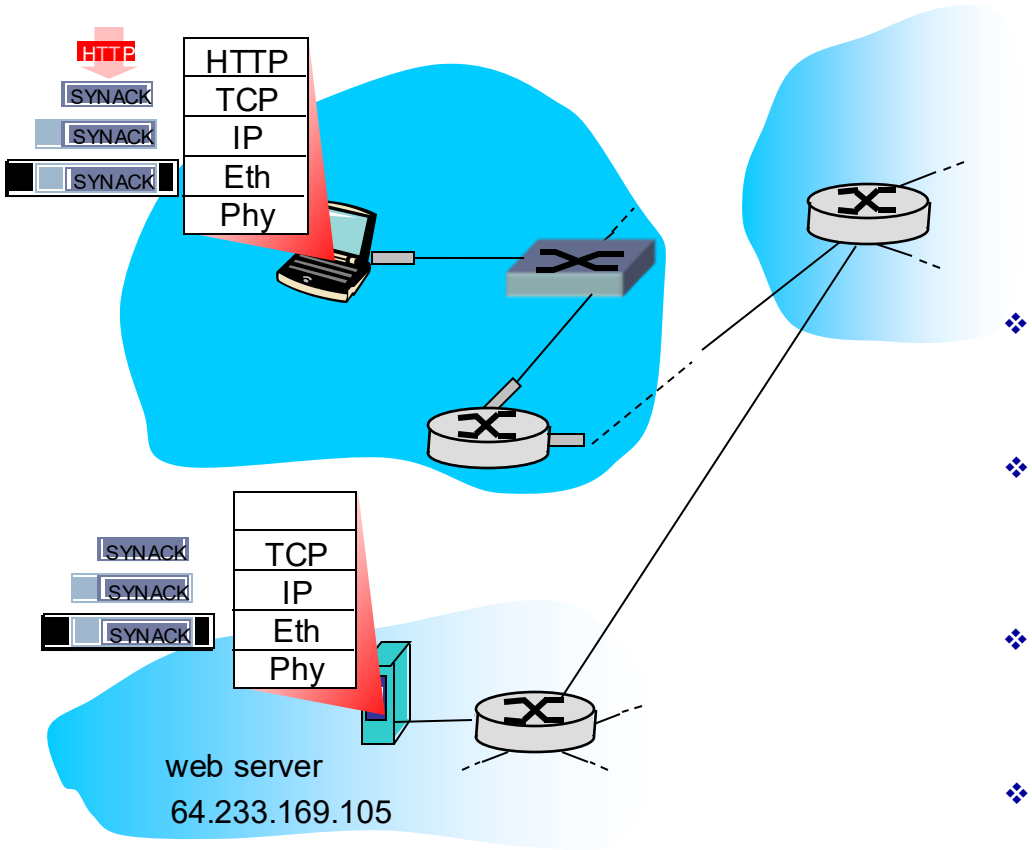
- client now knows MAC address of first hop router, so can now send frame containing DNS query

A day in the life… using DNS



- IP datagram containing DNS query forwarded via LAN switch from client to 1st hop router
- IP datagram forwarded from campus network into singtel/starhub network, routed (tables created by **RIP, OSPF, IS-IS** and/or **BGP** routing protocols) to DNS server
- demuxed to DNS server
- DNS server replies to client with IP address of www.google.com

A day in the life… TCP connection carrying HTTP



- to send HTTP request, client first opens **TCP socket** to web server
- TCP **SYN segment** (step 1 in 3-way handshake) **inter-domain routed** to web server
- web server responds with **TCP SYNACK** (step 2 in 3-way handshake)
- TCP **connection established!**

Q: To create a TCP/UDP socket, the client knows IP address. What else is needed?

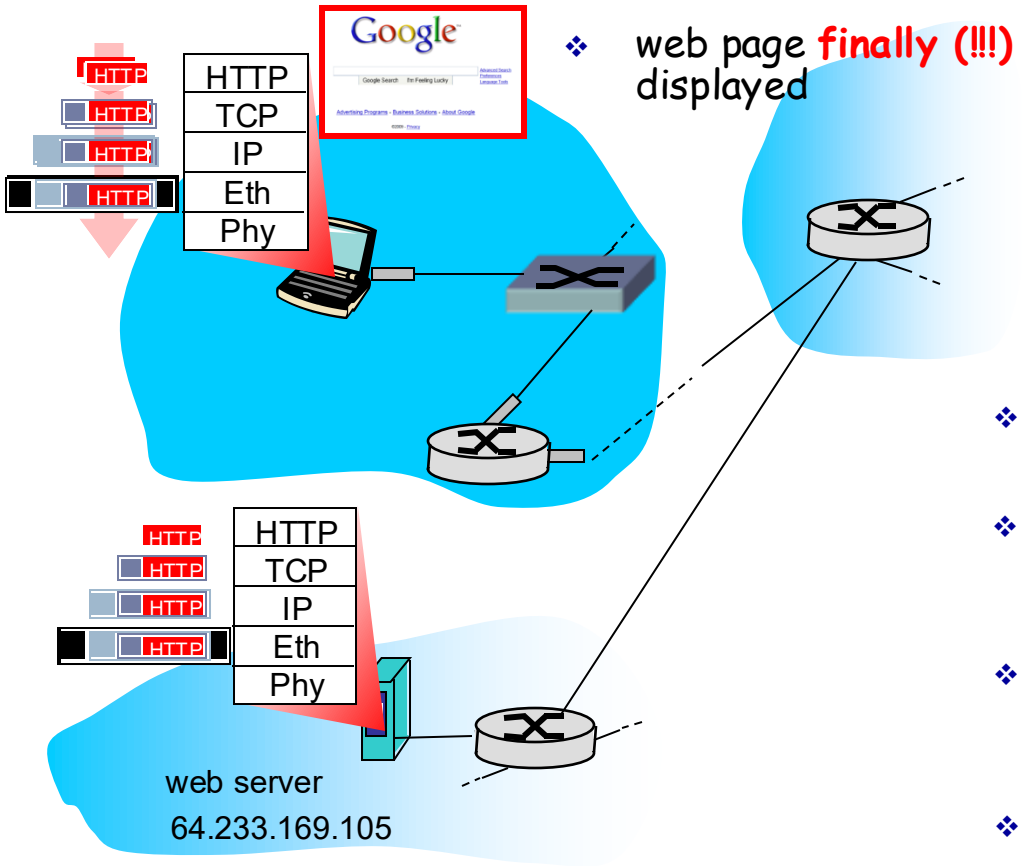
Finding the port number

- **Note:** Most services on the Internet are reachable via well-known ports. E.g. All HTTP servers on the Internet can be reached at port number "80".
- **So:** Argon simply knows the port number of the HTTP server at a remote machine.

- On most Unix systems, the well-known ports are listed in a file with name /etc/services. The well-known port numbers of some of the most popular services are:

ftp	21	finger	79
telnet	23	http	80
smtp	25	nntp	119

A day in the life… HTTP request/reply



- web page **finally (!!!)** displayed

- **HTTP request** sent into TCP socket
- IP datagram containing HTTP request routed to www.google.com
- web server responds with **HTTP reply** (containing web page)
- IP datagram containing HTTP reply routed back to client

Sample: HTTP Request

```
GET /index.html HTTP/1.1
Accept: image/gif, */*
Accept-Language: en-us
Accept-Encoding: gzip, deflate
User-Agent: Mozilla/4.0
Host: neon.tcpip-lab.edu
Connection: Keep-Alive
```

Sample: HTTP Response

```
HTTP/1.1 200 OK
Date: Sat, 25 May 2002 21:10:32 GMT
Server: Apache/1.3.19 (Unix)
Last-Modified: Sat, 25 May 2002 20:51:33 GMT
ETag: "56497-51-3ceff955"
Accept-Ranges: bytes
Content-Length: 81
Keep-Alive: timeout=15, max=100
Connection: Keep-Alive
Content-Type: text/html

<HTML>
<BODY>
<H1>Internet Lab</H1>
Click <a href="http://www.tcpip-
lab.net/index.html">here</a> for the Internet Lab
webpage.
</BODY>
</HTML>
```

COURSE TOPICS - tentative

- We will learn …
  - Studying the protocols in-depth (to a level required for Network Designers / Engineers) – [Basically CS2105 ++]
  - Investigate - HTTP, FTP, SMTP, POP3, IMAP ….
  - VLAN (port based, trunk port, MAC based)
  - Wireless Protocol [BSS, ESS, DS, Frame format and FC]
  - Inter-AS routing (BGP), Intra-AS routing (OSPF),
  - Cryptography, RSA algorithm , SSL protocol, PGP, IP-SeC/VPN, Firewall/Access Contro
  - VoIP with SIP
  - Network Virtualisation, Software Defined Networking (SDN) with Openflow Switches
  - Software Defined WAN (SD-WAN)
  - TCP [Slow start, Congestion control – AIMD; Silly Window Syndrome and Solution?]
  - Additional Topics: IPv6, Multicast Protocols

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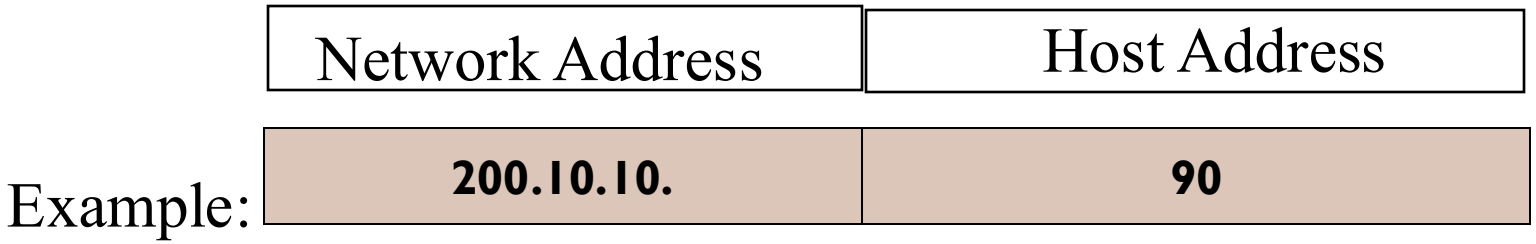
Internet Address

Revision ….

- Conceptually, each IP address is a pair (**netid**, **hostid**)
- Key Question: How many bits for network and how many for host?



Netmask example: /24 (or)

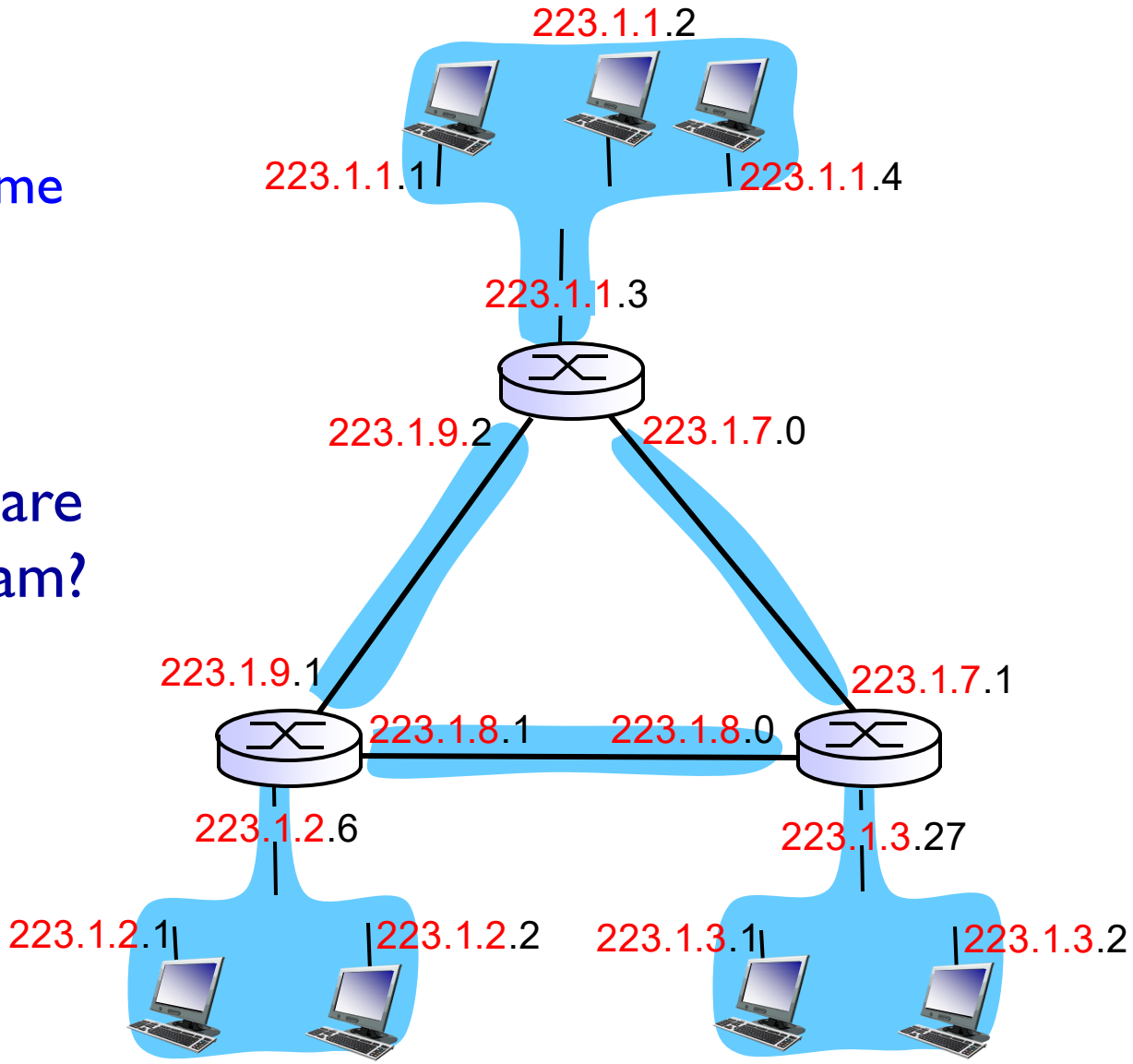
255.255.255.	0

Subnets (mask: /24)

Revision ….

- What's a subnet?
  - interfaces with same subnet part of IP address

How many subnets are there in the diagram?



IP address allocation by Country

FYORP

Source: http://www.countryipblocks.net/index.php

Country: SINGAPORE
ISO Code: SG
 # Total Networks: 394
 # Total Subnets: 4,351,488
58.65.0.0/19
58.145.192.0/18
58.146.128.0/18
.....

Country: CHINA
ISO Code: CN
 # Total Networks: 1,472
 # Total Subnets: 161,204,992
58.14.0.0/15
58.16.0.0/16
58.17.0.0/17
.....

Country: UNITED STATES
ISO Code: US
 # Total Networks: 35,756
 # Total Subnets: 1,434,427,902
3.0.0.0/8
4.0.0.0/8
6.0.0.0/8
....
21.0.0.0/8
22.0.0.0/8
24.0.0.0/12
24.16.0.0/13
.....

www.nus.edu.sg	137.132.21.117	137.132.0.0/16
www.ntu.edu.sg	155.69.5.163	155.69.0.0/16
www.smu.edu.sg	202.161.41.246	202.161.32.0/19

Special IP Addresses

- **first address & the last address** *in any IP network are reserved and not assigned to a host.*

  Example:

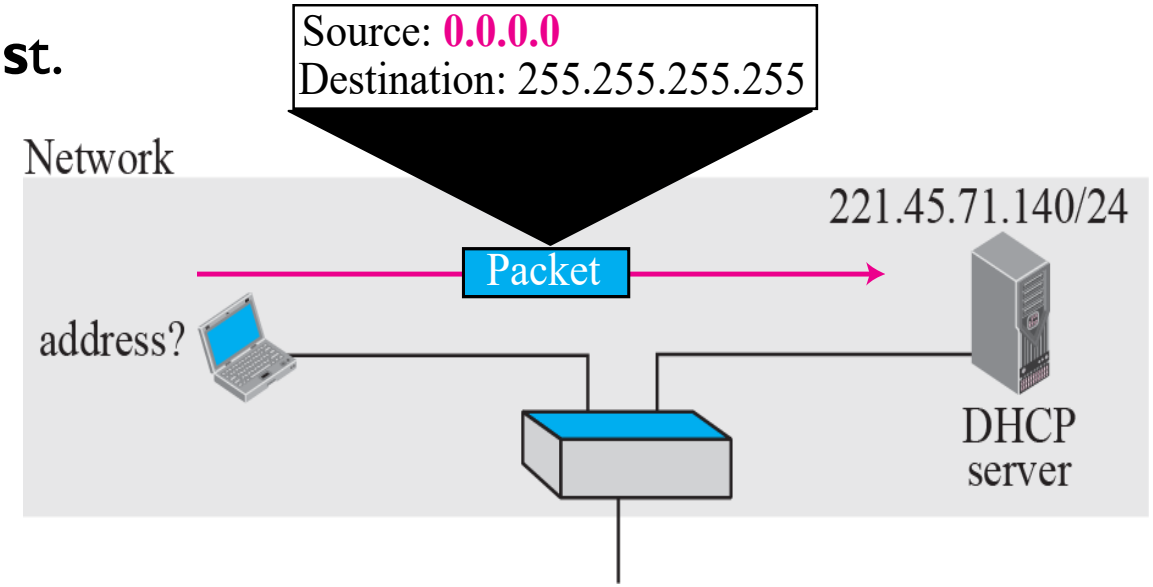
  200.10.10.0/24 → network identification

  200.10.10.255/24 → Broadcast address

- **255.255.255.255 → limited broadcast**

  Router blocks; otherwise whole Internet will be flooded.

- **0.0.0.0 → *this* host.**

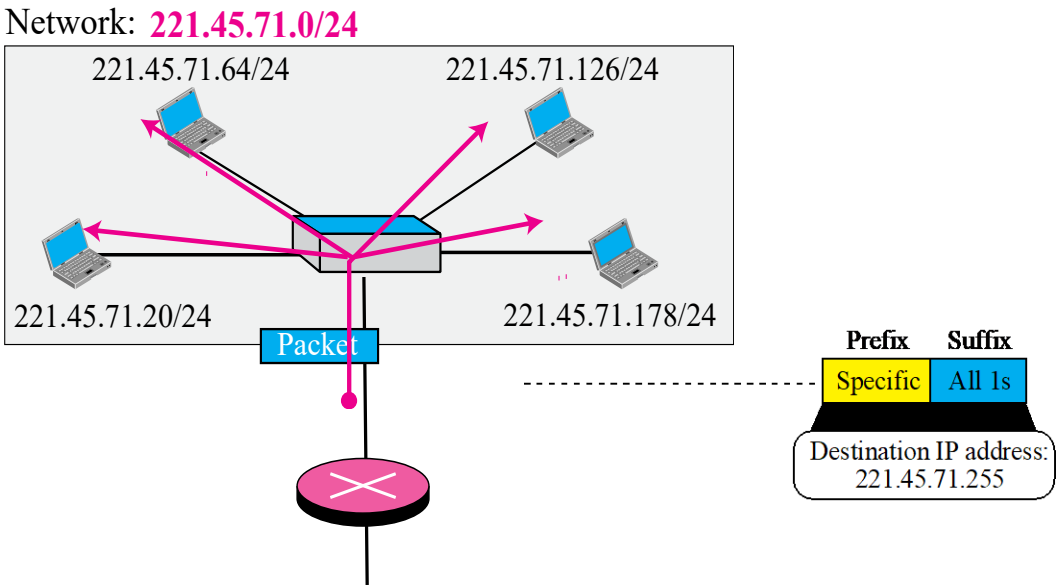


Special IP Addresses

the front pa

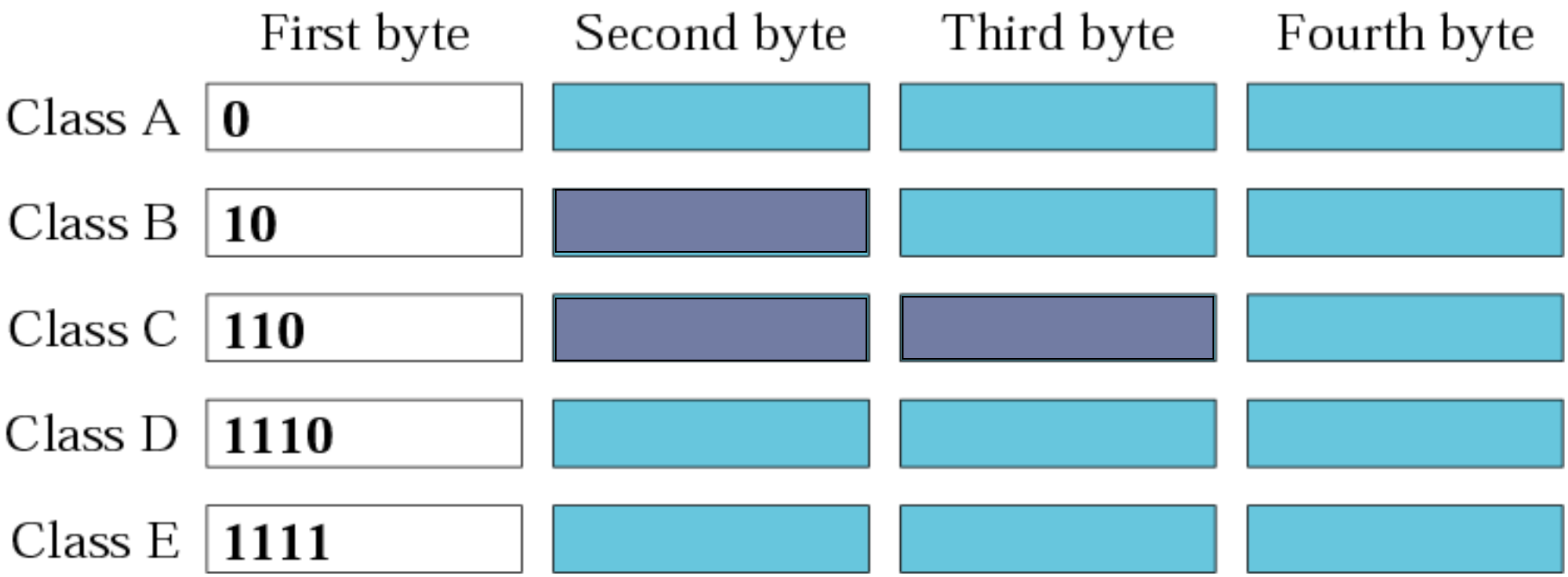
- **Network part all zeros → the host on *this* network.**
- **Host part all ones → Direct Broadcast address.**

the behind part, which is after the subnet mask

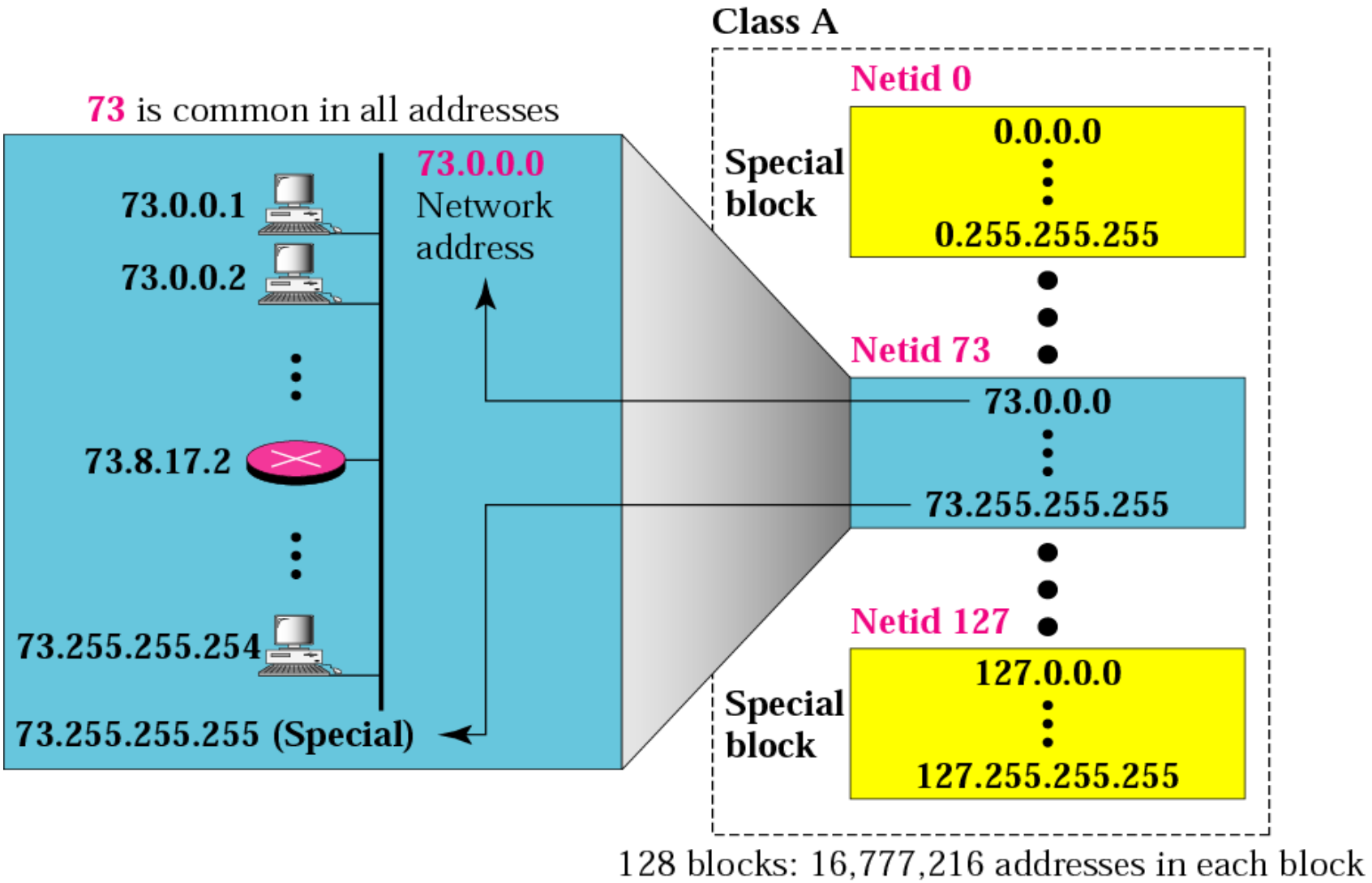


Classful Addresses

by bytes



any network, first and last not usable, first and last network also not usable



Problem: Millions of Class A addresses are wasted, Why?

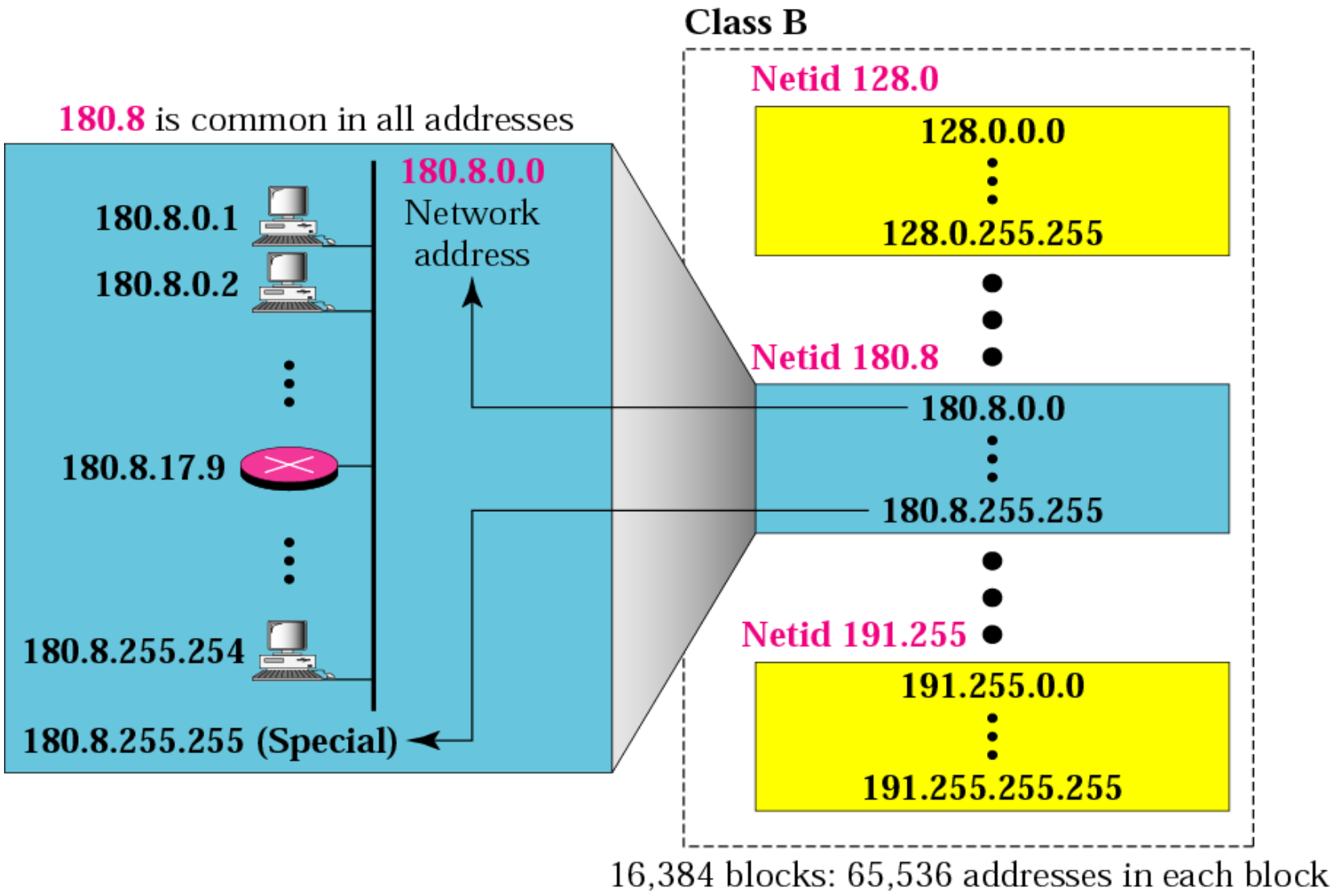
Some Owners of Class A Addresses

General Electric	3.0.0.0/8
IBM	9.0.0.0/8
AT&T	12.0.0.0/8, 32.0.0.0/8
Apple Inc.	17.0.0.0/8

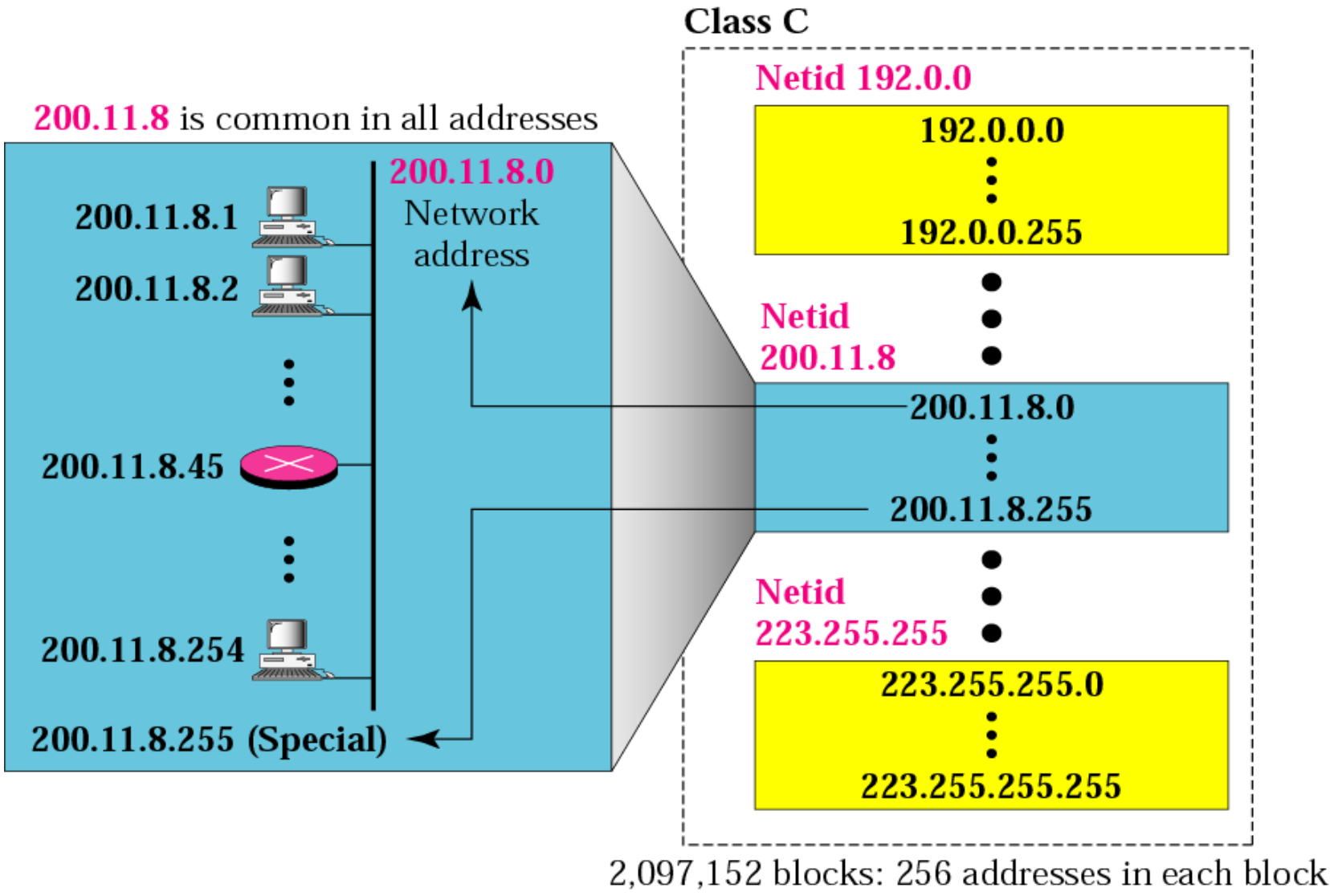
United States Department of Defense

6.0.0.0/8, 7.0.0.0/8, 11.0.0.0/8, 21.0.0.0/8, 22.0.0.0/8, 26.0.0.0/8, 28.0.0.0/8, 29.0.0.0/8, 30.0.0.0/8, 33.0.0.0, 55.0.0.0/8, 56.0.0.0/8

Massachusetts Institute of Technology 18.0.0.0/8



Problem: Many class B addresses are wasted.



Problem: The number of addresses in class C is smaller than the needs of most organizations.

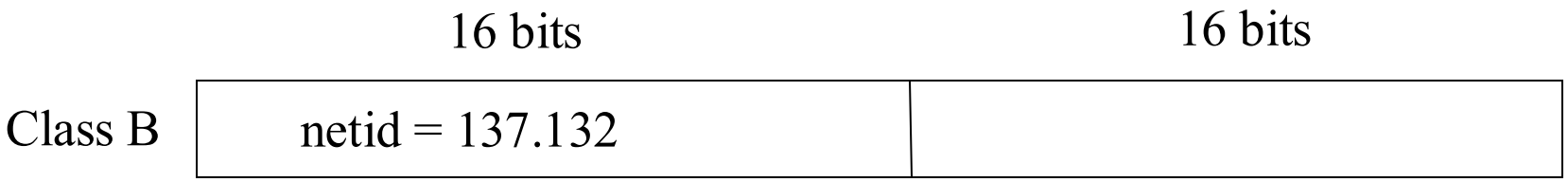
Classless Addressing

- Q: How IP address allocation problem is solved?
  - Classful addressing deals with a few fixed classes of prefix lengths (8 or 16 or 24)
  - Solution:
    - **Classless addressing** deals with any prefix length –Network part of an IP address can be any number of bits.
    - **220.78.168.0 255.255.248.0 → 220.78.168.0/21**
  - Hence each subnet can potentially have **Variable length subnet mask** (VLSM)
- Another approach is through use of NAT & Private IP addresses – discussed in Week 7

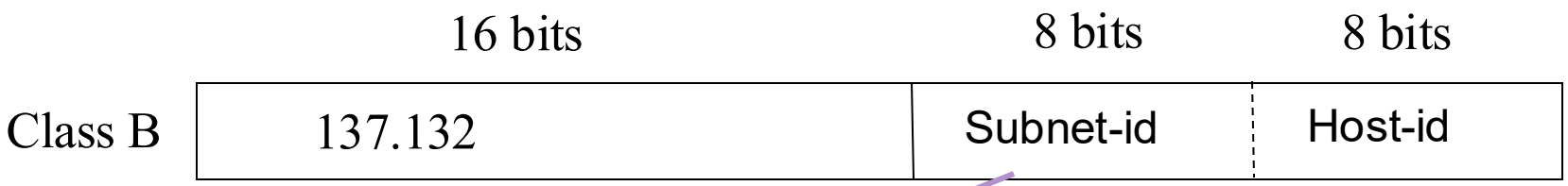
IP Subnet Addressing

Revision ….

- Organizations are owning large address blocks (eg. Class A and B) have too many hosts on a single network.
  - eg., Class B network has 2^{16} - 2 hosts
- Generally, network administrator of an organization divides a large network into smaller subnets.
  - Q: Why do we need to subnet?
- Subnetting involves borrowing bits from the host part to expand the network part
- Example: NUSNET



NUSNET Example



137.132.0.0
137.132.1.0
137.132.2.0
…
137.132.89.0
…
137.132.253.0
137.132.254.0
137.132.255.0

137.132.89.0
(network addr of subnet 89)

137.132.89.1

137.132.89.2

…

137.132.89.253

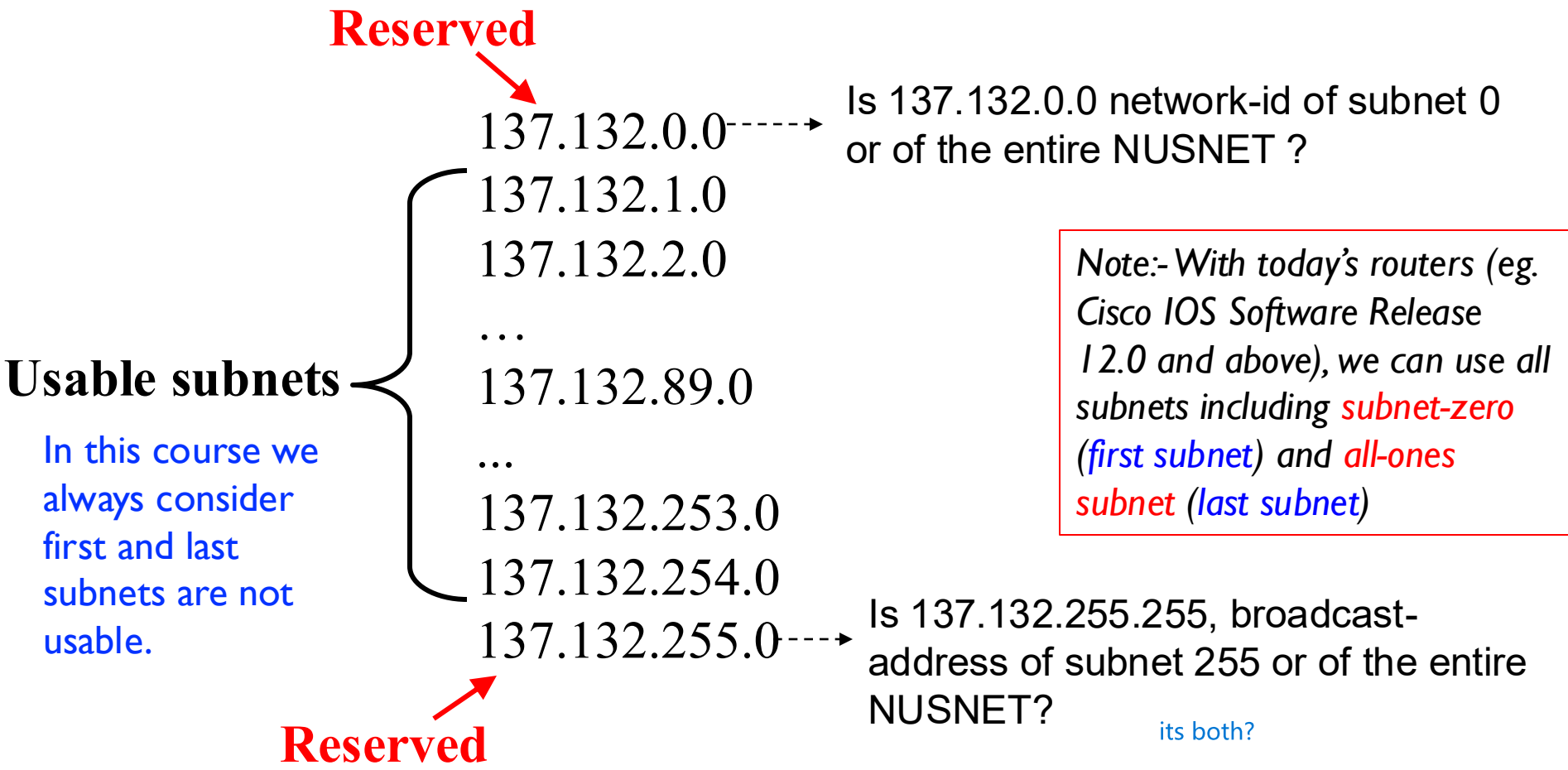
137.132.89.254

137.132.89.255
(broadcast addr of subnet 89)

In this course:
- Address block 2^8 addresses
- Only 2^8-2 assignable or usable addresses.

The number of IP addresses available for assignment in this subnet is **256-2=254 addresses**.

NUSNET Example *(cont)*



Second Level of subnetting

- Sometimes, further level of subnetting is desirable.
- Reasons include:
  - Security (eg., - prevent some hosts in a IP subnet accessing a database)
  - Performance - Unnecessary broadcast (broadcast domain)
  - Performance (if too many collisions create separate collision domains by creating subnets – However this is no longer a problem?)

Example:

- Consider the network 137.132.90.0/24
- Divide this network such that each subnet has 64 IP addresses (including first and last addresses).

EXAMPLE

An organization is granted the block 130.34.12.64/26. The organization needs 4 (same size) subnets. Assume all subnets (first and last) are usable. What is the subnet prefix length?

Find the first and last address in each subnet.

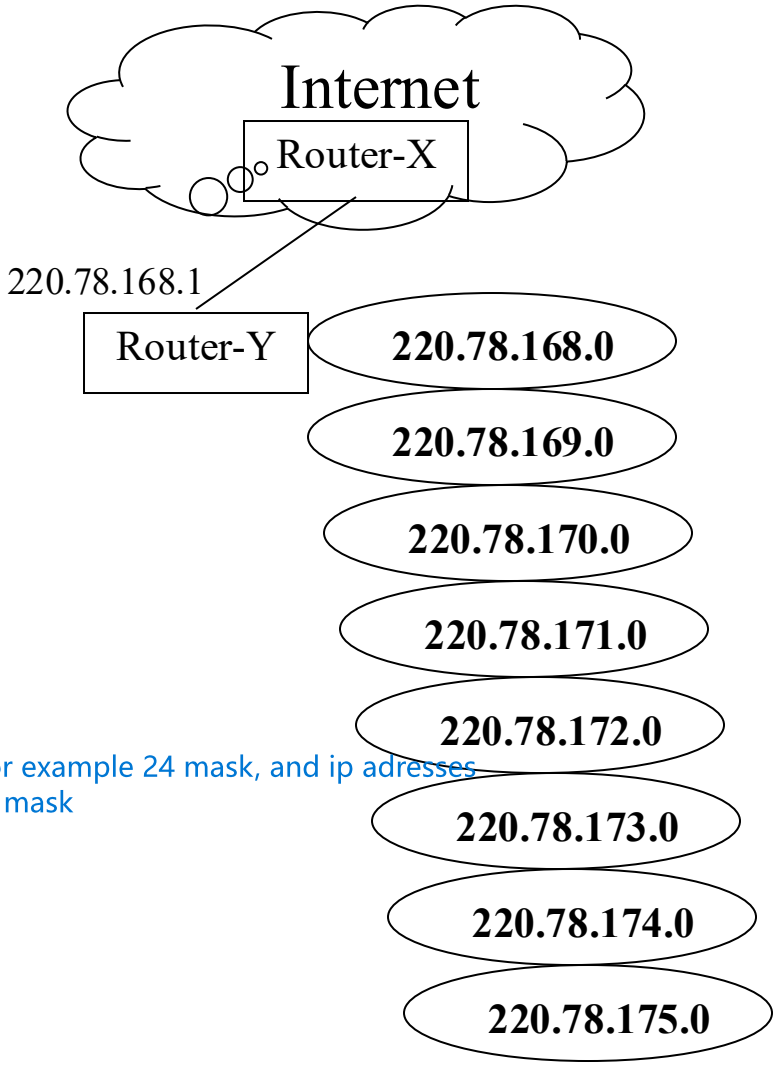
Supernetting

- Class C is too small for many organizations and companies
- Classless Internet Domain Routing (CIDR) also allows
  - Merging small networks like Class C networks into a larger network with single prefix

Example

Suppose 8 class C addresses each with 254 hosts giving 2032 addresses is allocated to a company that requires 2000 hosts.

Q: What is the problem with small address blocks?



Before Supernetting

Routing Table in router X

220.78.168.0 255.255.255.0 220.78.168.1
220.78.169.0 255.255.255.0 220.78.168.1
220.78.170.0 255.255.255.0 220.78.168.1
220.78.171.0 255.255.255.0 220.78.168.1
220.78.172.0 255.255.255.0 220.78.168.1
220.78.173.0 255.255.255.0 220.78.168.1
220.78.174.0 255.255.255.0 220.78.168.1
220.78.175.0 255.255.255.0 220.78.168.1

After Supernetting

supernetting = merging routes, for example 24 mask, and ip adresses with 1,2,3,4 can be changed to 22 mask

Routing Table in router X

220.78.168.0 255.255.248.0 220.78.168.1

Route aggregation

To simplify routing tables in routers and speed up lookups

Private IP Addresses

- Public IP addresses are globally unique, and are allocated by the Regional Internet Registries (RIRs) or ISPs

- Private IP addresses are non-routeable globally, and are available freely

10.0.0.0	to 10.255.255.255	1	Class A network
172.16.0.0	to 172.31.255.255	16	Class B networks
192.168.0.0	to 192.168.255.255	256	Class C networks

- What is the use of Private IP addresses?

Topics Today

Networking Concepts with A Simple Example

IP Address and Subnet - Revision

Network Address Translation

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Comment/feedback on lectures and labs through discord/email! Early!

Continuous feedback will help you and your classmates!

END

THANKS FOR YOUR TIME!

Module Theme: "Design and Build Networks, Configure and Observe the Protocols in Action, Develop and Implement protocols and network applications."