

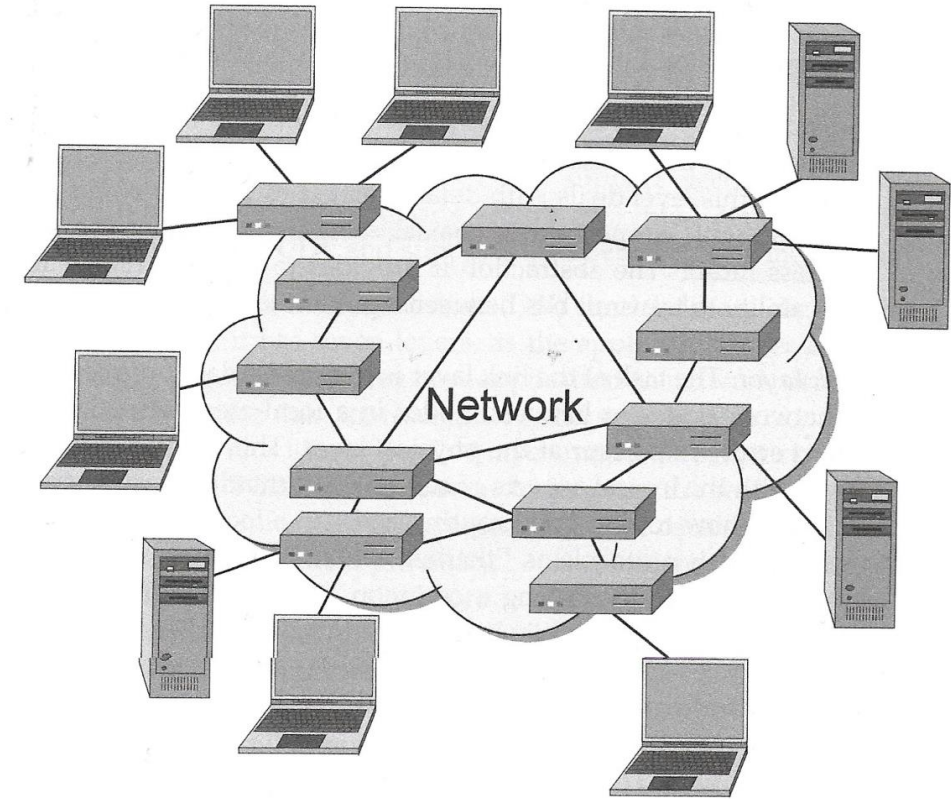
# TK2100: Informasjonssikkerhet

## Lesson 05: Network 1

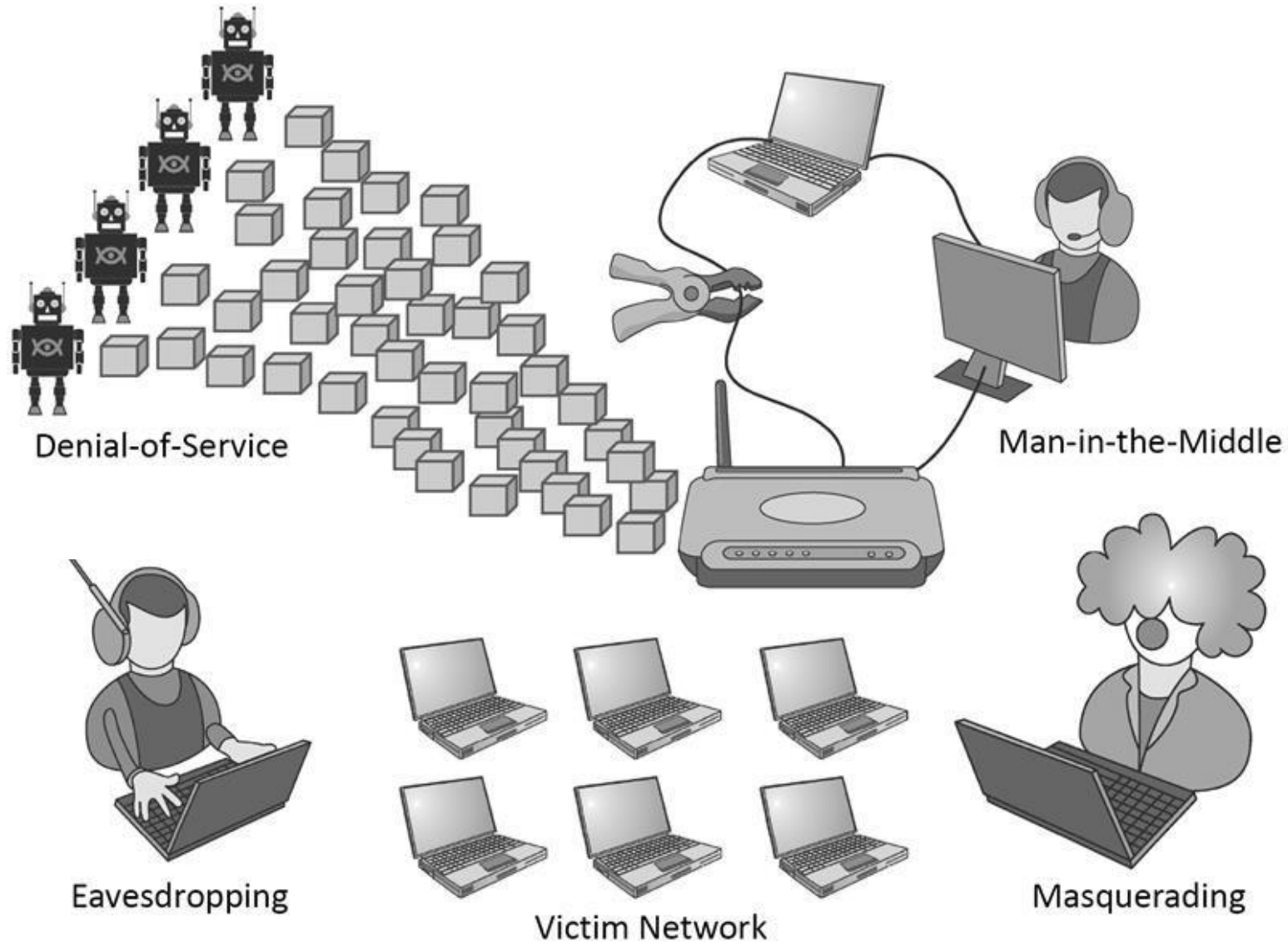
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# Goals

- Understand how computers can communicate over a network
  - eg, using browser to visit web pages
- Understand how an attacker can comprise communications over a network



# Many Different Kinds of Attacks

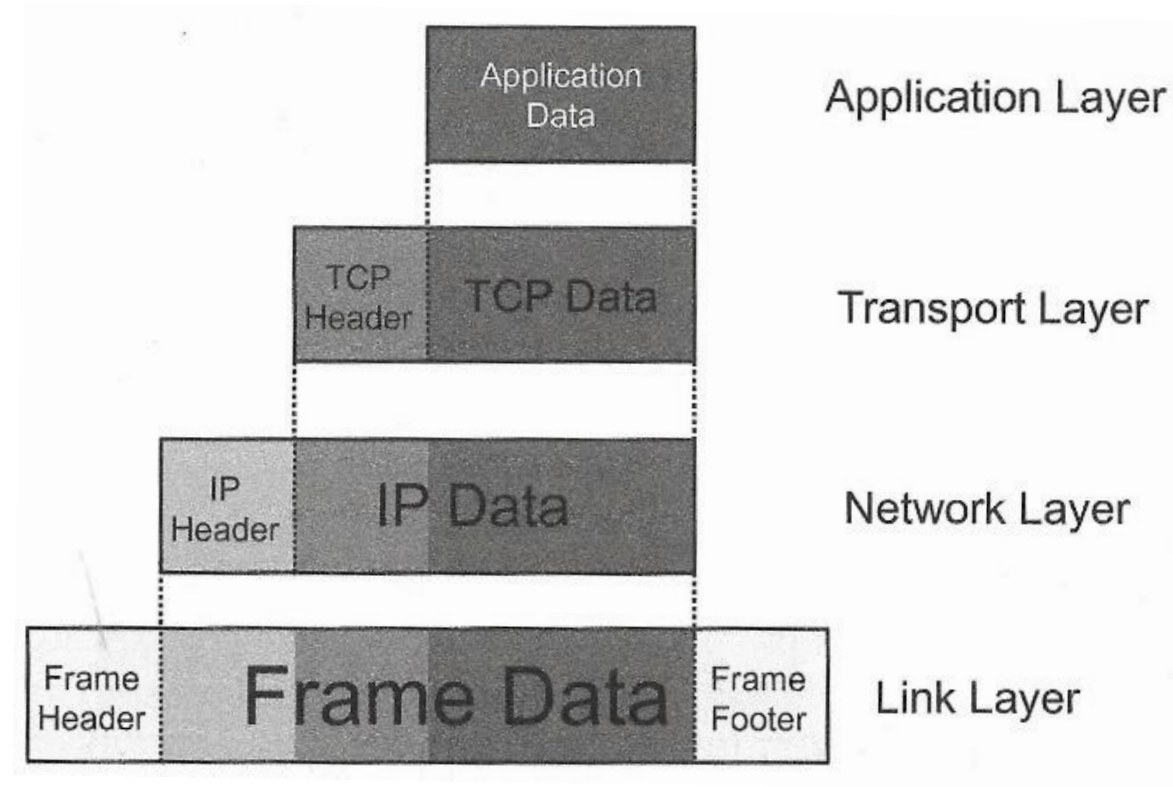


# Internet Protocol Layers

- Communications over internet are very complex
- The sending/receiving of messages is abstracted in *layers*
- When programming at a certain level, do not need to know of the layers directly underneath
  - eg, when making a request to retrieve an HTML page using HTTP, do not need to have to deal with low level details of sending of packets over a fiber optic vs WiFi
- Not only this makes coding easier, but also enable the use of variegated protocols/hardware in the lower layers

# 5 Main Layers

- **Physical Layer** is the one in which the 0/1 bits of the data are sent
- 0/1 are sent in groups, ie in *packets*
- A packet contains a *header* and a *payload* (sometimes also a *footer*)
- The payload in one level is the entire packet (header+payload) of its above layer



# Overview: Physical Layer

- Dealing with the low level details of the actual sending of 0/1 bits between two nodes
- Handling of connections on *copper wires, coaxial cables, optical fiber cables* or *wireless radio*
- *Best Effort*: cannot guarantee that bits arrive

# Overview: Link Layer

- Dealing with communications between 2 nodes on same *local area network (LAN)*
  - eg, different machines connected to same WiFi router/switch
- Need to find good paths connecting the 2 nodes
- Protocols like *Ethernet*
- MAC addresses to identify nodes on the local network

# Overview: Network Layer

- Moving of packets between nodes on wide area networks, like *internet*
- Nodes identified with IP addresses, eg 127.0.0.1
- **IP** (Internet Protocol)
- *Best Effort*: cannot guarantee a packet is going to be delivered without problems

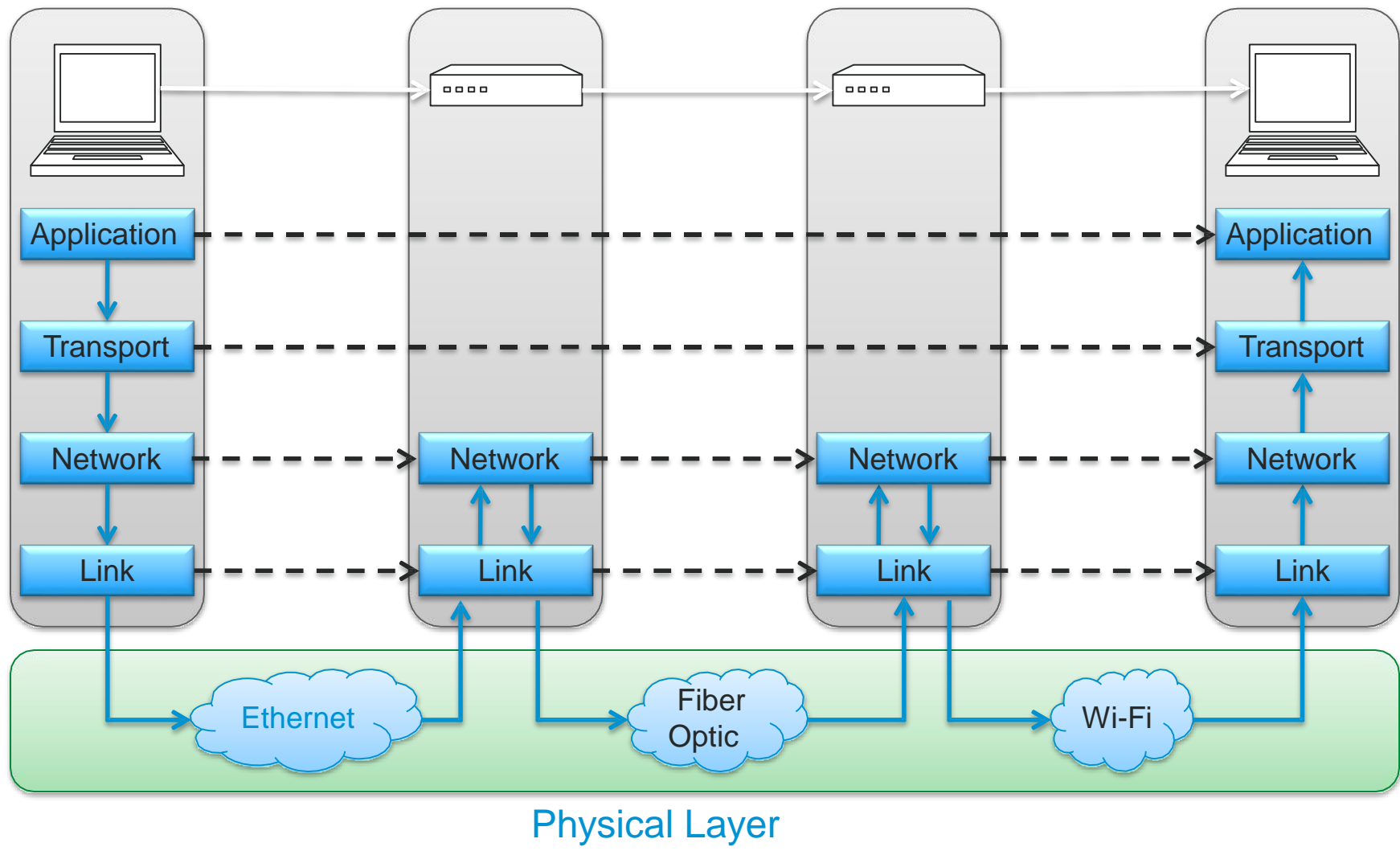


# Overview: Transport Layer

- Establish connection between different processes/applications on different nodes
- An application address is identified with an IP address **AND** a *port* number
- Protocols like TCP and UDP
- Can guarantee delivery (or tells you when that does not happen) of packets (eg, by automatically resending the lost ones)

# Overview: Application Layer

- Specific protocols for specific kinds of applications
- Eg, HTTP for web pages, and SMTP for emails
- By using a standard protocol, when you deploy your web applications to a conforming web server, then you know that all major browsers will be able to interact with them



# Network Security Issues: CIA

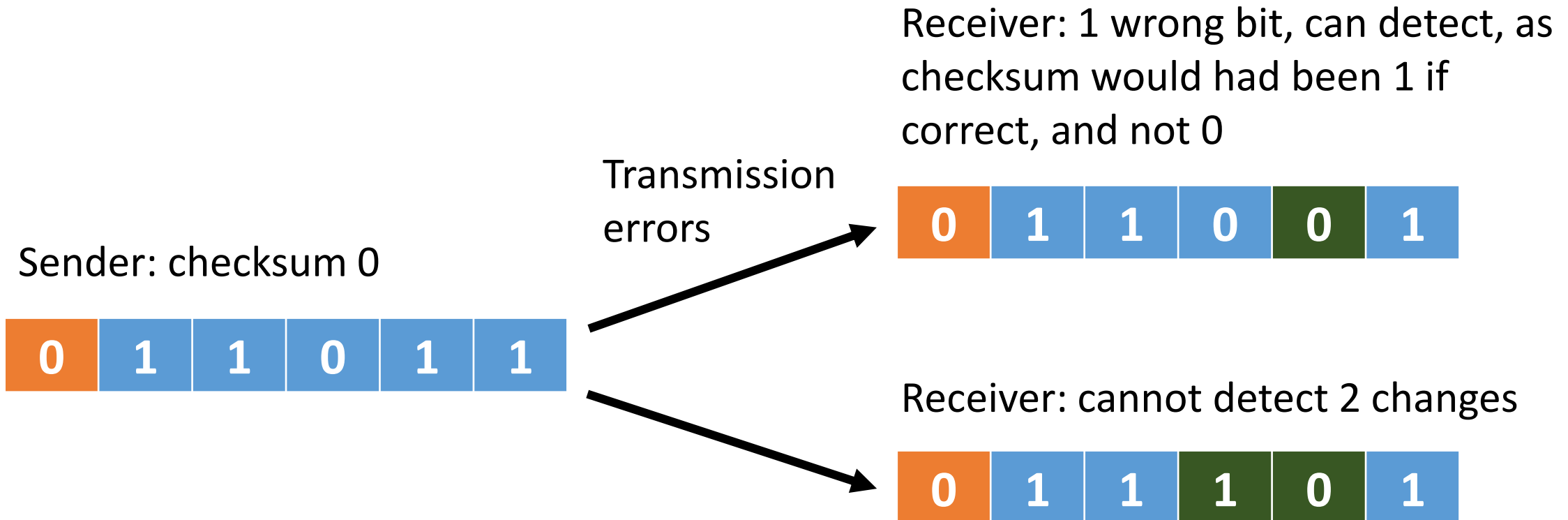
- *Confidentiality*: no requirement in any of the layers. If you need confidentiality, you need protocols that support encryption, like *HTTPS* and *IPsec*
- *Integrity*: support for basic *checksums*. Can detect small changes, but not cryptographically secure
- *Availability*: internet is designed to tolerate failure of routers and hosts, but cannot make strong guarantees, especially in the case of DDoS

# Checksum

- Technique to check if data has been altered
- This could happen due to errors at physical layer, or if hacker altering messages
- Simple checksum: add one extra bit, checking if in the data the number of 1s is even or odd
- Receiver of message will check if checksum is correct or not
- In this latter case, message has been altered

# Checksum Example

- A simple checksum (0 if even number of 1s, 1 otherwise) will only detect differences of 1 single bit change
- Tradeoff: message is now 1 bit longer



# Network Security Issues: AAA

- *Assurance*: usually packets are allowed to be sent between 2 nodes. Preventing it has to be done explicitly, eg a firewall in a local network
- *Authenticity*: on internet protocol, no concept of *users*, as communications are between computers, not people. If needed authenticity, have to handle it at application layer
- *Anonymity*: built-in anonymity, as no concept of users. Agencies tracking users need to correlate with other source of info, like credit cards and mobile subscriptions

Link Layer

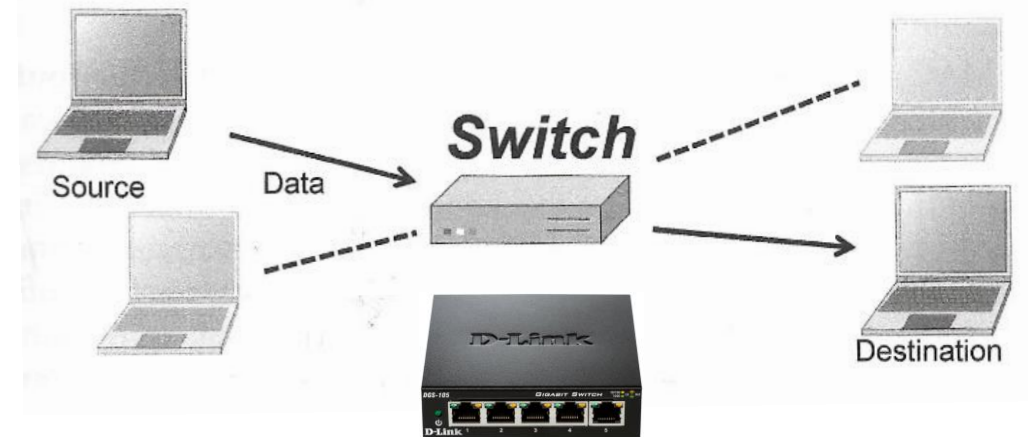
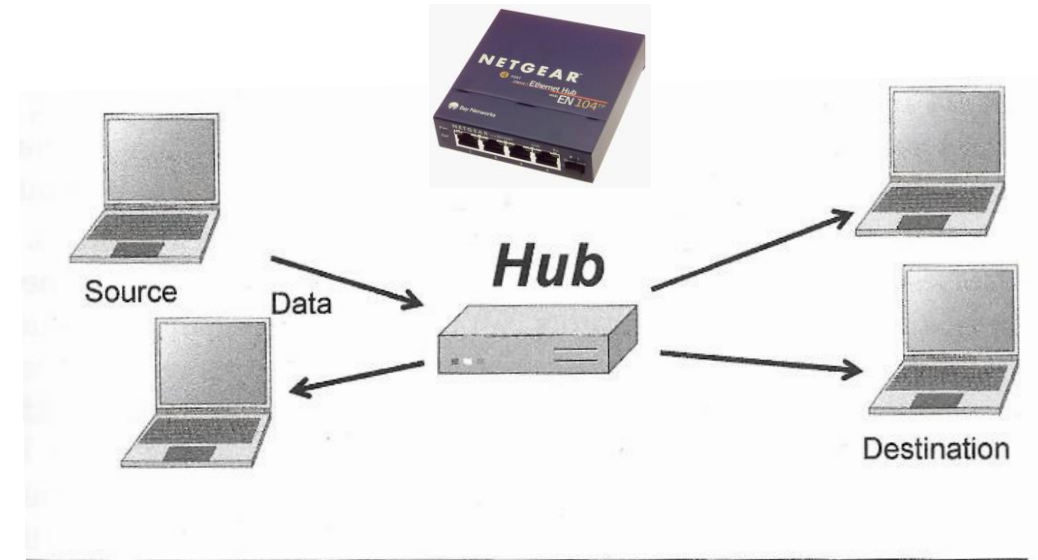


# Ethernet

- A Link Layer protocol, standardized as IEEE 802.3
- Communications on cables
- Physical transmission: frames (ie messages) sent as electrical impulses
- If collisions (two machine sending impulses at same time), they will resend after a random amount of time

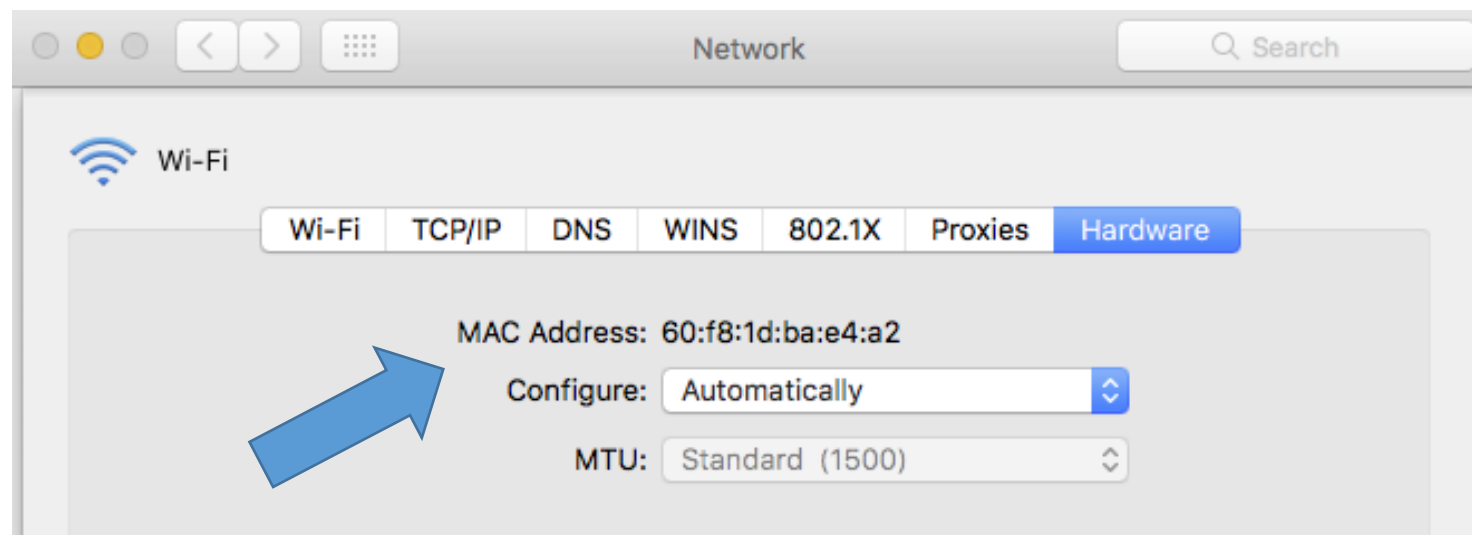
# Hubs and Switches

- Hardware components
- *Hub*: does *broadcast* of all incoming electrical impulses, ie the frame packets
- *Switch*: start with broadcast, but, once learned the MAC addresses, only send frames to the right route
- Nowadays, *Switches* are used and not so many *Hubs*, as more efficient and not so expensive anymore



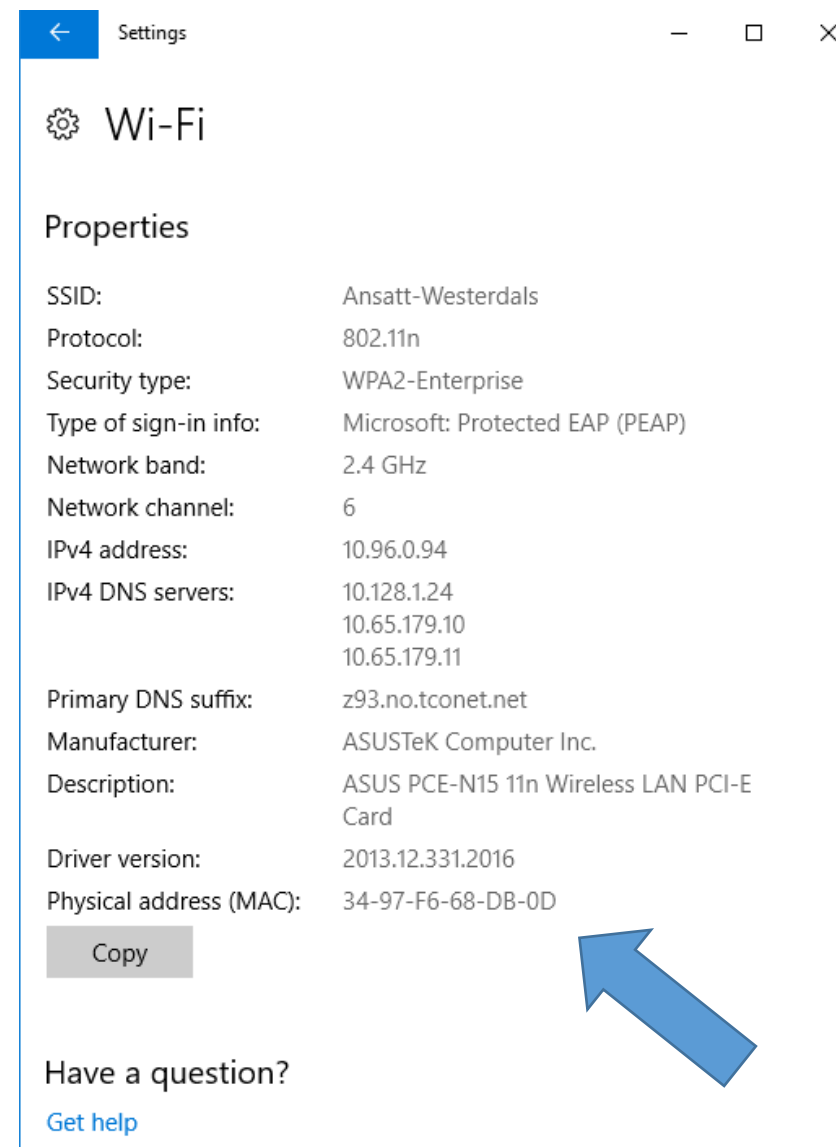
# Media Access Control (MAC) Addresses

- *48-bit identifier*, usually represented with 6-pairs of hexadecimal digits, eg. 00:16:B7:29:E4:7D
  - recall, hexadecimal is 0-9-A-F, so 16 values, using 4 bits
  - 6 pairs is 12 digits, so  $6 * 2 * 4 = 48$  bits / 6 bytes
- Associated with physical device
- First 24 bits represent the manufacturer (eg Asus) and sometime the specific model
- Remaining 24 bits are for identifier of the actual device instance
- Note:  $2^{24} = 16$  millions. Even if manufacturer starts to reuse MAC addresses, extremely unlikely to have two different devices on same local network with same MAC address



Mac

Windows



# Ethernet Frame Format

- *Header*: eg, source and destination MAC addresses
- *Payload*: the actual data, which usually would be a Network Layer packet
- *Footer*: eg, a checksum

Bits	Field	
0 to 55	Preamble (7 bytes)	Header
56 to 63	Start-of-Frame delimiter (1 byte)	
64 to 111	MAC destination (6 bytes)	
112 to 159	MAC source (6 bytes)	
160 to 175	Ethertype/Length (2 bytes)	
176 to 543+	Payload (46-1500 bytes)	Payload
543+ to 575+	CRC-32 checksum (4 bytes)	Footer
575+ to 671+	Interframe gap (12 bytes)	

# Address Resolution Protocol (ARP)

- The Link Layer works with MAC addresses
- But messages in the higher layers work with IP addresses
- ARP is a protocol to resolve an actual MAC address from the specified IP address

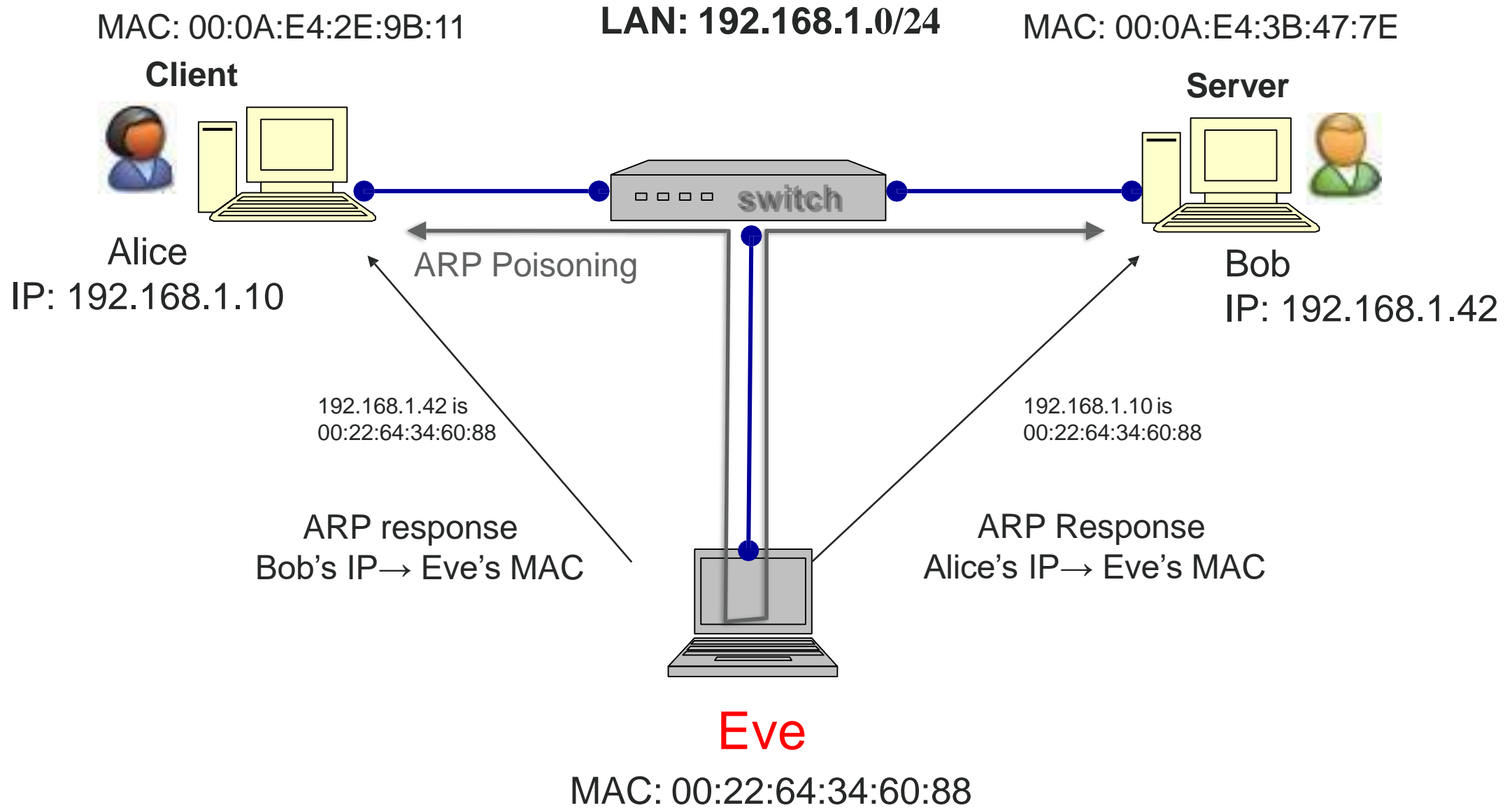
# ARP Broadcast

- Assume ARP is used to resolve the MAC address for the IP 192.168.1.105
- ARP will send a *broadcast* on the LAN looking like: “*Who has the IP address 192.168.1.105?*”
- All machines on the LAN receives the broadcast, and the one with that IP address will *respond*
- ARP Cache: the mapping can be cached. So once a node finds out who has that IP, does not need to re-ask again

# ARP Spoofing

- Any machine could reply to the ARP broadcast
- A malicious machine could lie and tell it is the one representing the requested IP address
- *Man-in-the-Middle* attack: trick Alice and Bob to send their messages to Eve





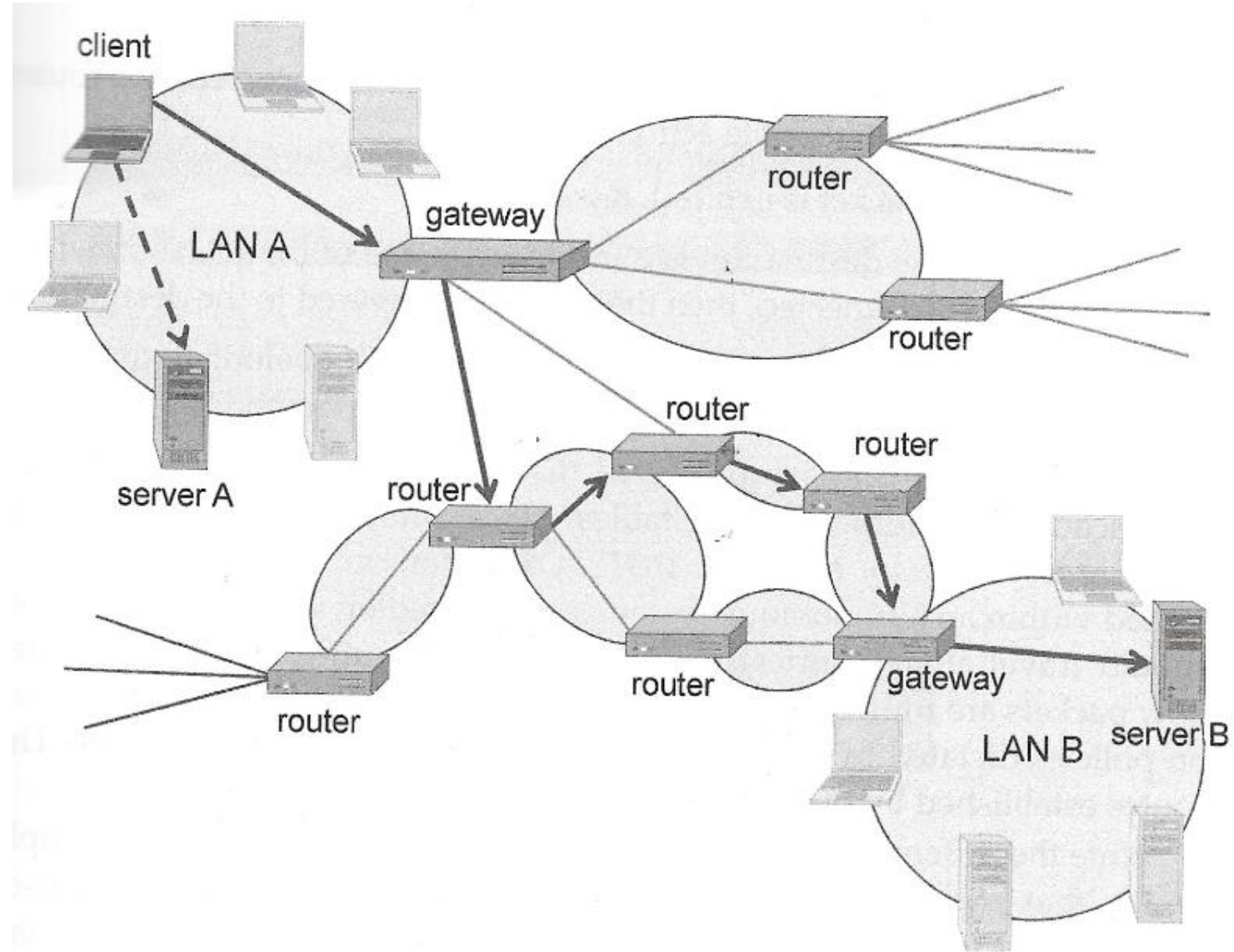
# ARP Spoofing Prevention

- Different prevention mechanisms
- Simplest: check if more than one different machine answer to a ARP request
  - cannot know which is the true one, but at least can know if someone is messing up with the network
- Static ARP tables: manual registration of MAC addresses to static, fixed IP addresses on a local network

Network Layer

# Internet Protocol (IP)

- A network protocol to move packets between 2 nodes on the internet
- Internet can be seen as a collection of independent LANs connected via routers and gateways
- Link Layer works on a LAN, but here we need communications with nodes on different LANs



# IP Addresses

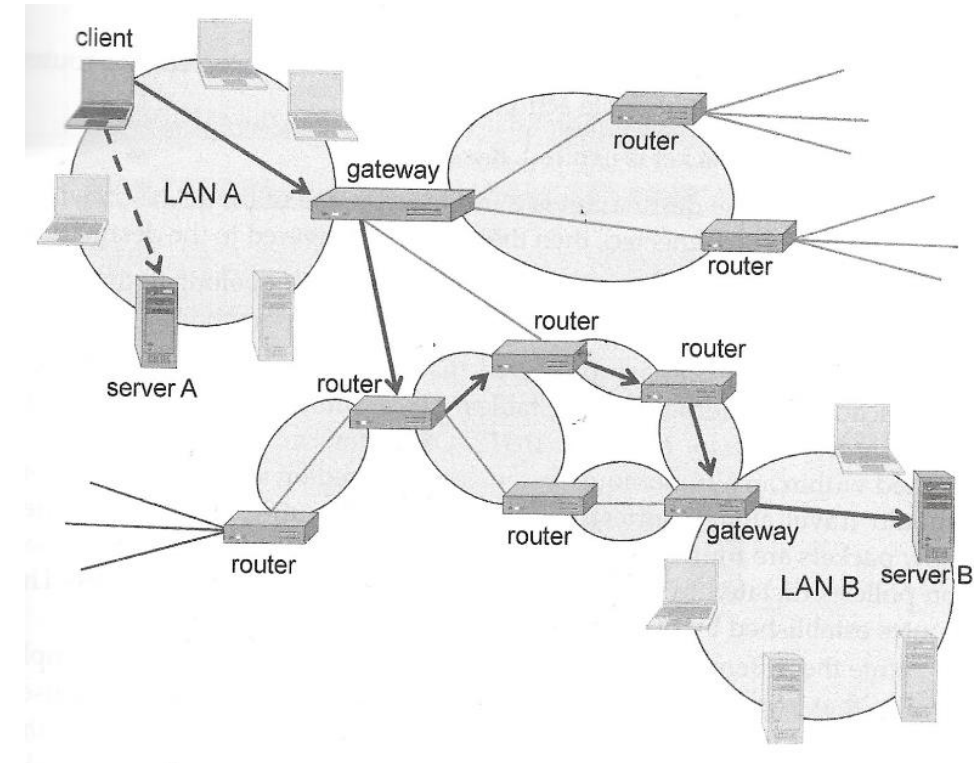
- 2 main versions, IPv4 and IPv6
- *IPv4*: 32-bits, currently most used, but running out of available new addresses for new machines
  - Represented with by 4 byte numbers (0-255 values) separated by “.”, eg 127.0.0.1
- *IPv6*: 128-bits, *slowly* trying to replace IPv4...

# Routing IP Packets

- If destination IP address is on same LAN, use ARP to get MAC address, and send it directly via Link Layer
- If destination IP address is on different LAN, need to send packet to the LAN *Gateway*
- Client needs to know IP address of Gateway, and then use ARP to get its MAC to send packet to it
- When Gateway receives packet for node not in the LAN, needs to route it out toward other routers

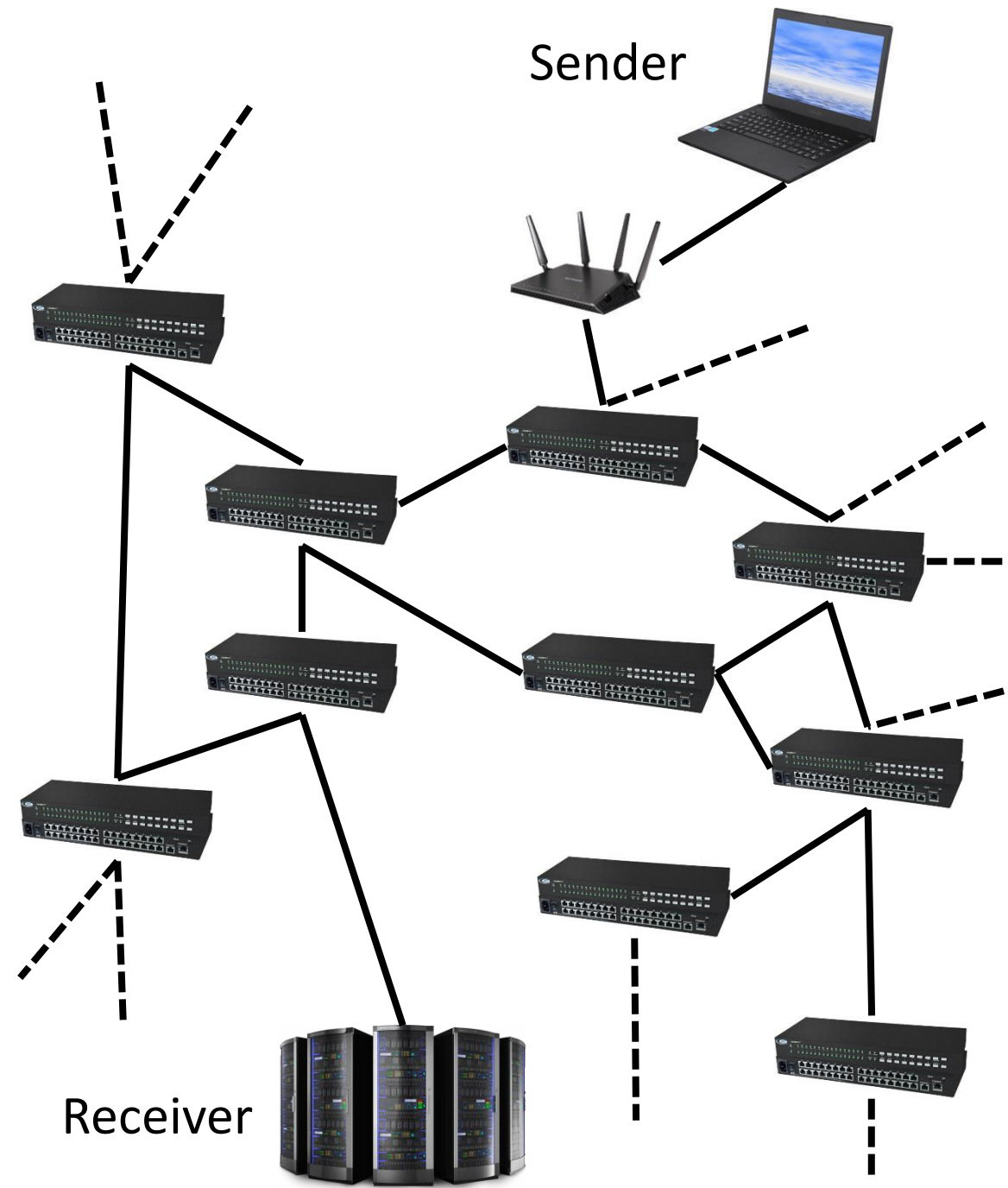
# Gateways

- Each LAN has 1 *gateway* (e.g., a WiFi router), which is the entry/exit point for the LAN
- A packet might go through several *routers* before reaching the gateway of the destination LAN
- *Very complex* algorithms to find out to which router to send packet next

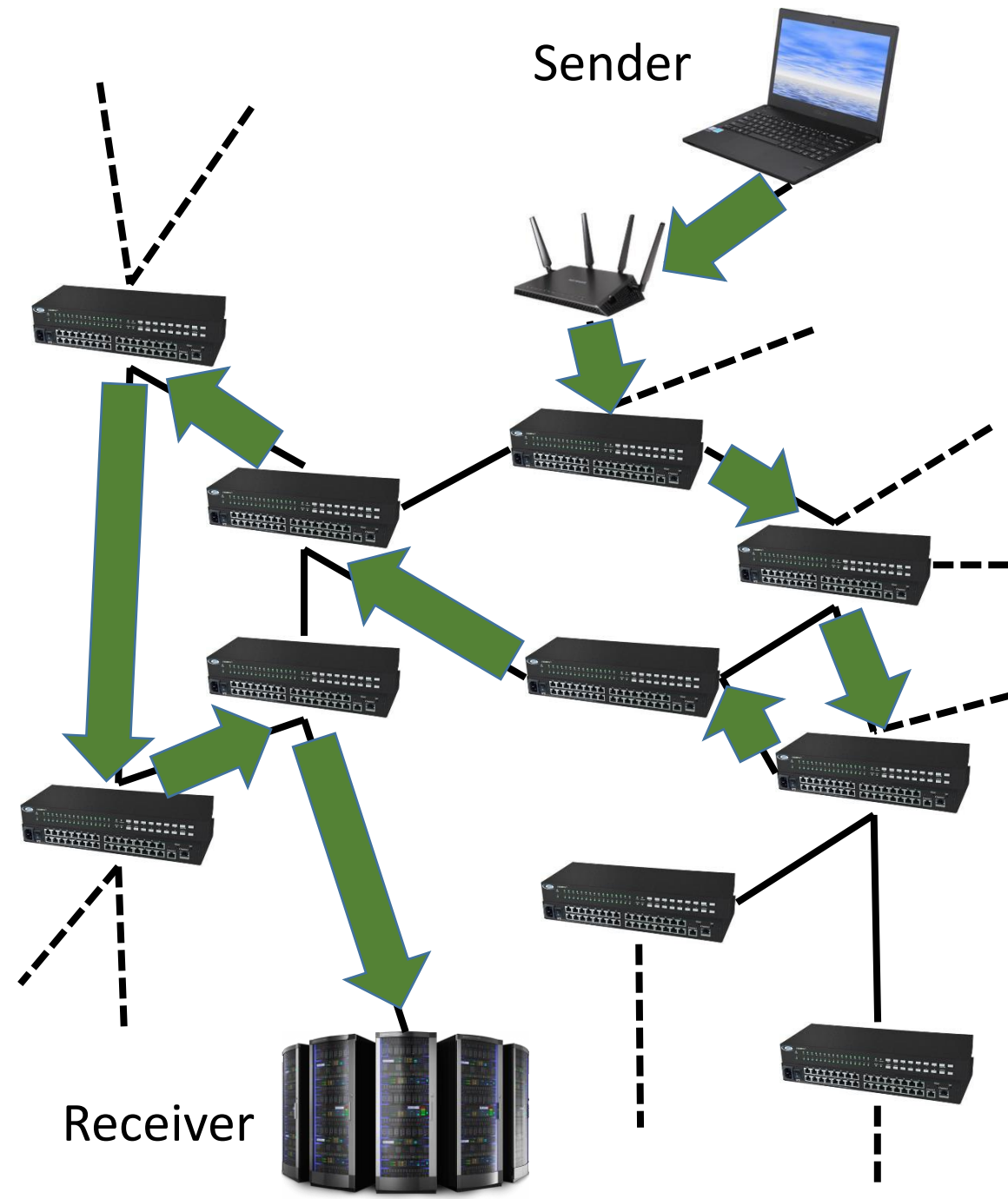
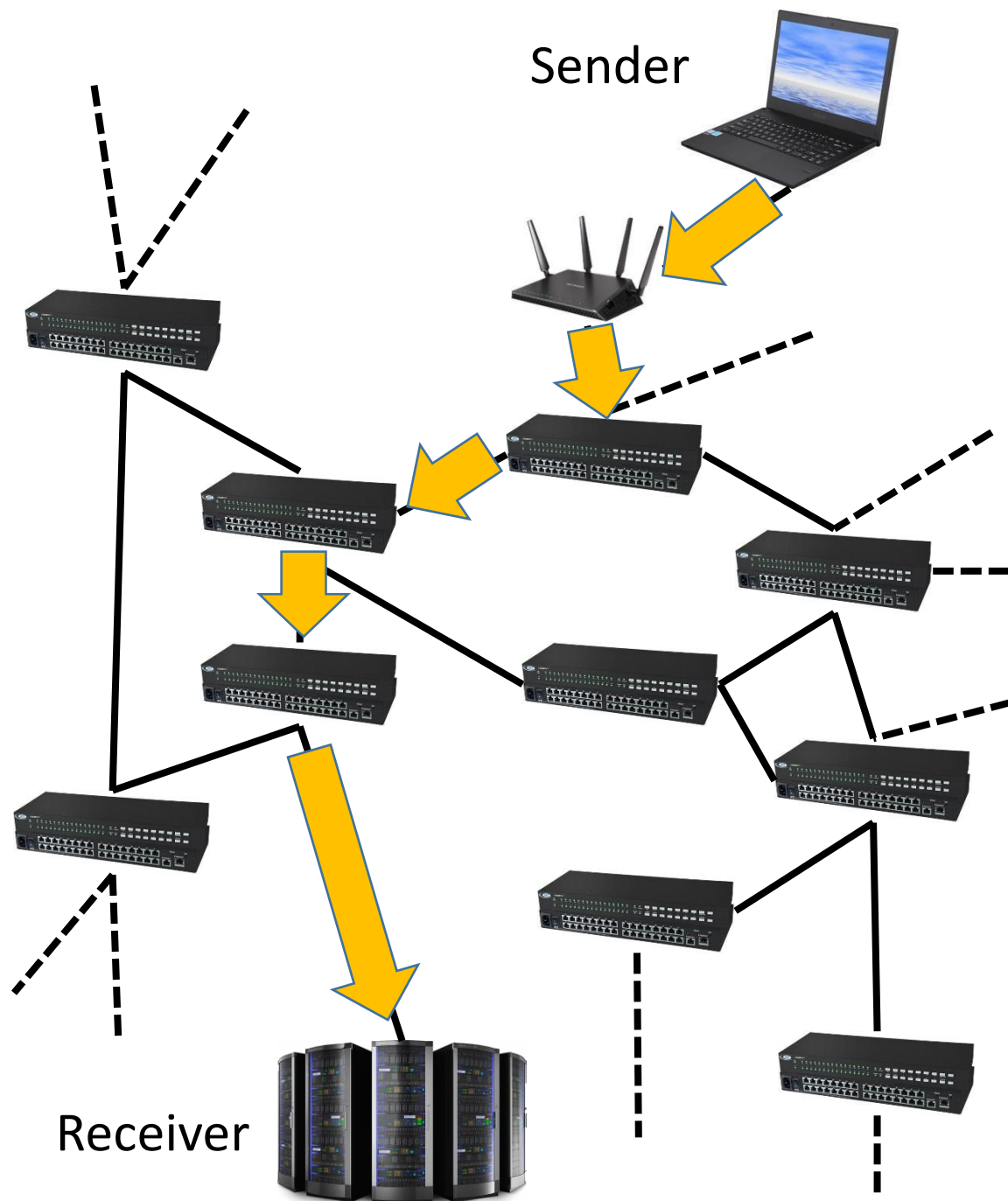


# Paths

- Many paths from a sender to a receiver
- Ideally, want the *shortest* one
- Problems: (1) routers can come and go; (2) a single router does not know the whole network topology; (3) some routers could be misconfigured
- Note: finding shortest path in a graph is something that some of you will see in *Algorithms* course next semester

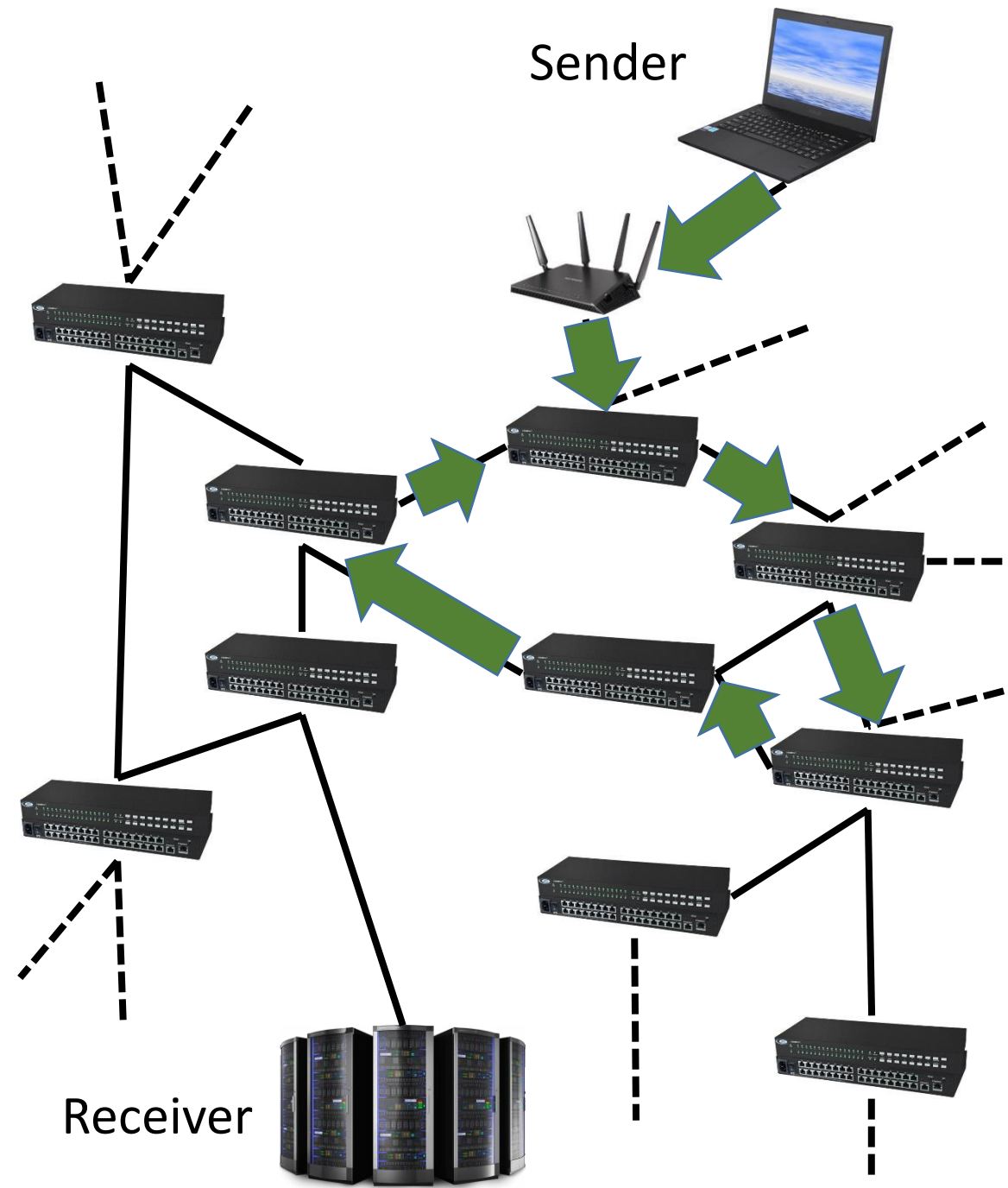






# Cycles

- Due to *misconfigurations*, or *dynamic changes in topology*, a packet could be sent back-and-forward in a *cycle*
- Packet will never be delivered, and client will just wait for nothing, in eternity
- Internet protocol has a mechanism to avoid such issue

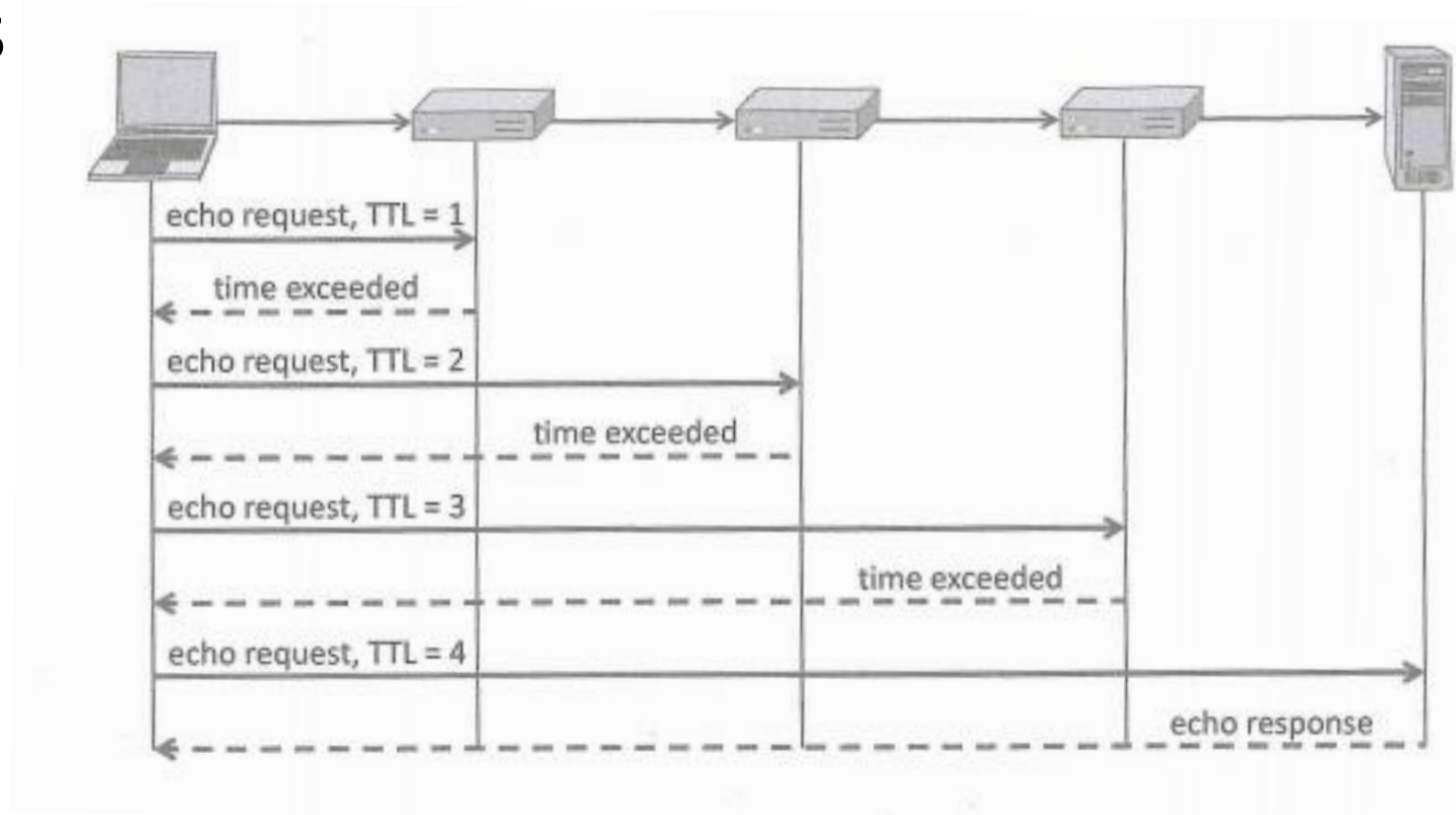


# Time-To-Live (TTL)

- Each IP packet has a TTL counter, eg set to  $N=50$
- Each time a router receives a packet, it *decreases* the counter by 1
- When a router sees a  $TTL=1$ , it *discards* the packet, and send an error message back to the client sender
- At most a path would be  $N$  long, and so impossible to have infinite cycles

# But what if low TTL on purpose?

- Start sending IP packets with TTL=1, and increase by 1 at each new request
- Each time getting back an error message from a router in the path
- This way can find all routers toward destination



# 13 machines from Fjerdingen to *google.com*

MINGW64:/e/WORK/code/teaching

```
arcu@DESKTOP-IR7IFID MINGW64 /e/WORK/code/teaching
```

```
$ tracert google.com
```

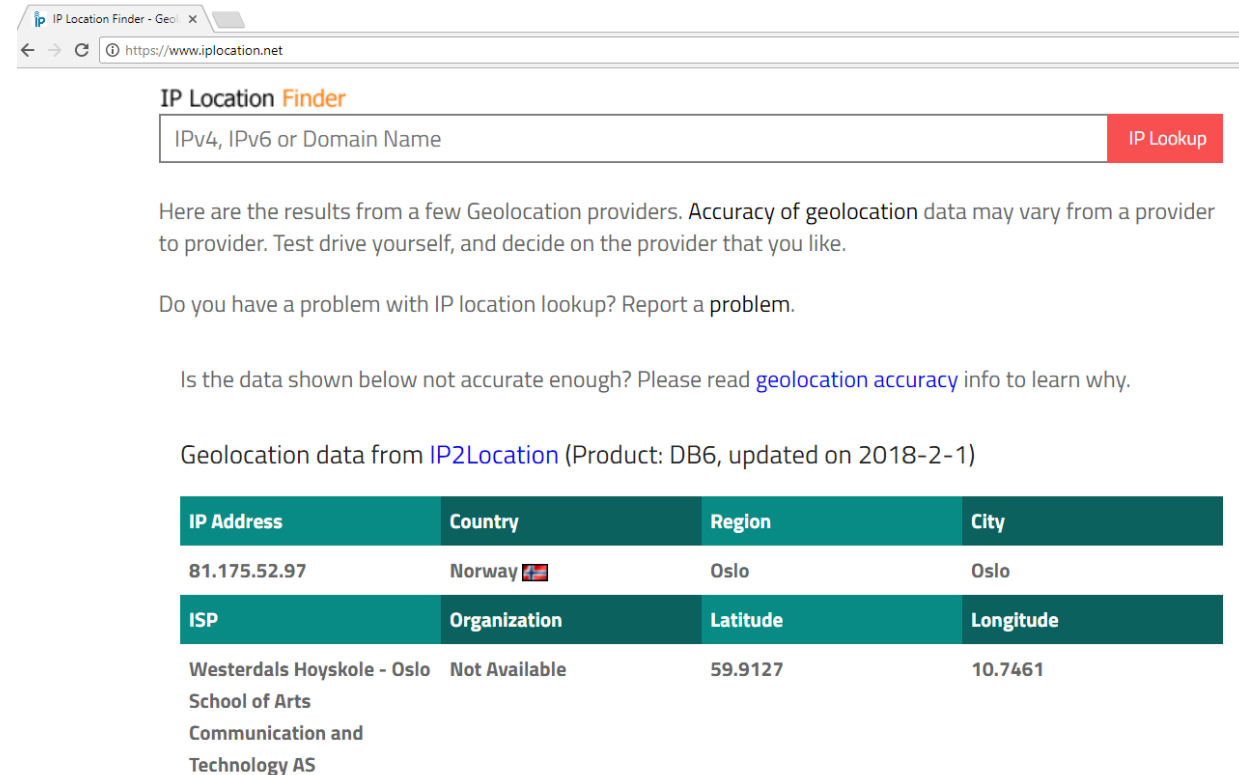
```
Tracing route to google.com [216.58.209.142]  
over a maximum of 30 hops:
```

1	1 ms	1 ms	1 ms	10.96.16.2
2	<1 ms	<1 ms	<1 ms	10.240.33.1
3	<1 ms	<1 ms	<1 ms	97.sopp10.party.fredrikstadlan.no [81.175.52.97]
4	<1 ms	<1 ms	<1 ms	77.88.111.60
5	1 ms	<1 ms	<1 ms	po5-v13008.ooe121-060.as41572.net [81.175.32.117]
6	5 ms	3 ms	4 ms	ten-2-1-v11504.ooe121-070.as41572.net [81.175.32.226]
7	1 ms	1 ms	1 ms	oso-b3-link.telialia.net [62.115.12.37]
8	8 ms	8 ms	8 ms	s-bb4-link.telialia.net [62.115.137.252]
9	8 ms	8 ms	8 ms	s-b5-link.telialia.net [62.115.133.27]
10	9 ms	9 ms	9 ms	google-ic-314684-s-b5.c.telialia.net [62.115.61.30]
11	8 ms	8 ms	8 ms	216.239.49.13
12	9 ms	8 ms	8 ms	216.239.49.217
13	8 ms	8 ms	8 ms	arn09s05-in-f142.1e100.net [216.58.209.142]

```
Trace complete.
```


# IP Registration

- IP addresses are allocated/sold to companies by a standard internet organization
- Given an IP address, can find *owner* and estimation of the *location*
- Different services can tell you that, eg *www.iplocation.net*



The screenshot shows the IP Location Finder website. At the top, there's a search bar with the text "IPv4, IPv6 or Domain Name" and a red "IP Lookup" button. Below the search bar, there's a message: "Here are the results from a few Geolocation providers. Accuracy of geolocation data may vary from a provider to provider. Test drive yourself, and decide on the provider that you like." followed by a link "Do you have a problem with IP location lookup? Report a problem." and another link "Is the data shown below not accurate enough? Please read [geolocation accuracy](#) info to learn why."

Geolocation data from [IP2Location](#) (Product: DB6, updated on 2018-2-1)

IP Address	Country	Region	City
81.175.52.97	Norway 	Oslo	Oslo

ISP	Organization	Latitude	Longitude
Westerdals Hoyskole - Oslo School of Arts Communication and Technology AS	Not Available	59.9127	10.7461

# On the route to *google.com*

- *10.x.x.x*: local IP (discussed later)
- *81.175.52.97*: Westerdals, Oslo
- *77.88.111.60*: backbone router
- *62.115.137.252*: Telia Company AB, Germany
- *216.58.209.142*: Google, California
- In other words, *before* reaching server in *California*, packets go first through *Germany*...

```
MINGW64/e/WORK/code/teaching
arcur@DESKTOP-IR7IFID MINGW64 /e/WORK/code/teaching
$ tracert google.com

Tracing route to google.com [216.58.209.142]
over a maximum of 30 hops:

  1      1 ms      1 ms      1 ms  10.96.16.2
  2     <1 ms     <1 ms     <1 ms  10.240.33.1
  3     <1 ms     <1 ms     <1 ms  97.sopp10.party.fredrikstadlan.no [81.175.52.97]
  4     <1 ms     <1 ms     <1 ms  77.88.111.60
  5      1 ms      <1 ms     <1 ms  po5-v13008.ooe121-060.as41572.net [81.175.32.117]
  6      5 ms      3 ms      4 ms  ten-2-1-v11504.ooe121-070.as41572.net [81.175.32.226]
  7      1 ms      1 ms      1 ms  oso-b3-link.telia.net [62.115.12.37]
  8      8 ms      8 ms      8 ms  s-bb4-link.telia.net [62.115.137.252]
  9      8 ms      8 ms      8 ms  s-b5-link.telia.net [62.115.133.27]
 10     9 ms      9 ms      9 ms  google-ic-314684-s-b5.c.telia.net [62.115.61.30]
 11     8 ms      8 ms      8 ms  216.239.49.13
 12     9 ms      8 ms      8 ms  216.239.49.217
 13     8 ms      8 ms      8 ms  arn09s05-in-f142.1e100.net [216.58.209.142]

Trace complete.
```

# Internet Control Message Protocol (ICMP)

- Protocol used to diagnostic a network
- *Ping*: utility/program that checks if a host is reachable, and how long it takes to reach it
- *Traceroute*: utility/program that checks the path toward a host
  - ie, what seen in previous slides based on TTL counters



# Pinging *google.com*: 8 milliseconds

MINGW64:/c/Users/arcu

arcu@DESKTOP-IR7IFID MINGW64 ~

\$ ping google.com

Pinging google.com [172.217.21.174] with 32 bytes of data:

Reply from 172.217.21.174: bytes=32 time=8ms TTL=51

Reply from 172.217.21.174: bytes=32 time=8ms TTL=51

Reply from 172.217.21.174: bytes=32 time=8ms TTL=51

Reply from 172.217.21.174: bytes=32 time=8ms TTL=51

Ping statistics for 172.217.21.174:

Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),

Approximate round trip times in milli-seconds:

Minimum = 8ms, Maximum = 8ms, Average = 8ms

# IP Spoofing

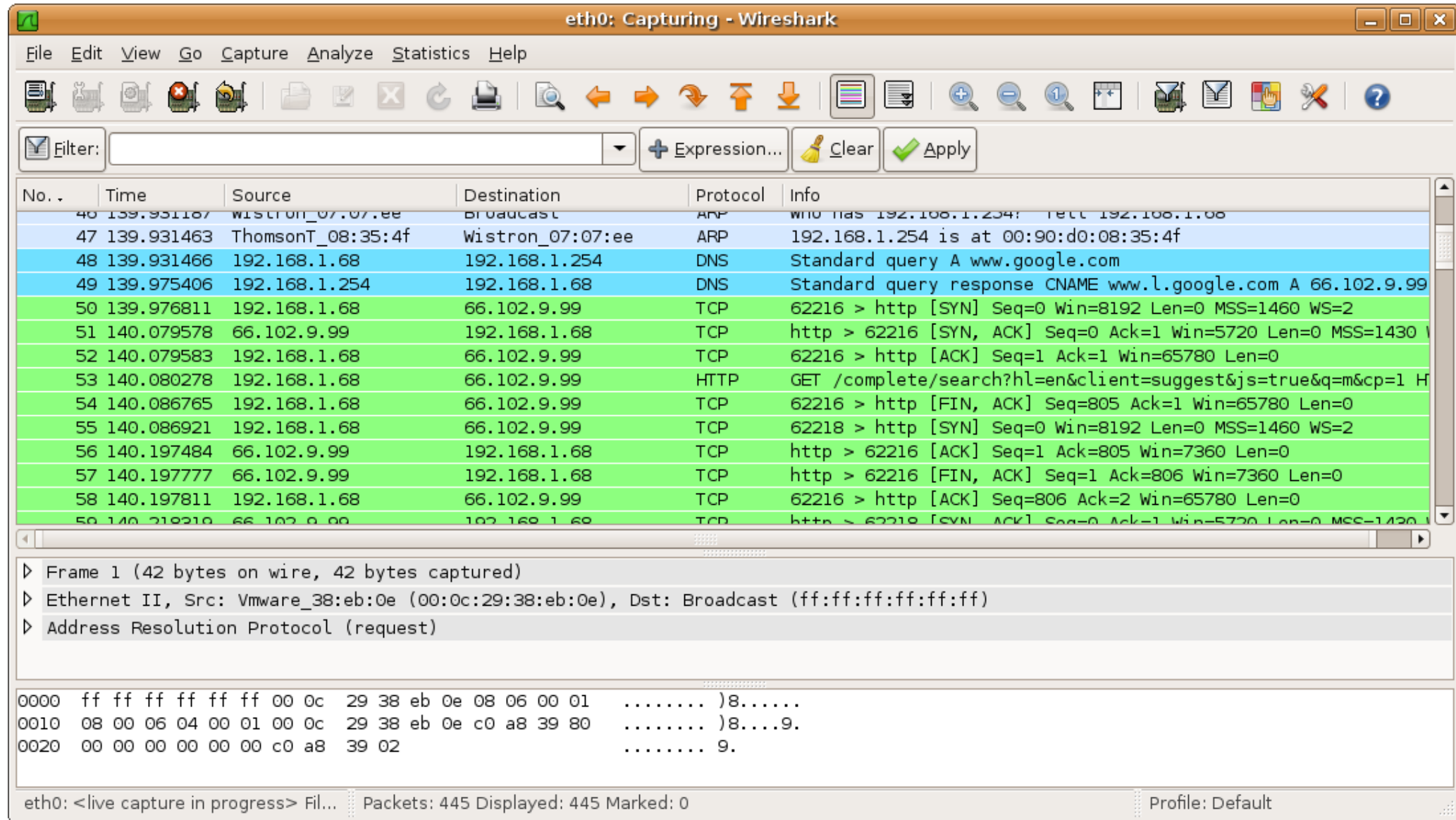
- IP Packet contains “*Destination*” and “*Source*” addresses
- But when you send a packet, you can alter the *Source* by using the IP of another machine
  - there is no check that Source address is the real one
- You will not get the reply, the other machine specified in Source will get it
- Why? Trick machine to send messages to another one (eg, DoS), or to circumvent firewall policies based on IP sources...

Bit Offset	0-3	4-7	8-15	16-18	19-31	
0	Version	Header length	Service Type	Total Length		Header
32	Identification			Flags	Fragment Offset	
64	Time to Live		Protocol	Header Checksum		
96	Source Address					
128	Destination Address					
160	(Options)					Payload
160+	Data					
	Data					
	Data					
	Data					
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# Packet Sniffing

- When using *hub*, packets are *broadcasted* to all connected device
- In *WiFi*, it is the same kind of *broadcasting*
- A computer will receive *all messages*, but then *discard* the ones meant for other MAC addresses
- You can analyze all packets, even the ones meant for others
  - Note: some network hardware cards do not support it, and neither some OS by default (eg, not trivial to get it to work on Windows...)

# Wireshark



eth0: Capturing - Wireshark

File Edit View Go Capture Analyze Statistics Help

Filter:  + Expression... Clear Apply

No.	Time	Source	Destination	Protocol	Info
40	139.931187	Wistron_07:07:ee	Broadcast	ARP	who has 192.168.1.254? Tell 192.168.1.68
47	139.931463	ThomsonT_08:35:4f	Wistron_07:07:ee	ARP	192.168.1.254 is at 00:90:d0:08:35:4f
48	139.931466	192.168.1.68	192.168.1.254	DNS	Standard query A www.google.com
49	139.975406	192.168.1.254	192.168.1.68	DNS	Standard query response CNAME www.l.google.com A 66.102.9.99
50	139.976811	192.168.1.68	66.102.9.99	TCP	62216 > http [SYN] Seq=0 Win=8192 Len=0 MSS=1460 WS=2
51	140.079578	66.102.9.99	192.168.1.68	TCP	http > 62216 [SYN, ACK] Seq=0 Ack=1 Win=5720 Len=0 MSS=1430
52	140.079583	192.168.1.68	66.102.9.99	TCP	62216 > http [ACK] Seq=1 Ack=1 Win=65780 Len=0
53	140.080278	192.168.1.68	66.102.9.99	HTTP	GET /complete/search?hl=en&client=suggest&js=true&q=m&cp=1 H
54	140.086765	192.168.1.68	66.102.9.99	TCP	62216 > http [FIN, ACK] Seq=805 Ack=1 Win=65780 Len=0
55	140.086921	192.168.1.68	66.102.9.99	TCP	62218 > http [SYN] Seq=0 Win=8192 Len=0 MSS=1460 WS=2
56	140.197484	66.102.9.99	192.168.1.68	TCP	http > 62216 [ACK] Seq=1 Ack=805 Win=7360 Len=0
57	140.197777	66.102.9.99	192.168.1.68	TCP	http > 62216 [FIN, ACK] Seq=1 Ack=806 Win=7360 Len=0
58	140.197811	192.168.1.68	66.102.9.99	TCP	62216 > http [ACK] Seq=806 Ack=2 Win=65780 Len=0
59	140.218210	66.102.9.99	192.168.1.68	TCP	http > 62218 [SYN, ACK] Seq=0 Ack=1 Win=5720 Len=0 MSS=1430

Frame 1 (42 bytes on wire, 42 bytes captured)

Ethernet II, Src: Vmware\_38:eb:0e (00:0c:29:38:eb:0e), Dst: Broadcast (ff:ff:ff:ff:ff:ff)

Address Resolution Protocol (request)

```
0000  ff ff ff ff ff ff 00 0c 29 38 eb 0e 08 06 00 01  ..... )8.....
0010  08 00 06 04 00 01 00 0c 29 38 eb 0e c0 a8 39 80  ..... )8....9.
0020  00 00 00 00 00 00 c0 a8 39 02  ..... 9.
```

eth0: <live capture in progress> Fil... Packets: 445 Displayed: 445 Marked: 0 Profile: Default

# Please, do NOT...

- ... go to a place with a public WiFi...
- ... use Wireshark in promiscuous/monitor mode...
- ... and then check if any #@^%&\* person is accessing not-encrypted web sites or mobile apps...
- And first of all, do **NOT** be that kind of #@^%&\* person!!!
  - Especially if you see someone running Wireshark on their screens...



Transport Layer

# Applications

- When application  $X$  wants to send a message to application  $Y$  on different machine  $S$ , needs to know its IP address
- But on  $S$  there can be *different applications* running
- How can we know on which application in  $S$  should the messages of  $X$  go to?
- IP address of  $S$  is not enough... we also needs *port* numbers

# Ports

- Ports are 16-bit unsigned numbers, so in 0-65535 ( $2^{16} - 1$ )
- An application wanting to receive messages, needs to open a *listening* port on its side
- Given the same Transport Layer protocol, no 2 applications can open the same port at the same time
  - combination of protocol + port should be unique
  - eg, starting 2 web servers on same port would have the second failing



# Ports to know

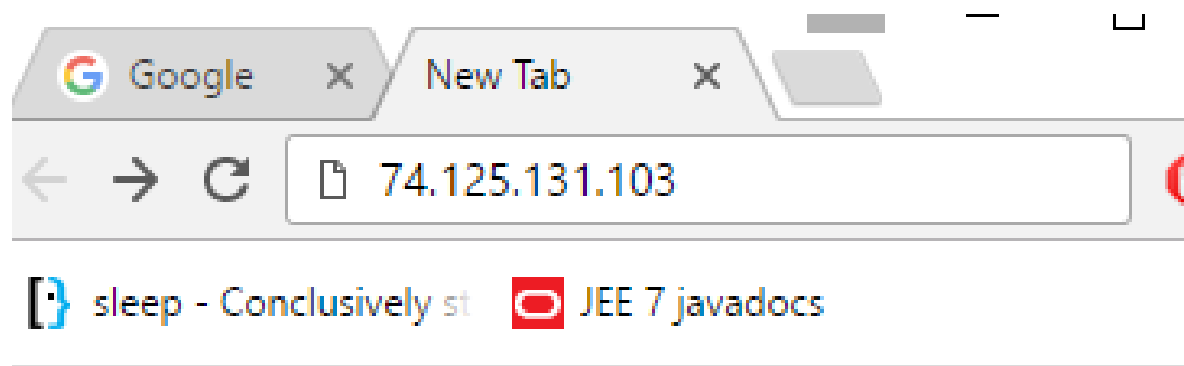
- 0: dynamically allocated (see next slide)
- 22: for SSH connections
  - Very common when you need to connect to a remote server or an IoT device using a terminal
- 80: for a HTTP connection
  - When browsing the web without encryption
- 443: for HTTPS, ie secure/encrypted HTTP over TLS/SSL
  - More and more common nowadays, even when no user authentication
- 8080: unreserved port.
  - “Typically” used by tools when running a HTTP server locally on your machine
- Note: HTTP is an Application Layer protocol specific for the web

# Ephemeral/Dynamic ports

- “Typically” in range 49152–65535
  - But will vary based on the OS
- For reading responses from the other machine
  - when you establish a connection to a remote machine, a port will be open locally to read the responses
- During development, when using port 0
  - Get a dynamic port which is free, not used
  - Eg, if you want to start a server locally for debugging/testing, you might want to avoid conflicts with other applications using the same port

# Defaults

- When nothing specified, browsers do default to known ports for the given *application* protocol
  - Default protocol is HTTP, and default resource is the root “/”
- So typing *www.google.com* is equivalent to ***http://www.google.com:80/***
- Typing *https://www.google.com* is equivalent to ***https://www.google.com:443/***
- Note: the page you request might not be the one you will get, as you could get a HTTP *3xx redirection*



- If you know the IP address, you can type it directly
- Same “name” can be mapped to different IP addresses, ie different servers
- The mapping can change
- We will go in more details on DNS next class

# Before going into the details...

- ... of Transport Layer protocols like **TCP** and **UDP**, let's go back a moment to IP addresses
- *How many devices are connected to the internet?*

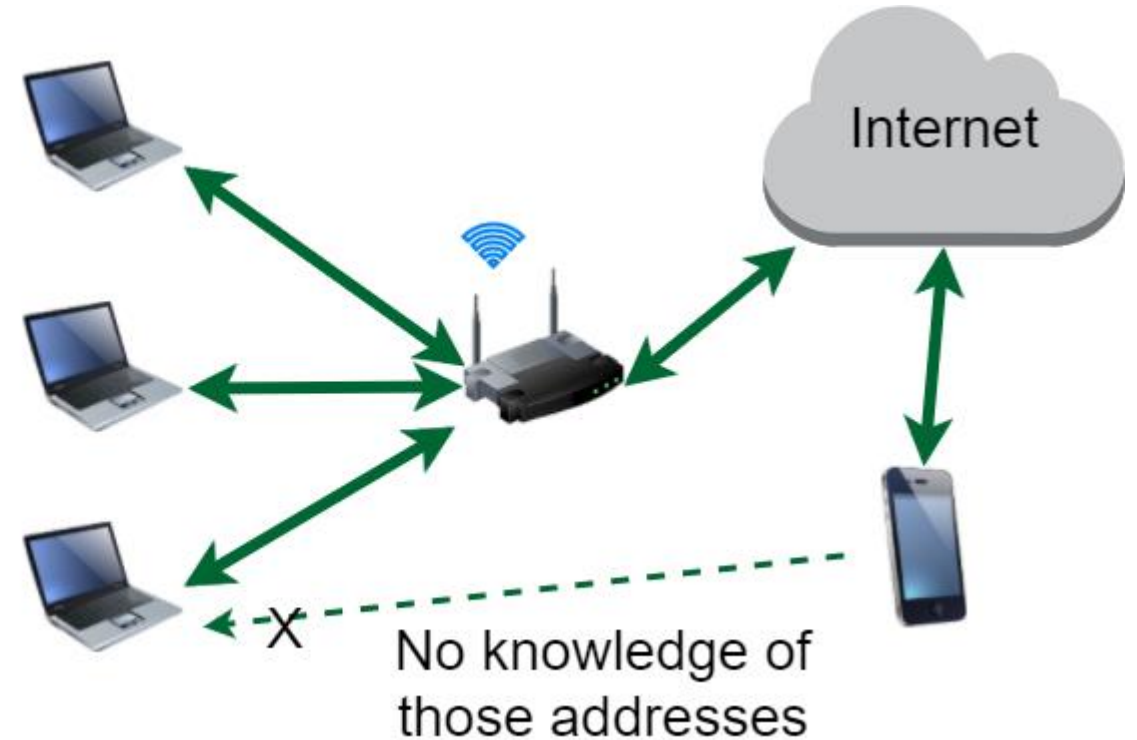
# Some Estimations

- 2016: around 300 **Millions** *new* devices connected *each month*
- 2020: estimated around 50 **Billions** devices connected
- *Why is this a problem?*
- IPv4 are 32-bits, so can only represent 4 **Billion** devices
- What to do until IPv6 is widely supported?

# Local Networks

- Router has IP accessible from internet
- Machines connected to it have *local IP* not visible from outside
- Cannot use mobile to connect to such machines, unless special settings on router, or WiFi directly to same router

10.x.x.x  
172.[16-31].x.x  
192.168.x.x



# Network Address Translation (NAT)

- A LAN will have IP addresses in
  - 10.x.x.x,  $2^{24} = 16m$  numbers, class A network
  - 172.[16-31].x.x,  $2^{20} = 1m$  numbers, class B network
  - 192.168.x.x,  $2^{16} = 65k$  numbers, class C network
- These local IP addresses are NOT used on internet
- Different LANs can use same local IP addresses with **NO** conflicts
- Only the gateway has an IP address that is reachable from outside
  - So behind a single IP address, there could be millions of devices
- Gateway has to handle the mapping/translation of IP:port



# NAT Example

- Let's see a HTTP connection to *google.com:80*
- Packet: source 192.168.0.1:61234, where the port is ephemeral
- Gateway does *change* the packet content by replacing source with itself, with an ephemeral port that can be different (eg 12345)
- Google will send back HTML page to the gateway at 81.175.52.97:12345
- When gateway receives message on port 12345, it knows that it has to route it to 192.168.0.1:61234
- Google server does NOT know about the IP and port of the laptop in the LAN



192.168.0.1:61234



81.175.52.97:12345



216.58.209.142:80

# IP Addresses to Know

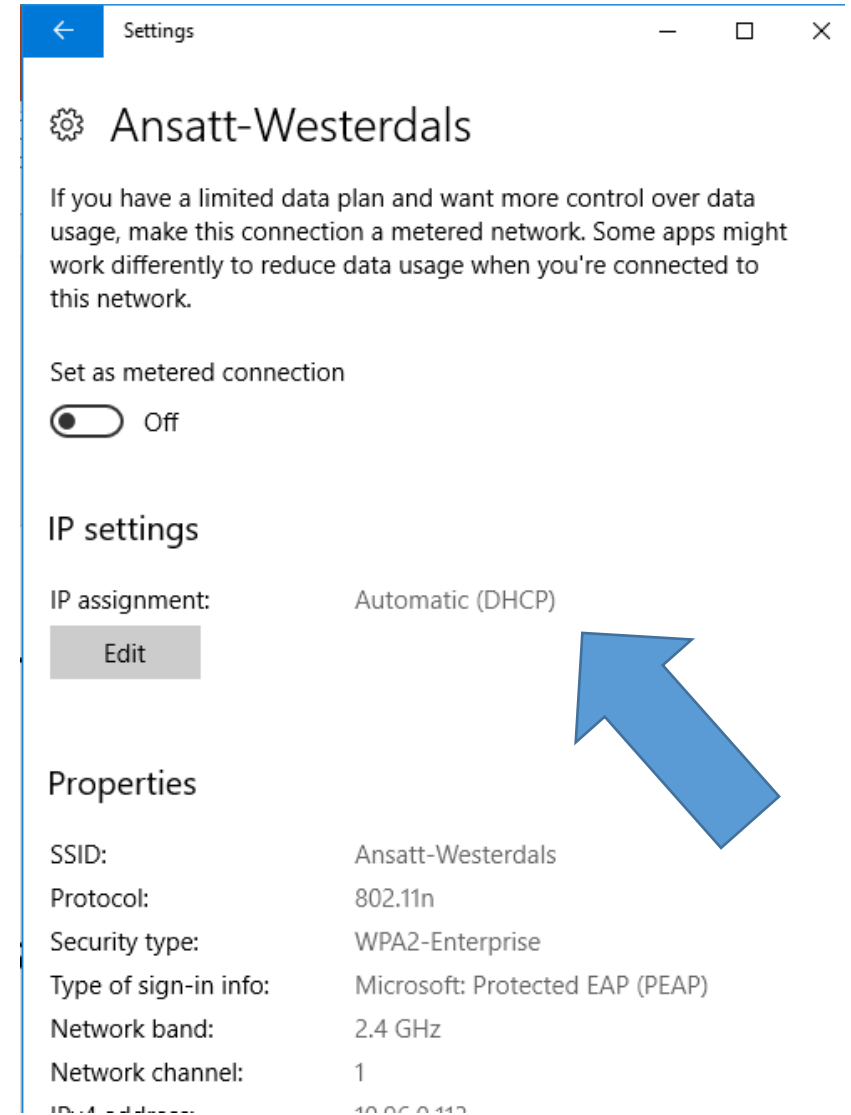
- 127.0.0.1
  - loopback address. Virtual one bypassing the network card. Useful for debugging, when running network applications (eg a web server) on your machine
- 10.x.x.x, 172.[16-31].x.x, 192.168.x.x
  - local LAN addresses
- 255.255.255.255
  - broadcast address. LANs might have it disabled for security reasons (discussed later)
- 0.0.0.0
  - all addresses on local machine. Useful when starting a server, and want it to listen to all possible incoming messages (a machine can have more than a network card, eg a cable and a WiFi)

# How do you get an IP address in a LAN?

- When you connect a laptop to a WiFi, you have an IP address
- Connecting to a different network (eg, WiFi at home and at work) will likely result in having a different IP address
- You can set up an IP address *manually* on your OS, but:
  - if this was not agreed with the network administrators, the network routers/switches might not route packages to it
  - if users choose own IPs, there can be clashes (eg 2 users trying to use same IP, and so network security system could think it is a man-in-the-middle attack)

# Dynamic Host Configuration Protocol (DHCP)

- A LAN will have a DHCP server
- A client computer connecting to the LAN will send a broadcast (eg 255.255.255.255) message stating to want an IP address, and providing its MAC identifier
  - it has to be a broadcast, because usually the client would not know a priori the IP address of the DHCP server
- The DHCP will choose an available IP address, and send a broadcast message with the mapping IP-MAC
- The client will then use such IP address
- All other machines on network will ignore these broadcasts, as for different MAC addresses



# UDP (User Datagram Protocol)

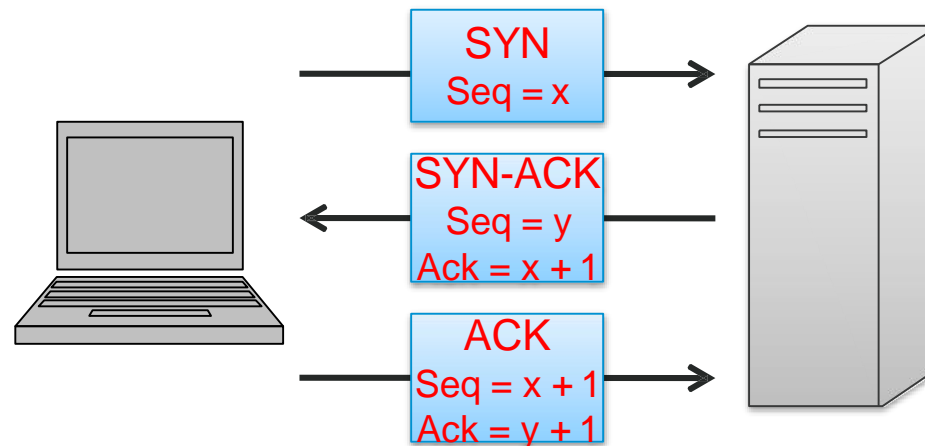
- One of the main Transport Layer protocols
- Single *independent* packets
- No guarantee of delivery
- No guarantee that packets are received in same order of sending
  - might go through different routing paths
- Useful in *time-sensitive* applications when lost of some data is acceptable

# TCP (Transmission Control Protocol)

- The main protocol used for the web
  - eg, when using a browser to access HTML pages
- Cannot guarantee delivery, *but* will try to resend packets if detects that were not received
  - ie, getting back an acknowledgement when packets are received
- Packets are logically linked together in a *session*, each one having an increasing index number
- Buffer of packets on receiving side, to re-order packets if arrived in wrong order
- Can automatically slow down sending of packets if too many are lost

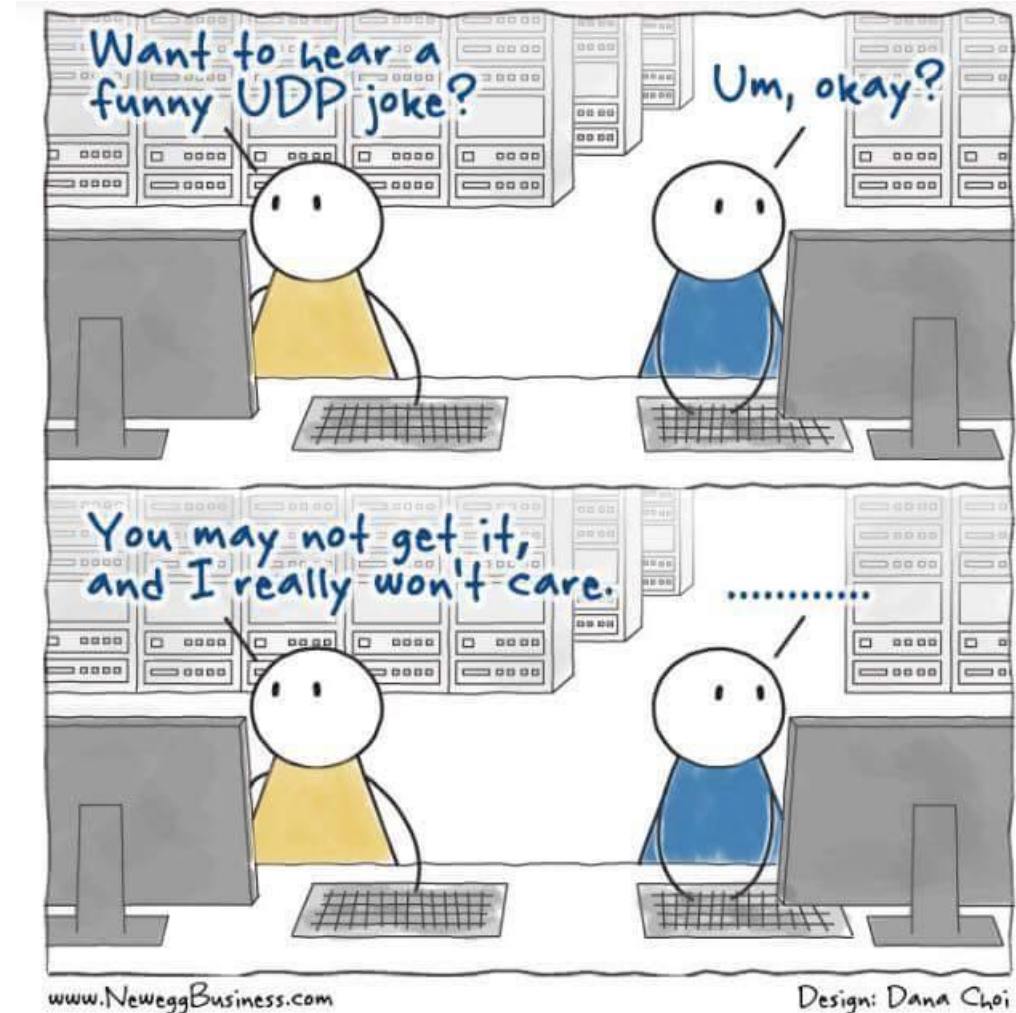
# Three-Way Handshake

- X and Y are originally chosen at random
- Needed to decide increasing numbers for ordering of packets
- If packet is received with an unexpected number, then buffered until the previous packets arrive



# TCP vs. UDP

"Hi, I'd like to hear a TCP joke."  
"Hello, would you like to hear a TCP joke?"  
"Yes, I'd like to hear a TCP joke."  
"OK, I'll tell you a TCP joke."  
"Ok, I will hear a TCP joke."  
"Are you ready to hear a TCP joke?"  
"Yes, I am ready to hear a TCP joke."  
"Ok, I am about to send the TCP joke. It will last 10 seconds, it has two characters, it does not have a setting, it ends with a punchline."  
"Ok, I am ready to get your TCP joke that will last 10 seconds, has two characters, does not have an explicit setting, and ends with a punchline."  
"I'm sorry, your connection has timed out."  
...Hello, would you like to hear a TCP joke?"

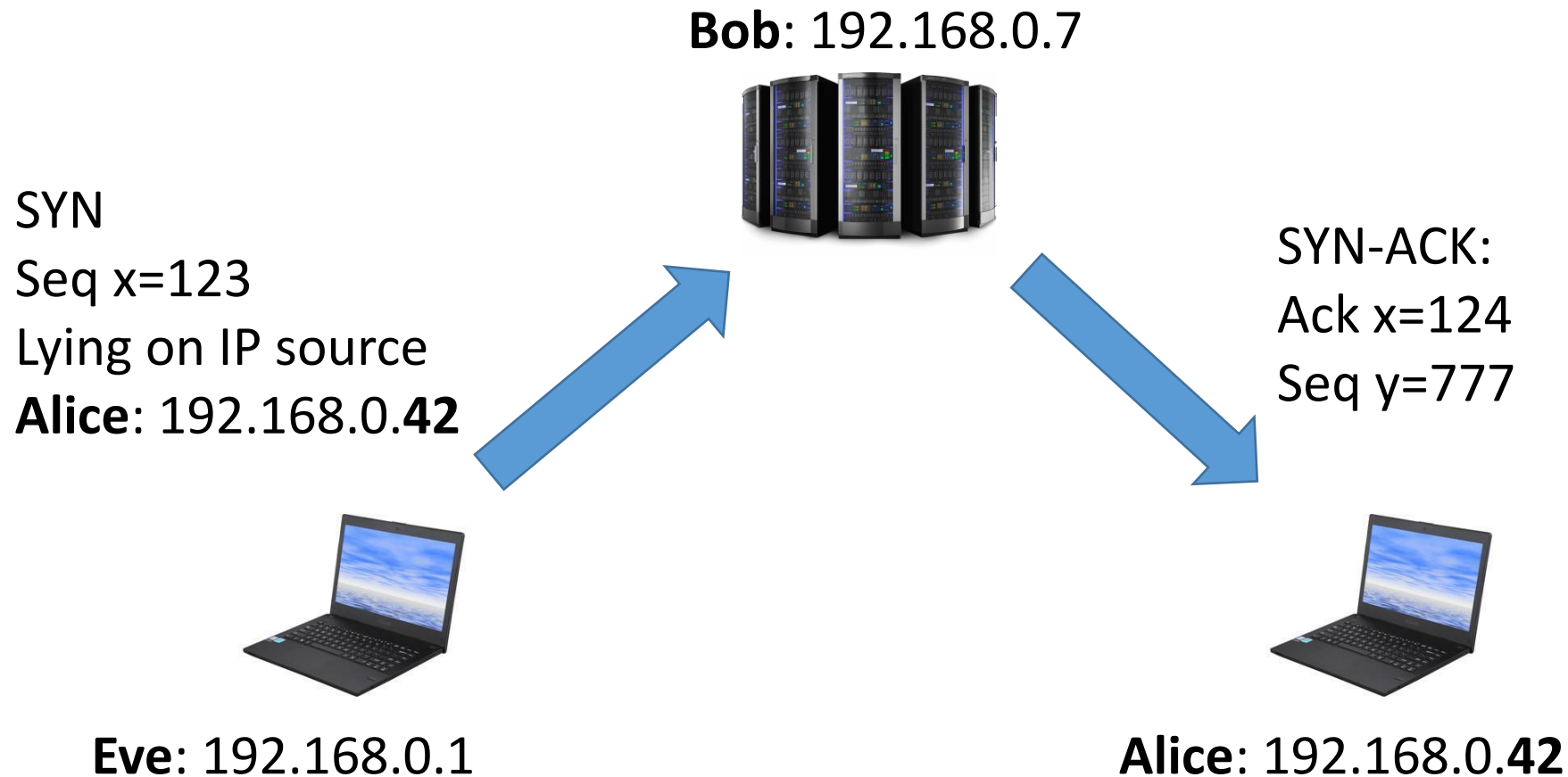




# TCP Session Hijacking

- Old TCP implementations used X-Y starting from fixed value, eg 0
- Attacker can hijack a TCP connection, by sending packet with IP of attacked machine Z, and predict TCP session numbers
  - Note: the attacker will not see the responses (*blind*), because sent to Z, and that is the reason why it needs to find out the correct session numbers
  - Can do man-in-the-middle attack
  - Random session numbers prevent such issue
- If on same LAN, can use Wireshark to see the session numbers
- Have to use encryption to prevent this kind of attack

Example: after sending the first SYN by spoofing the IP of Alice, Eve needs to find out the Seq  $y=777$  of Bob before sending the next TCP packet



# Denial-of-Service (DoS) Attacks

# Limits

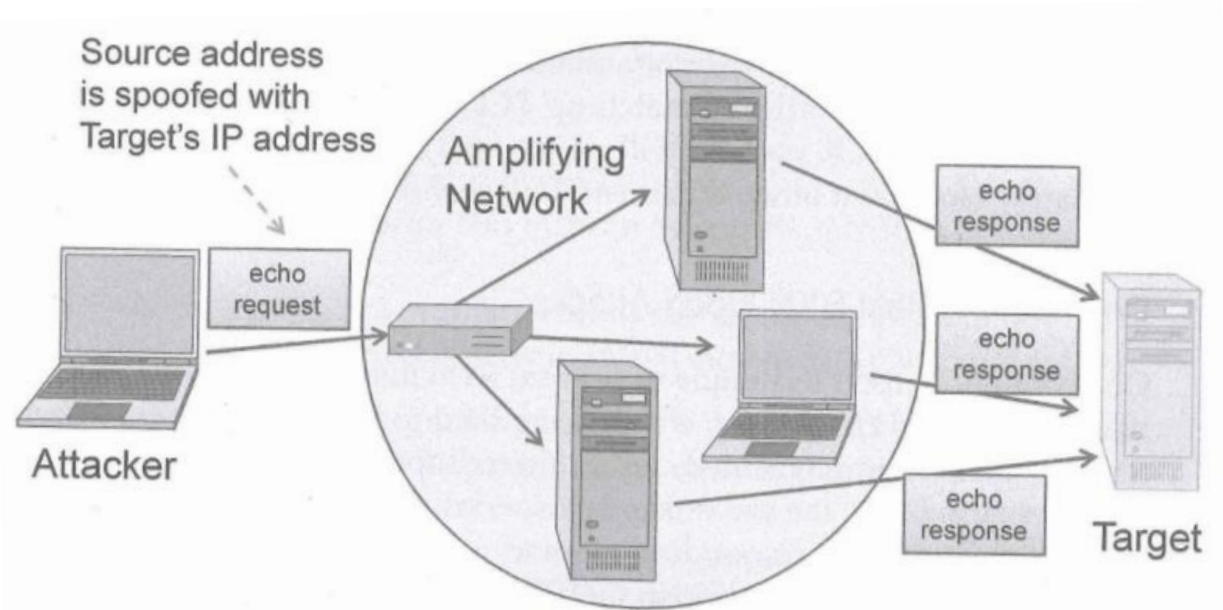
- Servers have limits on:
  - Memory
  - CPUs
  - Bandwidth
  - etc.
- If receiving too many requests from an attacker, then server cannot answer legitimate users, ie a so called *denial-of-service*

# Ping Flood Attack

- Simple attack
- Just do a lot of Ping/ICMP requests against a target
- Only works if attacking machine has more *resources* than the victim one

# Smurf Attacks

- Many LANs do have a broadcast address (e.g., 255.255.255.255)
- A packet sent to such address will be broadcast to all machines on the network
- If ICMP packet, the machines will reply to the source of that packet (eg Ping)
- But you can spoof the IP of a target machine, and so use the whole network to DoS the target



# WARNING!!!

- A Smurf Attack is quite simple to do...
  - and just to be on safe side, I will not show the actual code, but you could google it...
- Do **NOT** do this kind of attack (or any attack), nor any broadcasting, on the WiFi network in school...
  - due to some services needing it, broadcasting is not disabled
- WiFi connections of students are logged, and this kind of disruption of school services (eg abuse of broadcasting or DoS) can be ground for *degree termination* and *expulsion*
  - this is explicitly stated in the contract you signed...
- If you want to try it, do it at *home* with a private router you own...

# SYN Flood

- One of the most typical types of DoS attack
- In TCP connection, server needs to keep some *state*
  - eg, the X/Y session numbers
- An attacker might send many SYN requests, never followed by the ACK
- Each time, different IP source (can be spoofed)
- Server can run out of memory, because would keep state of connection until timeout
- Some attempts to prevent this type of attack (eg SYN Cookies), but nothing widely used/supported



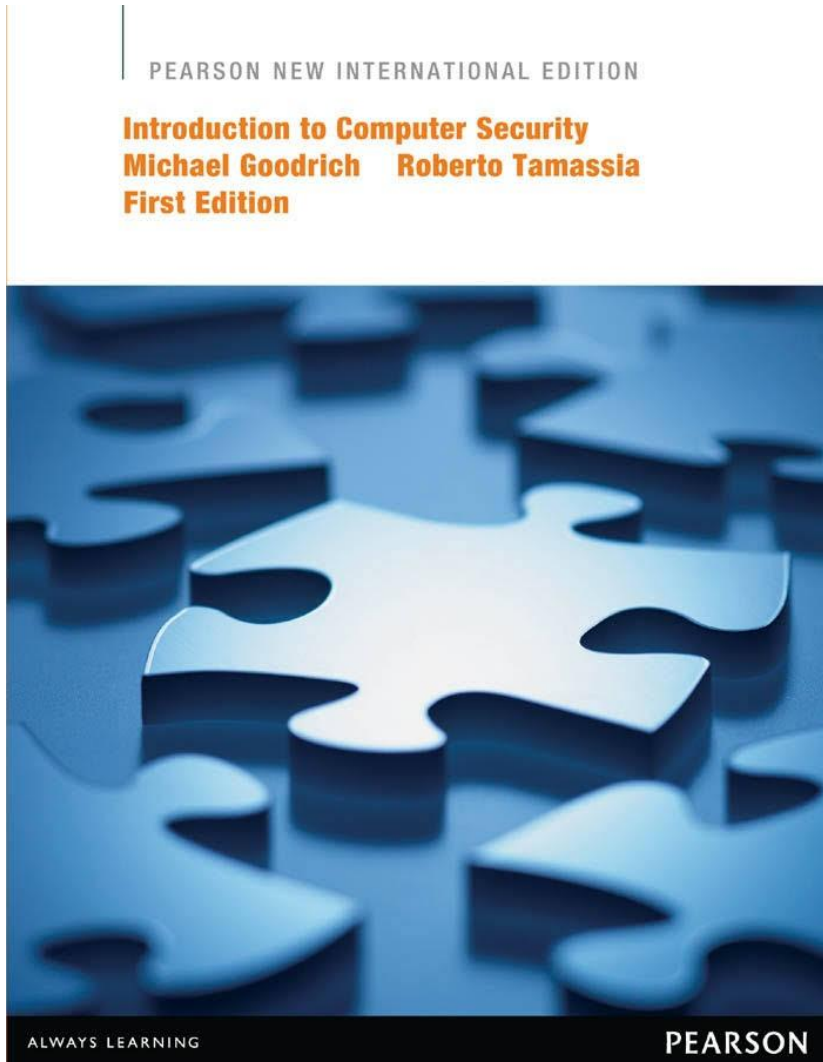
# Distributed DoS (DDoS)

- A single machine is unlikely to have the same resources of an enterprise system (eg, Amazon, Google or Facebook)
- But with Malwares, can have a bot-army that can do SYN Floods
- Servers of large corporations can be taken down

# DDoS Prevention

- If see that there are many requests coming from same IP, such IP can be *blocked*
- But that is usually *futile*, as IP addresses can be easily spoofed
- Many different techniques proposed to detect if packets are coming from the same source *without* relying on IP addresses
- But because they require changes on all routers on internet, only little is really used in practice...

# For Next Week



- Book pages: 221-263
- Note: when I tell you to **study** some specific pages in the book, it would be good if you also *read* the other pages in the same chapter at least once
- Exercises for Lesson 5 on GitHub repository