
Networks, Security, and Privacy

158.235

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<https://powcoder.com>
A/Prof. Julian Jang-Jaccard

Massey University
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Network

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Layer

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Reading: Chapter 5 in the prescribed textbook

Network Layer

- **Layer 3 in the Internet model**

- Responsible for moving messages from a source computer to the intended destination computer

- **Main function;**

- IP fragmentation
- Addressing
- Routing

Internet Model

Application

Transport

Network

Data Link

Physical

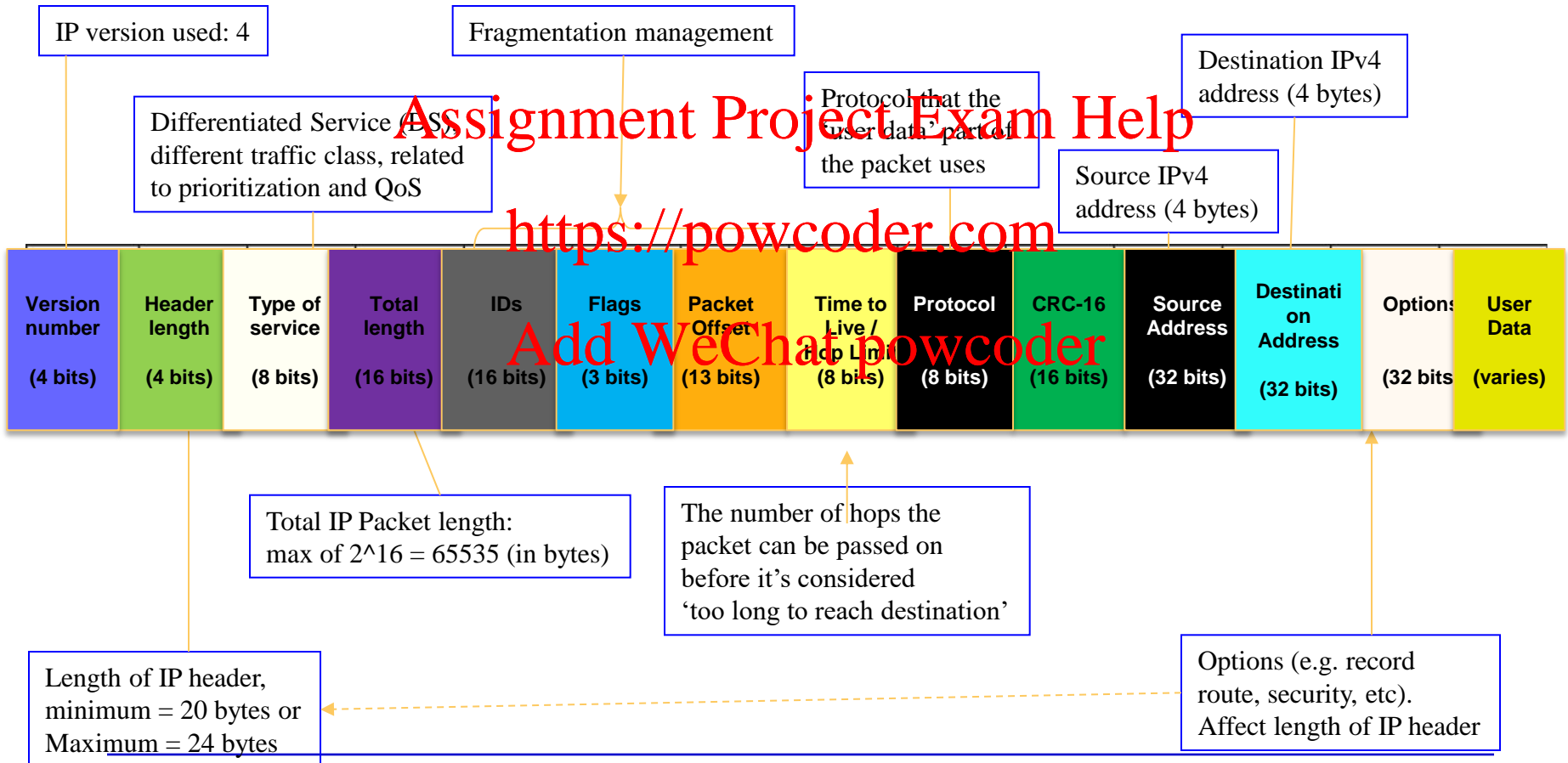
Network Layer Protocols

- Internet Protocol (IP)
 - IP version 4 (IPv4)
 - Most common Version of IP used
 - 32-bit addresses (2^{32} or ~4.29 billion possible)
 - Exhaustion of address space

Version number (4 bits)	Header length (4 bits)	Type of service (8 bits)	Total length (16 bits)	IDs (16 bits)	Flags (3 bits)	Packet Offset (13 bits)	Time to Live / Hop Limit (8 bits)	Protocol (8 bits)	CRC-16 (16 bits)	Source Address (32 bits)	Destination Address (32 bits)	Options (32 bits)	User Data (varies)
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IP Packet Formats

IPv4 Header: 192 bits (24 bytes)



340,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000

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Network Link Layer

- **IP fragmentation**

- **Addressing**

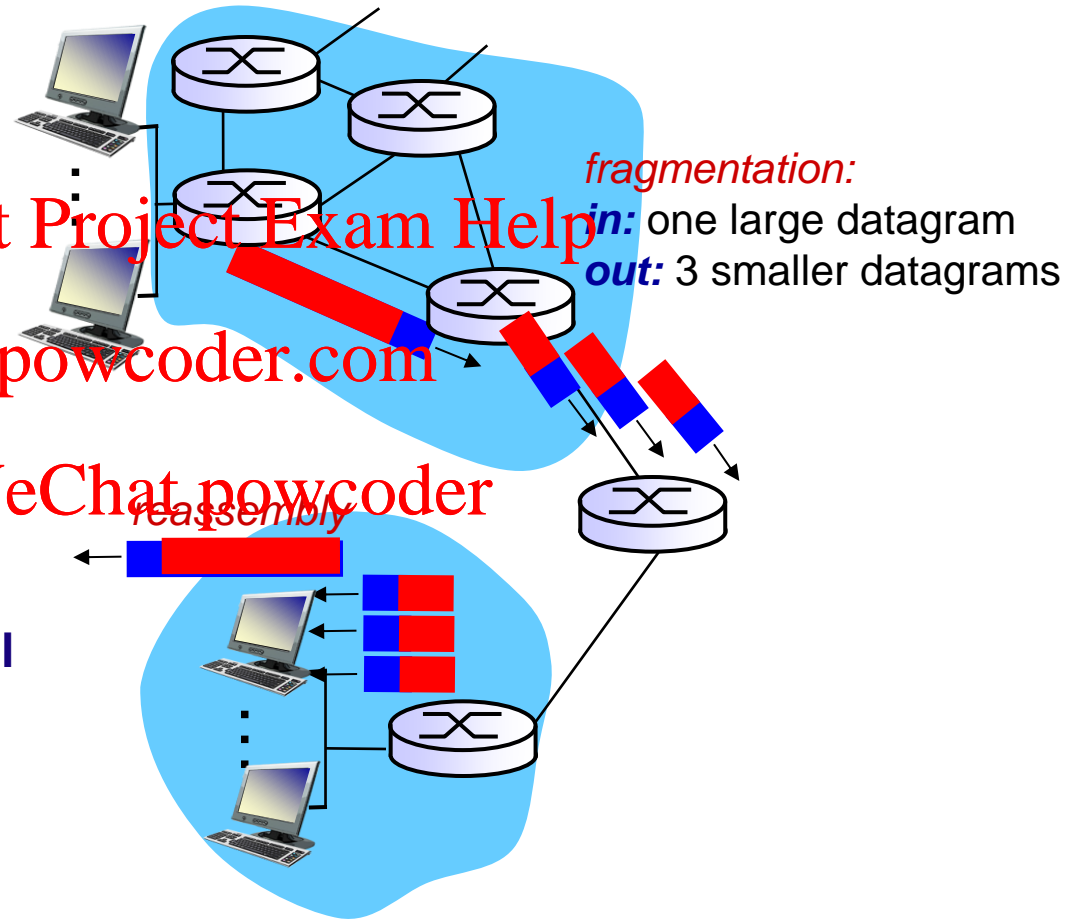
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- **Routing**

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IP Fragmentation

- network links have MTU (max.transfer size) - largest possible link-level frame
 - ✓ different link types, different MTUs
- large IP datagram divided (“fragmented”) within net
 - ✓ one datagram becomes several datagrams
 - ✓ “reassembled” only at final destination
 - ✓ IP header bits used to identify, order related fragments



IP Fragmentation

- Fragmentation management fields:

- *identification* (16 bits): unique identification for *all packets* related to the same upper-layer datagram

- *flags* (3 bits): fragment ability management

- 0xx : not used (reserved)

- x0x : fragment

- x1x : do not fragment

- xx0 : the last fragment

- xx1 : more fragments

- *offset* (13 bits): starting sequence number for the packet (measured in the unit of 8 byte blocks)

- *To keep track of order of packets*



IP Fragmentation

example:

- ❖ 4000 byte segment
- ❖ MTU = 1500 bytes

		ID =f2			data =4000
--	--	-----------	--	--	---------------

one large segment becomes
several smaller packets

IP overhead (20 byte) +
data (1480 byte) =
1500

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offset (measured in octet)=
1480/8

	length	ID	fragflag	offset	data
	=1500	=f2	=x01	=0	=1480

	length	ID	fragflag	offset	data
	=1500	=f2	=x01	=185	=1480

	length	ID	fragflag	offset	data
	=1060	=f2	=x00	=370	=1040

Network Link Layer

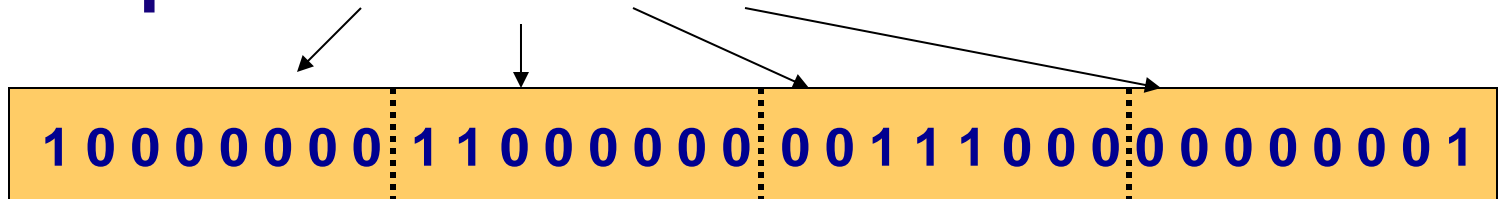
- IP fragmentation

- Addressing
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- Routing
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IP Addressing

- 4 byte (32 bit) addresses
 - Strings of 32 binary bits
- Dotted decimal notation
 - Used to make IP addresses easier to understand for human readers
 - Breaks the address into four bytes and writes the digital equivalent for each byte
- Example: 128.192.56.1



IP Addressing

- A portion of an IP address represents **the network** and the rest identifies **the host**
- **Classful addressing**
 - Uses the first bits to determine number of hosts
 - Discontinued (but nomenclature still used)
- **Classless Inter-Domain Routing (CIDR)**
 - No fixed subnet part and host parts
 - Flexible way to decide

Classful Addressing

Class A	7 bits		24 bits		$2^7 \rightarrow 128$ networks $2^{24} \rightarrow$ over 16 millions hosts per network $2^{31} \rightarrow$ over 2 Billion addresses in total
	0	Net ID		Host ID	
	0 -127				
Class B	14 bits		16 bits		$2^{14} \rightarrow$ over 16K networks $2^{16} \rightarrow$ over 65K hosts per network $2^{30} \rightarrow$ over 1 Billion addresses in total
	1 0	Net ID		Host ID	
	128 -191				
Class C	21 bits		8 bits		$2^{21} \rightarrow$ over 2 million networks $2^8 \rightarrow 255$ hosts per network $2^{29} \rightarrow 536$ Million addresses
	1 1 0	Net ID		Host ID	
	192 -223				
Class D	1 1 1 0				Multicast address $2^{28} = 268$ Million addresses
Class E	1 1 1 1				Reserved $2^{28} = 268$ Million addresses

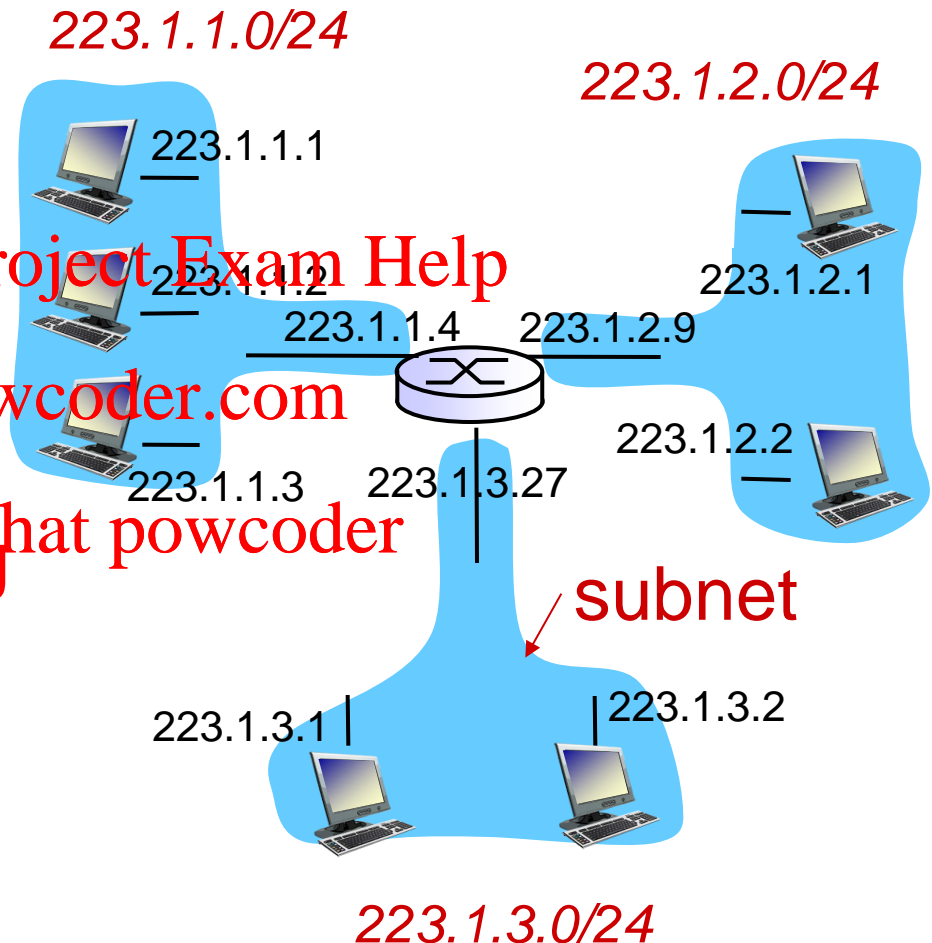
Classless Inter-Domain Routing

- Subnet portion of address of arbitrary length
- address format: **a.b.c.d/x**, where x is # bits in subnet portion of address



Subnets

- Group of computers on the same LAN with IP address sharing the same prefix
- Can physically reach each other without intervening router



IP Assignment

Q: How does a *host* get IP address?

- **hard-coded by system admin in a file**

- Windows: control-panel->network->configuration->tcp/ip->properties
- UNIX: /etc/rc.config

- **DHCP: Dynamic Host Configuration Protocol:**

- Plug and play
-

DHCP

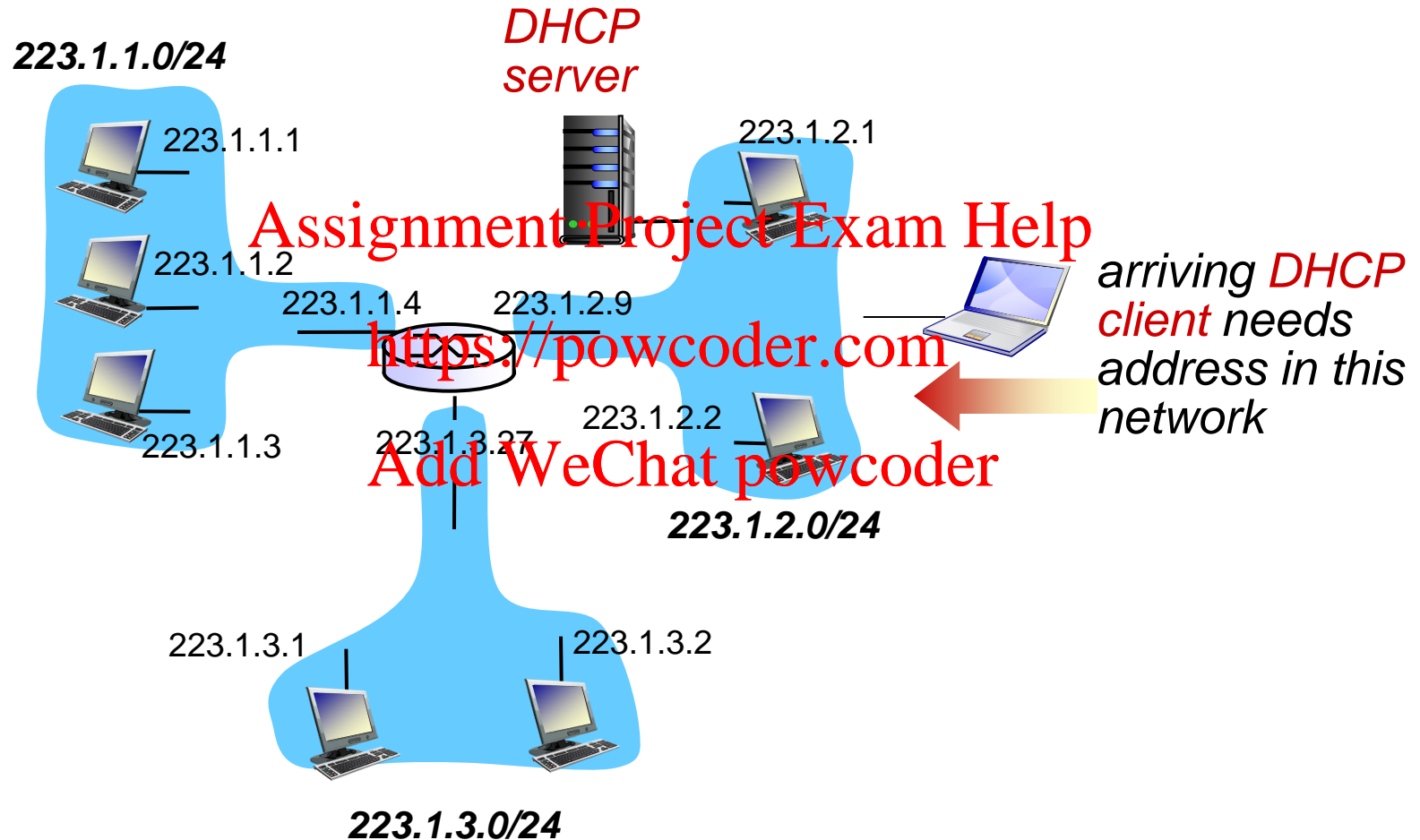
Goal allow host to *dynamically* obtain its IP address from network server when it joins network

- can renew its lease on address in use
- allows reuse of addresses (only hold address while connected/“on”)
- support for mobile users who want to join network

How it works: Add WeChat powcoder

- host broadcasts “DHCP discover” msg
 - DHCP server responds with “DHCP offer” msg
 - host requests IP address: “DHCP request” msg
 - DHCP server sends address: “DHCP ack” msg
-

DHCP Scenario



DHCP Scenario

DHCP server: 223.1.2.5

DHCP discover

src : 0.0.0.0, 68
dest.: 255.255.255.255,67
yiaddr: 0.0.0.0
transaction ID: 654

arriving
client



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DHCP offer

src: 223.1.2.5, 67
dest: 255.255.255.255, 68
yiaddr: 223.1.2.4
transaction ID: 654
lifetime: 3600 secs

DHCP request

src: 0.0.0.0, 68
dest.: 255.255.255.255, 67
yiaddr: 223.1.2.4
transaction ID: 655
lifetime: 3600 secs

DHCP ACK

src: 223.1.2.5, 67
dest: 255.255.255.255, 68
yiaddr: 223.1.2.4
transaction ID: 655
lifetime: 3600 secs



Address Resolution

- **Addresses exist at different layers**

Address Type	Example	Example Address
Application layer	Web address (URL)	www.indiana.edu
Network layer	IP address	129.79.78.193 (4 bytes)
Data link layer	MAC address	1C-6F-65-F8-33-8A (6 bytes)

- **Addresses may be translated (resolved) from one layer to another**

Address Resolution

- **Server Name Resolution**

- Translating destination host's domain name to its corresponding IP address
- www.yahoo.com is resolved to → 204.71.200.74
- Uses one or more Domain Name Service (DNS) servers to resolve the address

- **Data Link Layer Address Resolution**

- Identifying the MAC address of the next node (that packet must be forwarded)
 - Uses Address Resolution Protocol (ARP)
-

DNS: domain name system

Domain Name System:

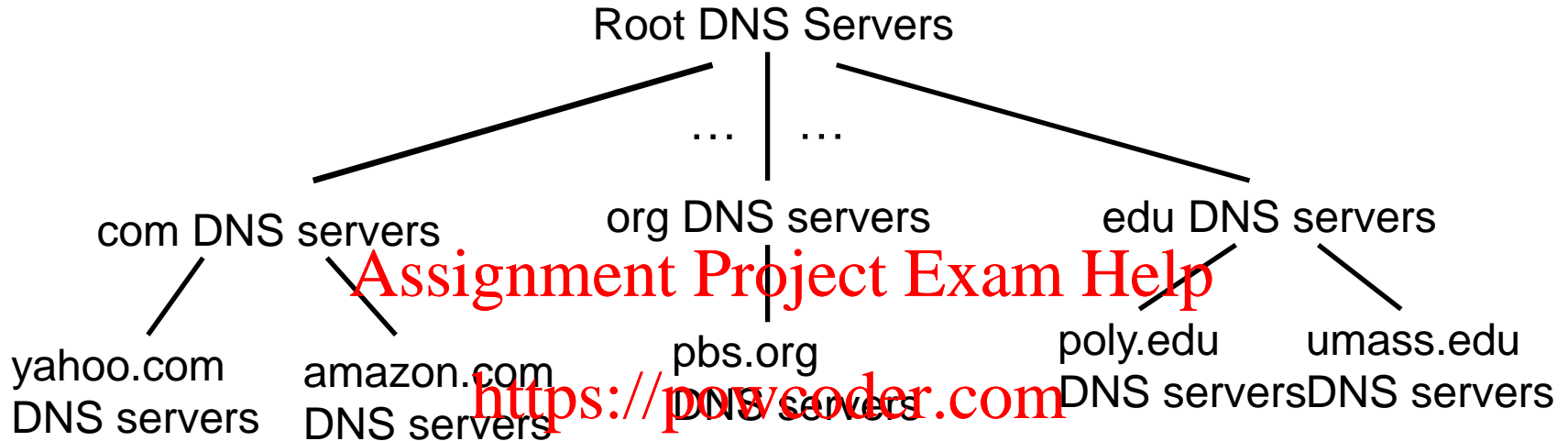
- hostname to IP address translation
- *distributed database implemented in hierarchy of many name servers*
- *application-layer protocol: hosts, name servers communicate to resolve names (address/name translation)*

why not centralize DNS?

- single point of failure
- traffic volume
- distant centralized database
- maintenance

doesn't scale!

DNS: domain name system



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client wants IP for www.amazon.com; 1st approx:

- client queries root server to find com DNS server
 - client queries .com DNS server to get amazon.com DNS server
 - client queries amazon.com DNS server to get IP address for www.amazon.com
-

DNS: root name servers

- contacted by local name server that can not resolve name

- **root name server:**

- contacts authoritative name server if name mapping not known
- gets mapping
- returns mapping to local name server

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*13 root name
“servers”
worldwide*

TLD, authoritative servers

top-level domain (TLD) servers:

- responsible for com, org, net, edu, aero, jobs, museums, and all top-level country domains, e.g.: uk, fr, ca, jp
- Network Solutions maintains servers for .com TLD
- Education for .edu TLD

authoritative DNS servers:

- organization's own DNS server(s), providing authoritative hostname to IP mappings for organization's named hosts
 - can be maintained by organization or service provider
-

Local DNS name server

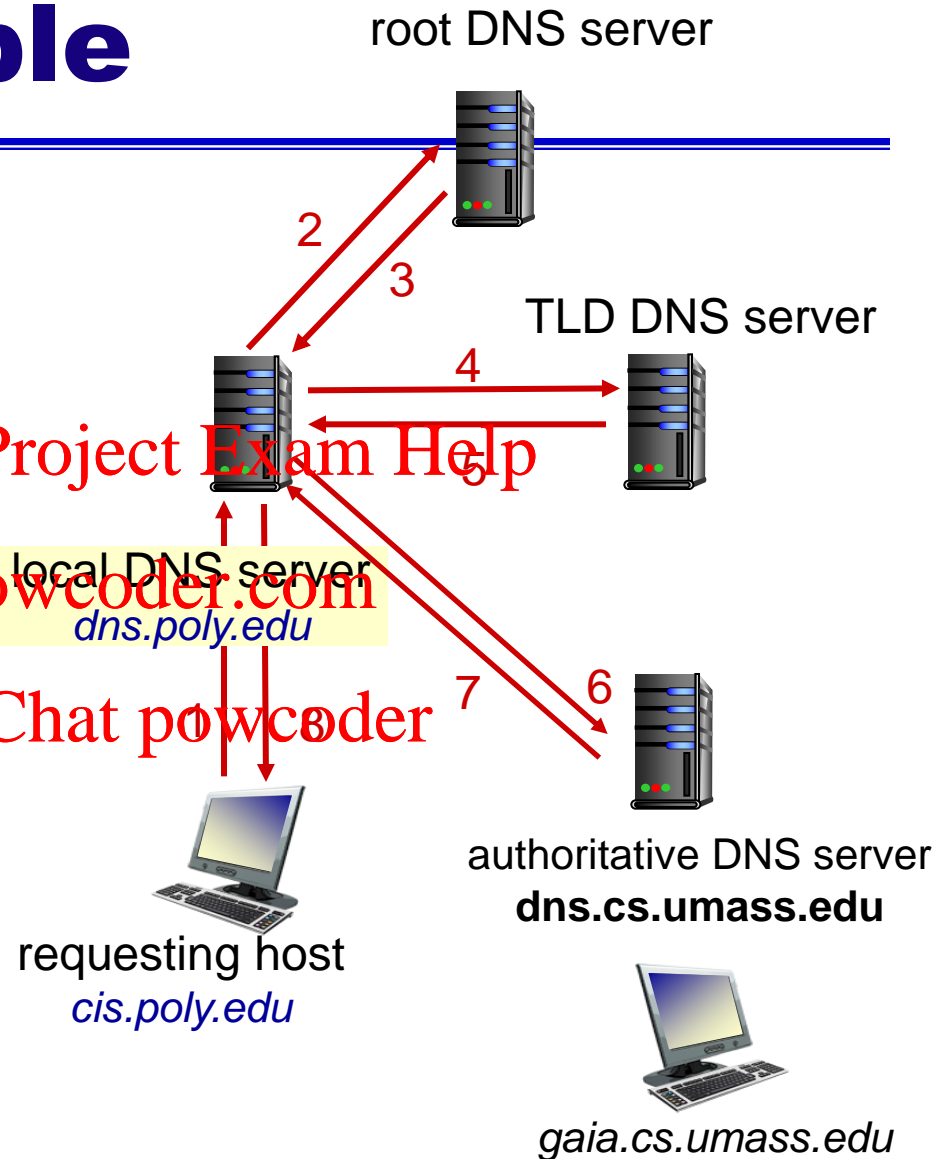
- does not strictly belong to hierarchy
- each ISP (residential ISP, company, university) has one
 - also called “default name server”
- when host makes DNS query, query is sent to its local DNS server
 - has local cache of recent name-to-address translation pairs (but may be out of date!)
 - acts as proxy, forwards query into hierarchy

DNS example

- host at `cis.poly.edu` wants IP address for `gaia.cs.umass.edu`

iterated query: <https://powcoder.com>

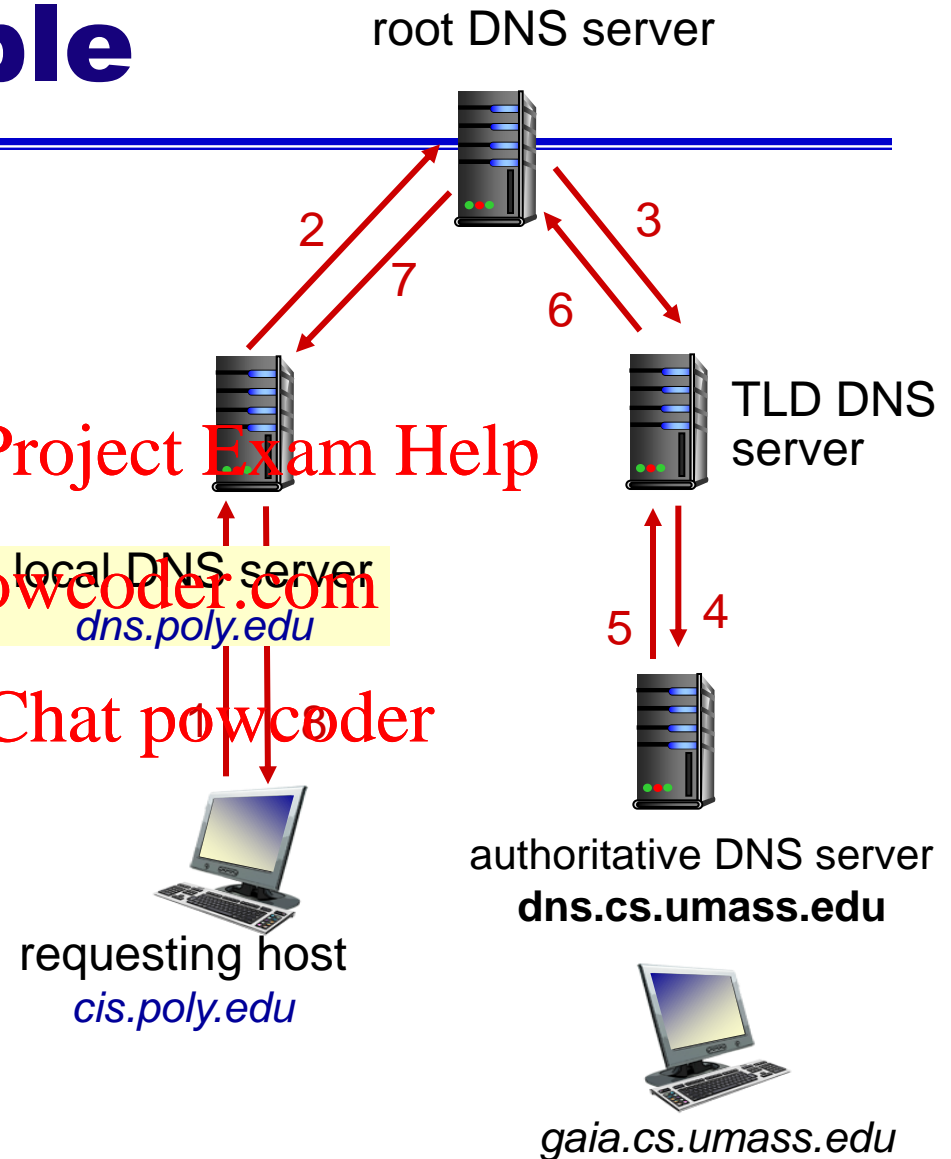
- ❖ contacted server replies with name of server to contact
- ❖ “I don’t know this name, but ask this server”



DNS example

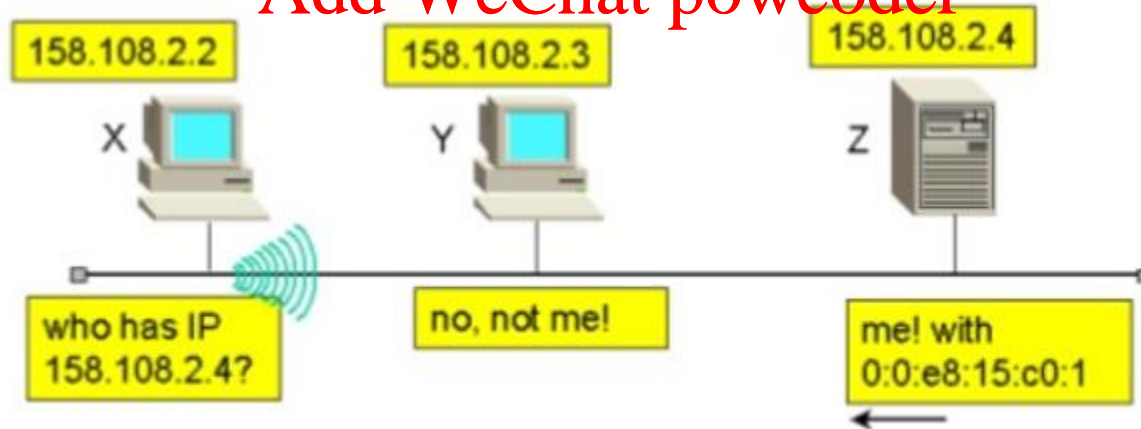
recursive query:

- ❖ puts burden of name resolution on contacted name server
- ❖ heavy load at upper levels of hierarchy?



ARP name resolution

- Identifying the MAC address by IP address
- Operation
 - Broadcast an ARP message to all nodes on a LAN asking which node has a certain IP address
 - Host with that IP address then responds by sending back its MAC address
 - Store this MAC address in its address table
 - Send the message to the destination node



MAC addresses and ARP

- **32-bit IP address:**
 - *network-layer* address for interface
 - used for layer 3 (network layer) forwarding
- **MAC (or LAN or physical or Ethernet) address:**
 - function: *used 'locally' to get frame from one interface to another physically-connected interface (same network, in IP-addressing sense)*
 - 48 bit MAC address (for most LANs) burned in NIC ROM, also sometimes software settable
 - e.g.: 1A-2F-BB-76-09-AD

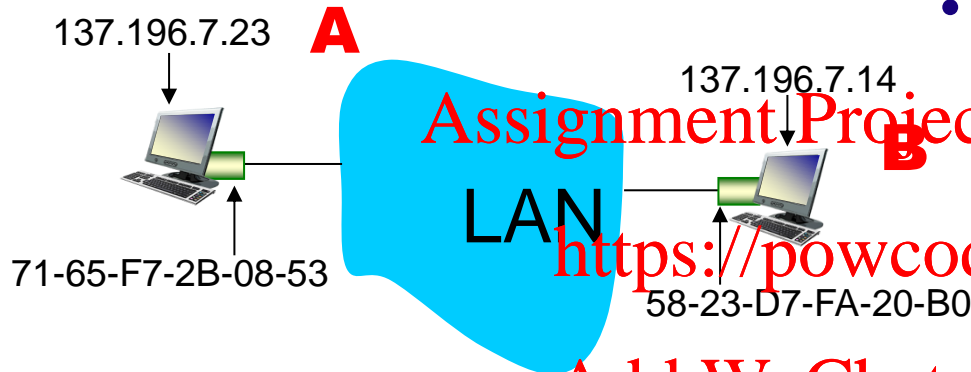
hexadecimal (base 16) notation
(each “number” represents 4 bits)

LAN addresses (more)

- MAC address allocation administered by IEEE
 - manufacturer buys portion of MAC address space (to assure uniqueness)
 - analogy: <https://powcoder.com>
 - MAC address: like Social Security Number
 - IP address: like postal address
 - MAC flat address → portability
 - can move LAN card from one LAN to another
 - IP hierarchical address *not* portable
 - address depends on IP subnet to which node is attached
-

ARP

Question: how to determine a MAC address knowing its IP address?



- A **broadcasts** ARP query packet, containing B's IP address

– dest MAC address = FF-FF-FF-FF-FF-FF

- all nodes on LAN receive ARP query (broadcast)

- B receives ARP packet, replies to A with its (B's) MAC address

- frame sent to A's MAC address (unicast)

	ARP query	ARP reply
Src IP address	137.196.7.23	137.196.7.14
Dest IP address	137.196.7.14	137.196.7.23
Src MAC address	71-65-F7-2B-08-53	58-23-D7-FA-20-B0
Dest MAC address	FF-FF-FF-FF-FF-FF	71-65-F7-2B-08-53

Network Link Layer

- **IP fragmentation**

- **Addressing**

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- **Routing**

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Routing

- **Process of determining the route (or path) a message will travel from the sending computer to the receiving computer**
 - **Routers**
 - Special purpose devices used to handle routing decisions on the Internet
 - Maintain their own routing tables
 - **Routing Tables**
 - Shows which path to send packets on to reach a given destination
 - Kept by computers making routing decisions
-

Routing

- **Unicast** - one computer to another computer
- **Broadcast** - one computer to all computers in the network
- **Multicast** - one computer to a group of computers (e.g., videoconference)
 - Same data needs to reach multiple receivers and avoid transmitting it once for each receiver
 - Particularly useful if access link has bandwidth limitations
 - Many implementations at different layers
 - In IP multicast, hosts dynamically join and leave multicast groups using Internet Group Management Protocol (IGMP)

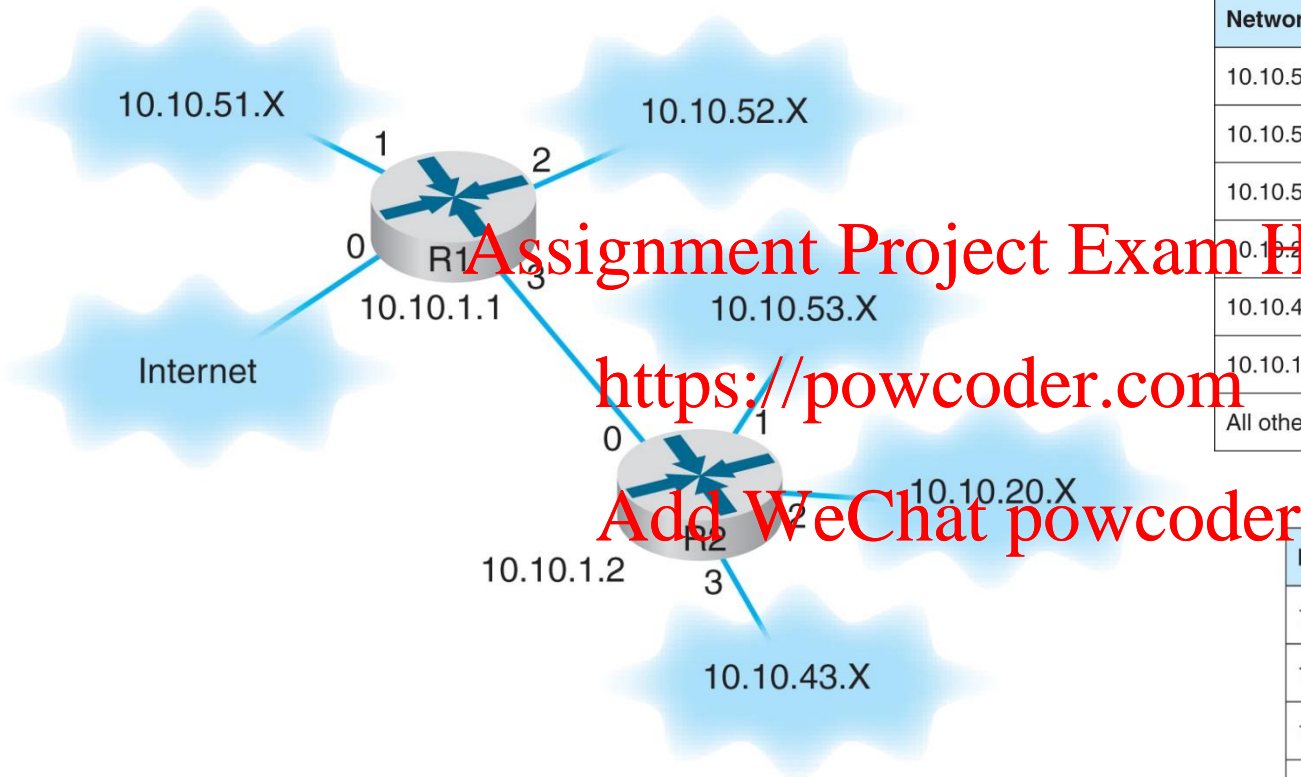
Routing

Router R1's Routing Table

Network Address	Interface
10.10.51.0 to 10.10.51.255	1
10.10.52.0 to 10.10.52.255	2
10.10.53.0 to 10.10.53.255	3
10.10.20.0 to 10.10.20.255	3
10.10.43.0 to 10.10.43.255	3
10.10.1.2	3
All other addresses	0

Router R2's Routing Table

Network Address	Interface
10.10.1.1	0
10.10.53.0 to 10.10.53.255	1
10.10.20.0 to 10.10.20.255	2
10.10.43.0 to 10.10.43.255	3
All other addresses	0



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Types of Routing

- **Centralized routing**

- Decisions made by one central computer
- Used on small, mainframe-based networks
- Not common anymore

- **Decentralized routing**

- Decisions made by each node independently of one another
- Information needs to be exchanged to prepare routing tables
- Used by the Internet

Static vs. Dynamic

- **Static routing:**

- Fixed routing tables
- Manually configured by network administrator
- Used on relatively simple networks with few routing options that rarely change

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- **Dynamic routing**

- Routing tables updated periodically
- Routers exchange information using protocols to update tables

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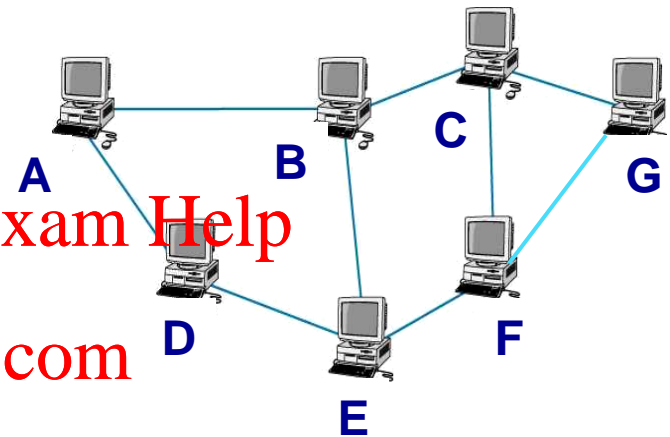
Dynamic Routing Algorithms

- **Distance Vector**

- Uses the least number of hops to decide how to route a packet

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- **Link State**

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From A to G → ABCG

- Uses a variety of information types to decide how to route a packet (more sophisticated)
 - e.g., number of hops, congestion, speed of circuit
- Provides more reliable, up to date paths to destinations

Routing Protocols

- Used to exchange info among nodes for building and maintaining routing tables
- **Types of Routing Protocols**
 - Interior routing protocols (RIP, OSPF, EIGRP, ICMP)
 - Operate within a network
 - Provide detailed info about each node and paths
 - Exterior routing protocols (BGP)
 - Operate between networks (autonomous systems)

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Routing Information Protocol (RIP)

- Dynamic **distance vector** protocol used for interior routing
- Operations:
 - Commonly used in smaller networks
 - Network managers use RIP to build a routing table
 - When a new node added, RIP counts number of hops between computers and updates routing tables
 - Routing table status are broadcasted periodically (every minute or so) by all nodes

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Open Shortest Path First (OSPF)

- A *dynamic hybrid (distance vector + link state)* interior routing protocol
 - More reliable paths, incorporates traffic and error rate measures
 - Most widely used interior routing protocol on large enterprise networks, preferred by TCP/IP
 - Less burdensome to the network
 - Only the updates sent (not entire routing tables) and only to other routers (no broadcasting)

Other Interior Routing Protocols

- **Enhanced Interior Gateway Routing Protocol (EIGRP)**

- A dynamic hybrid interior protocol (developed by Cisco)
- Records transmission capacity, delay, time reliability and load for all paths
- Keeps the routing tables for its neighbors and uses this information in its routing decisions as well

- **Internet Control Message Protocol (ICMP)**

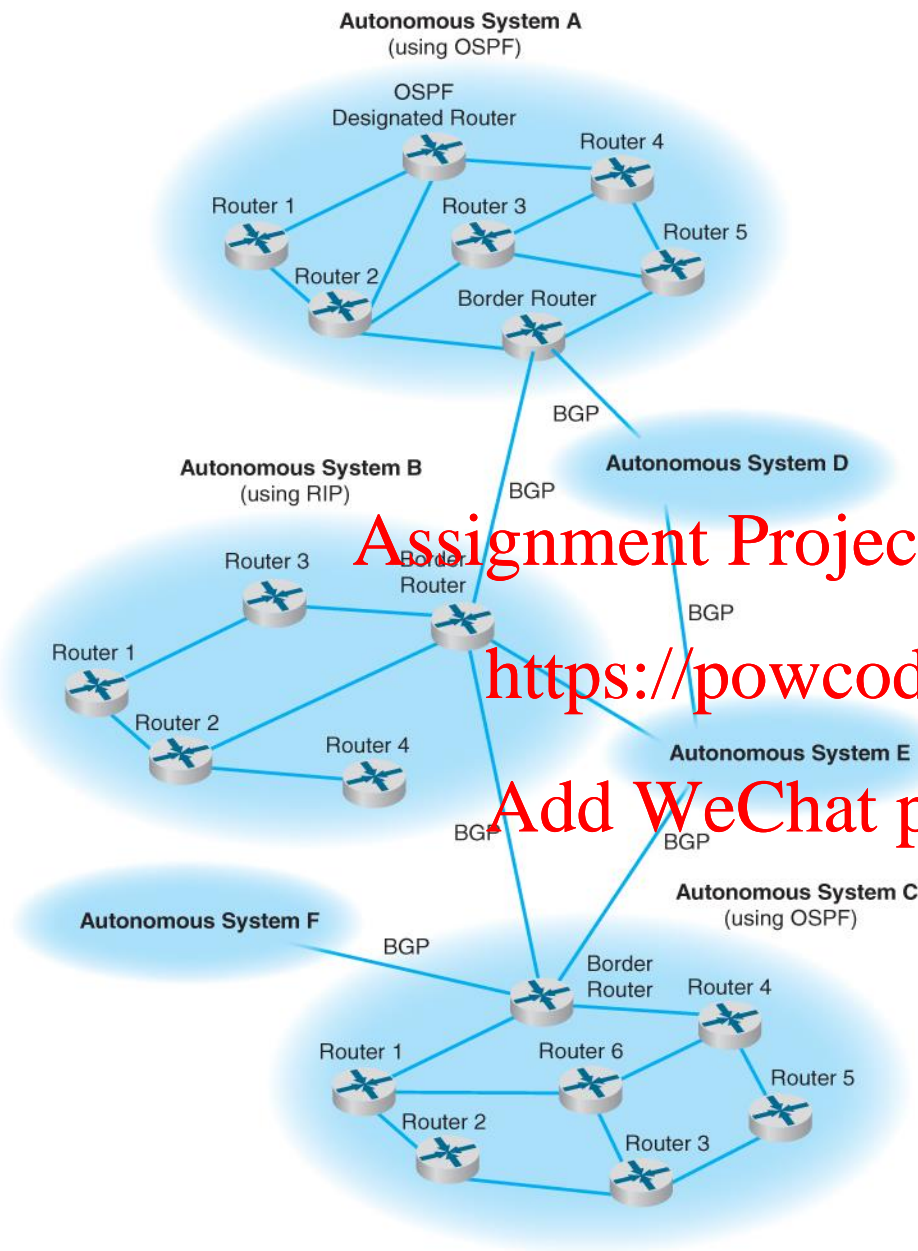
- Simplest and most basic: checks the reachability of a certain nodes and paths (e.g., Ping)
 - An error reporting protocol (report routing errors to message senders)
-

Exterior Routing Protocols

- **Border Gateway Protocol (BGP)**

- Used to exchange routing info between autonomous systems
- Based on a *dynamic distance vector* algorithm
- Far more complex than interior routing protocols
- Provide routing info only on selected routes (e.g., preferred or best route)
 - Too many routes; can't maintain tables of every single route

Internet Routing using BGP, OSPF and RIP



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