see [ZCC] Part II
or { [PF6.1], [PF6.2],[PF6.4],[PF6.6],[PF6.9]}

Lecture 5: Network Security

5.1 Background

5.2 Attack on Naming

5.3 Denial of Service attack

5.4 Useful tools

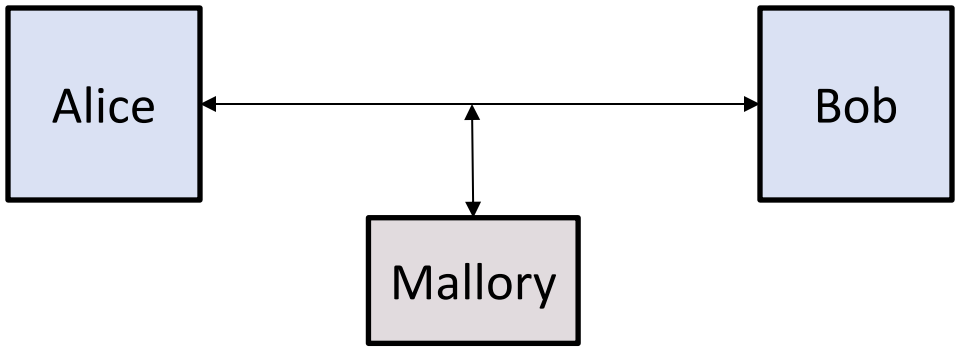
5.5 Protection: Securing the Channel using Cryptography

5.6 Protection: Firewall, Intrusion Detection System

5.7 Protection: Management

[ZCC] ED Zwicky, S Cooper, DB Chapman, **Building Internet Firewalls: Internet and Web Security,** 2000
(free from books.google.com
http://dbmanagement.info/Books/Others/O%27Reilly_Building_Internet_Firewalls_2nd_Edition.pdf)

- Previous lectures illustrate that, using cryptographic techniques + PKI, we can secure the public communication channel between Alice and Bob, so as to achieve ***authenticity*** & ***confidentiality***.



- Mission accomplished? There are many other issues:
  1. Other security requirements (e.g. availability, anonymity, access control);
  2. Other information, in particular networking information, to be protected (e.g. DNS, routing information);
  3. Access control, monitoring and other management issue (e.g. firewall) ;
  4. etc

5.1 Background on Networking

Important notions for this module:

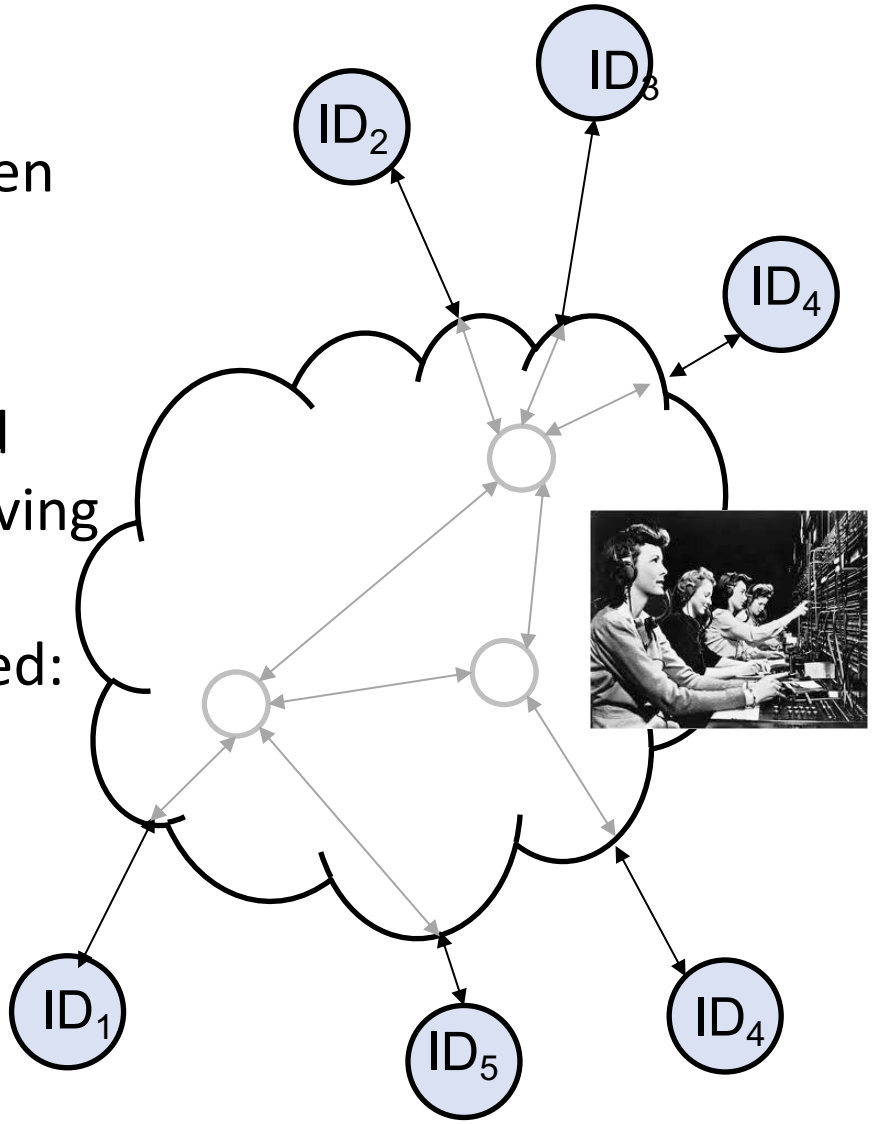
- Layers
- Naming
- Ports

Computer Network

laying 1 line for every pair is not feasible, since need n^2

- Computer Network establishes communicating connection between entities.

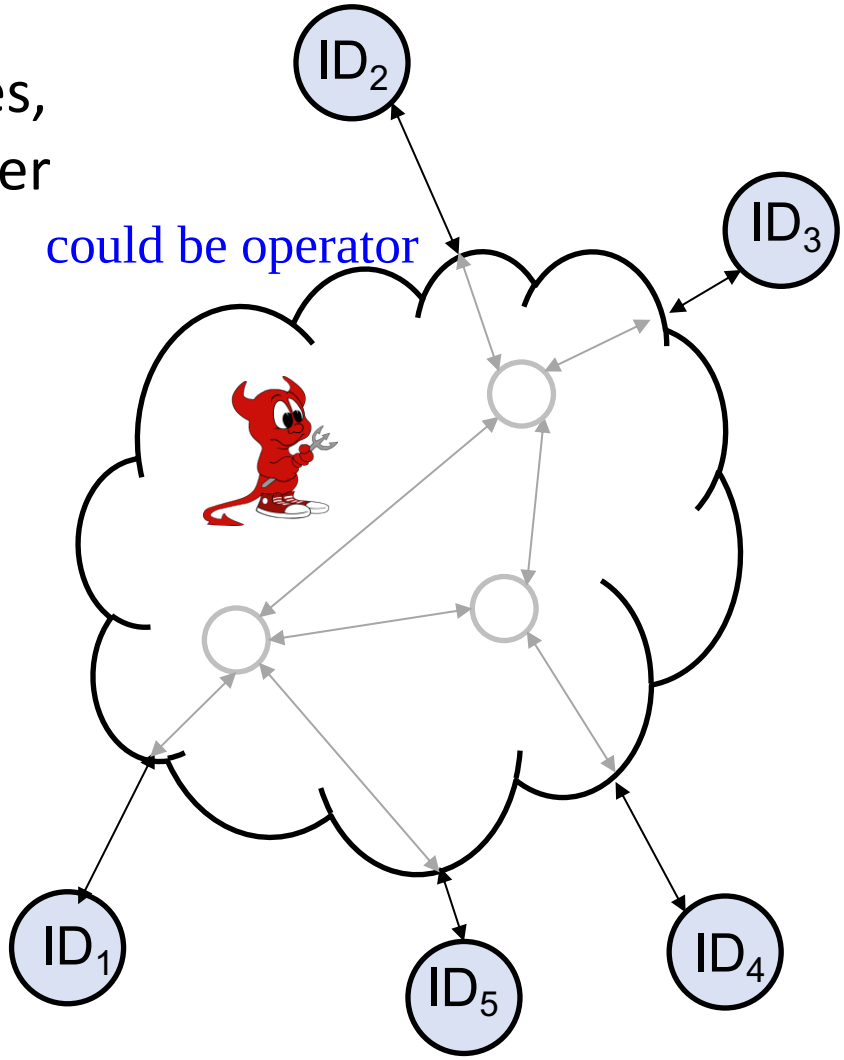
- To share networking resources and enhance robustness, instead of having dedicated line between any two nodes, ***packet switching*** is deployed:
  1. Messages route via multiple switches and routers.
  2. Messages are broken into "packets/frames".



Network Security

- While networking technologies focus on how to deliver messages, network security focus on another aspect. Under the presences of attackers:

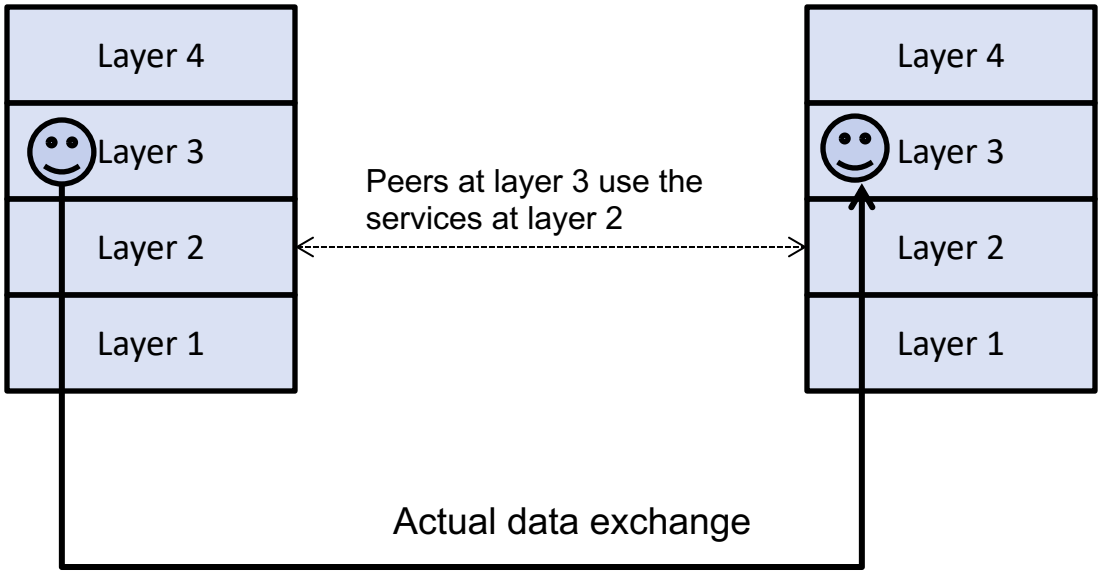
1. Preserving confidentiality and authenticity of the messages and various entities;
2. Maintaining availability of the network;
3. Controlling and monitoring the traffic flow.



Network layers

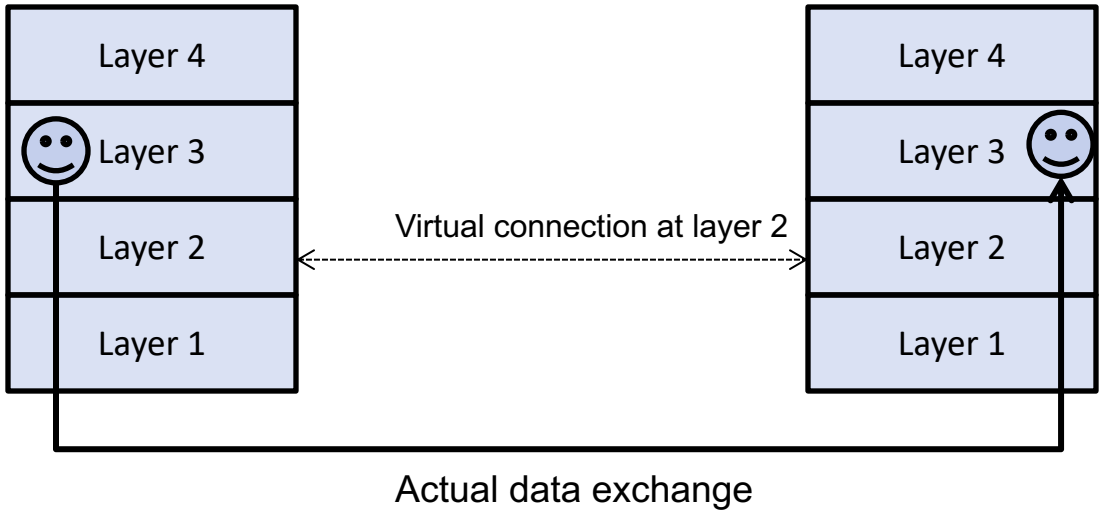
- Network protocols are abstracted as layers.

- Conceptually, layer (N-1) provides services for entities in layer N. The *peer entities* in the N layer communicate by executing protocols provided by layer (N-1).



Network layers

- In other words, the layer N services/protocols are built on top of services provided by layer (N-1). We can view the services at (N-1) as a virtual connection.
- In turn, the layer N can provide services for (N+1).
- The actual data sent by layer N are often divided into smaller units, and each unit is called a PDU (protocol data unit).



A hypothetical example:

A Layer 3 services (called ***handshake***) is designed as follow,

Handshake (A,B):

(1) A → B: "hello"

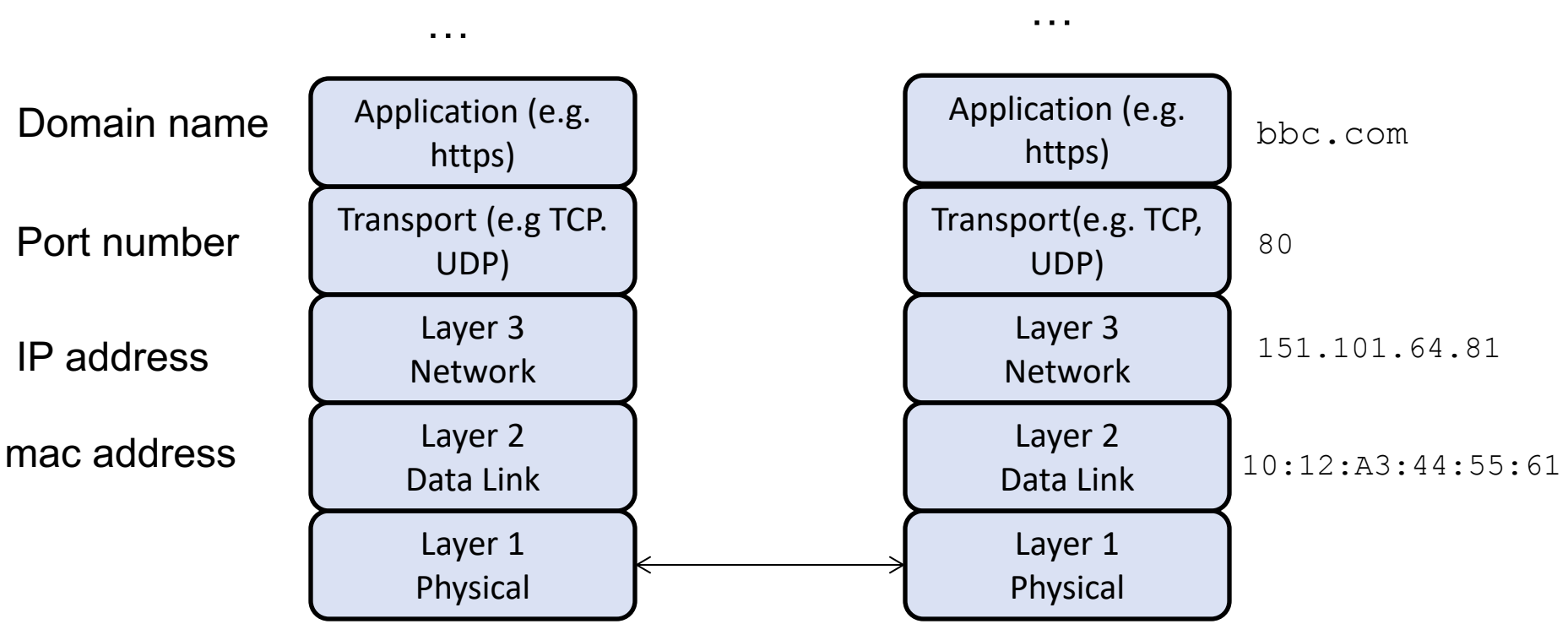
(2) A ← B: certificate of B.

library call provided by lower layer

The connection "A → B" is provided by Layer 2. The "virtual connection" at layer 2 sends the message "hello" from A to B in step (1), and sends the certificate in step (2).

Now, another entity in Layer 4 can use the layer 3's service *handshake.*

Internet layers:



While the Open Systems Interconnection model (OSI model) gives 7 layers. In practice and this module, we are interested in the above layering.

Naming

- A node in a network has different names in different layers.

- Four types of names are of particular concern in here.

  - Domain Name: `bbc.com`
  - Port Number: `80`
  - IP-address: `151.101.64.81`
  - mac-address: `10:12:A3:44:55:61`

Datagram, Packet, Frame (PDU)

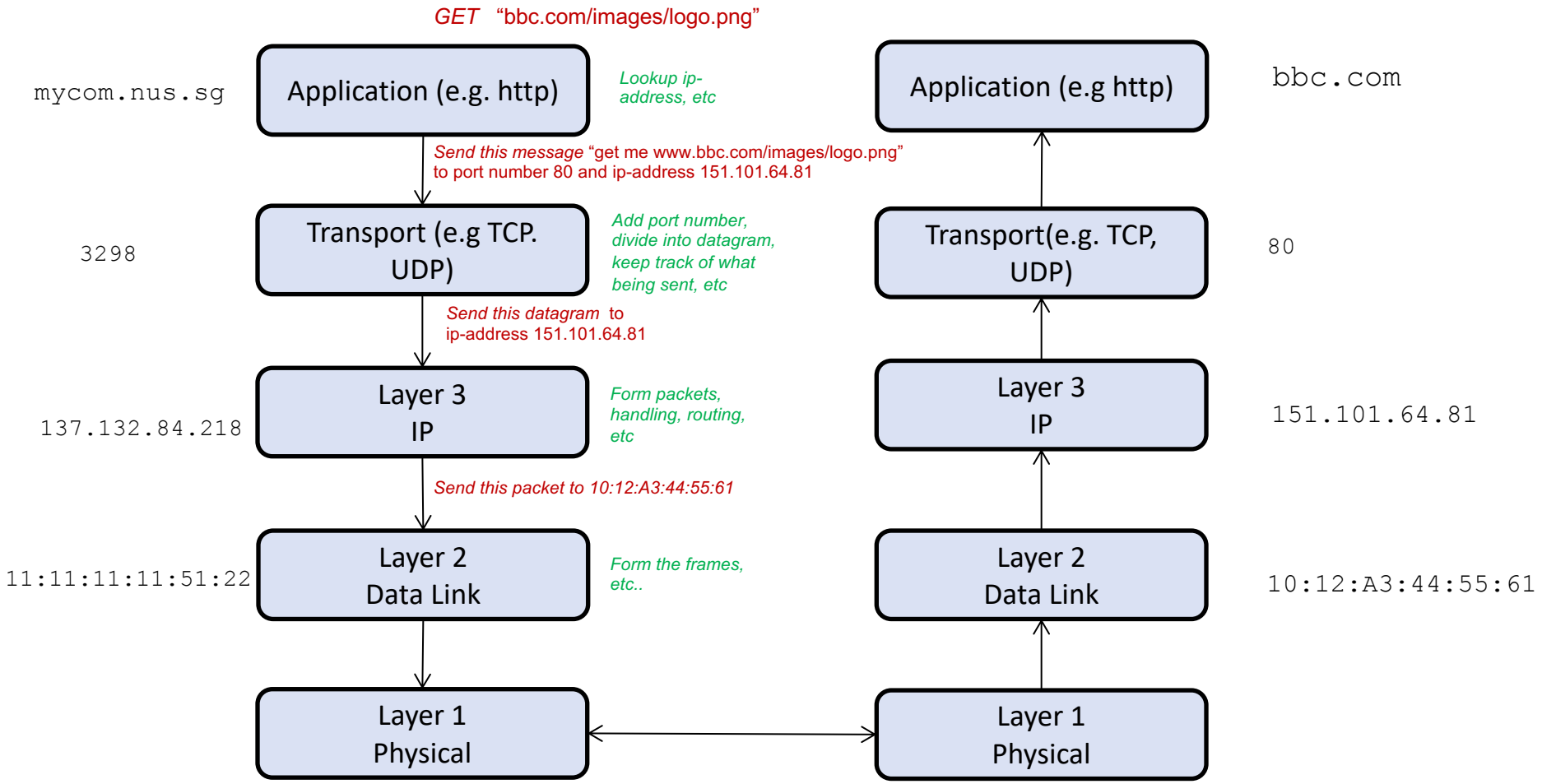
- When a layer-N service is invoked to send a message, the protocol in layer N might divide/merge the message into smaller units (i.e. the PDU).
  - In transport layer (layer 4), each portion is called a “datagram”.
  - In network layer (layer 3), it is called a “packet”.
  - In datalink layer (layer 2), it is called a “frame”.

- A packet/frame consists of two parts:
  - Header: this contains at least two pieces of information
    - The source (src) address, i.e. the sender’s address;
    - The destination (dest) address, i.e. the receiver’s address;
  - The payload: the data to be sent.

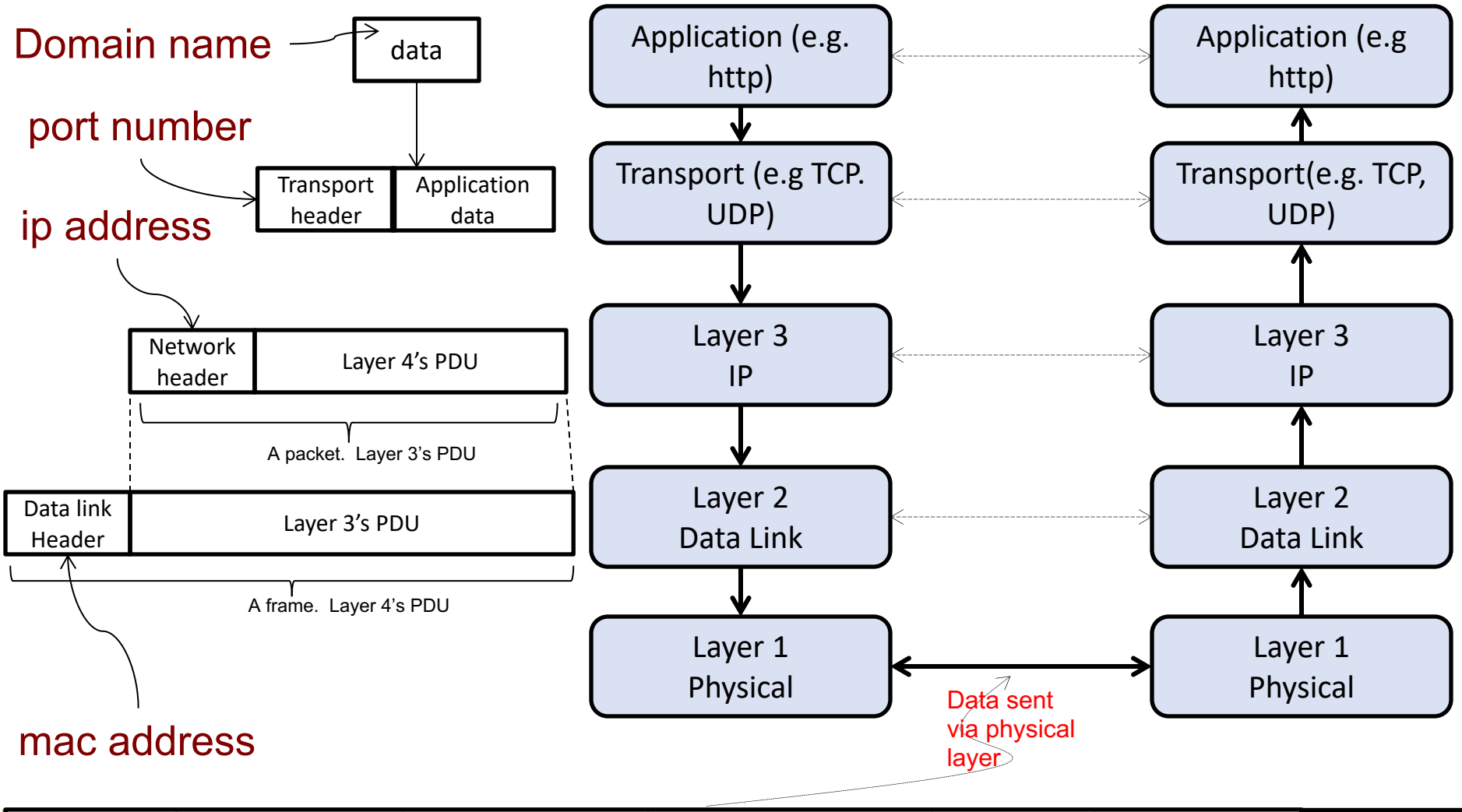
header: meta data Payload: the message/information intend to be sent

Data flow across the layers between two nodes

- When a node sends a message to another, the information flow “down” across the layers within the sender, and then ”up” within the receiver.



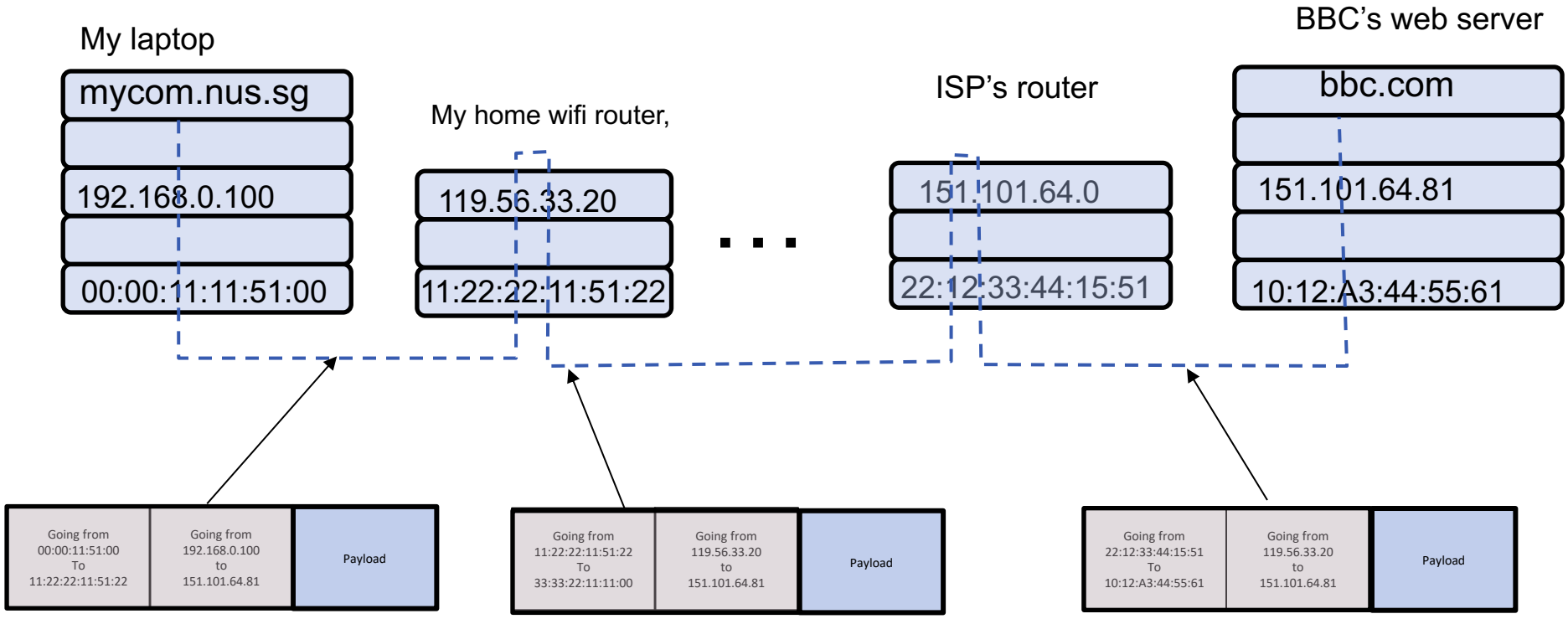
Data flow across the layers between two nodes



Source mac	Destination mac	Source IP-address	Destination IP-address	Source Port	Destination port	payload

Multiple hops

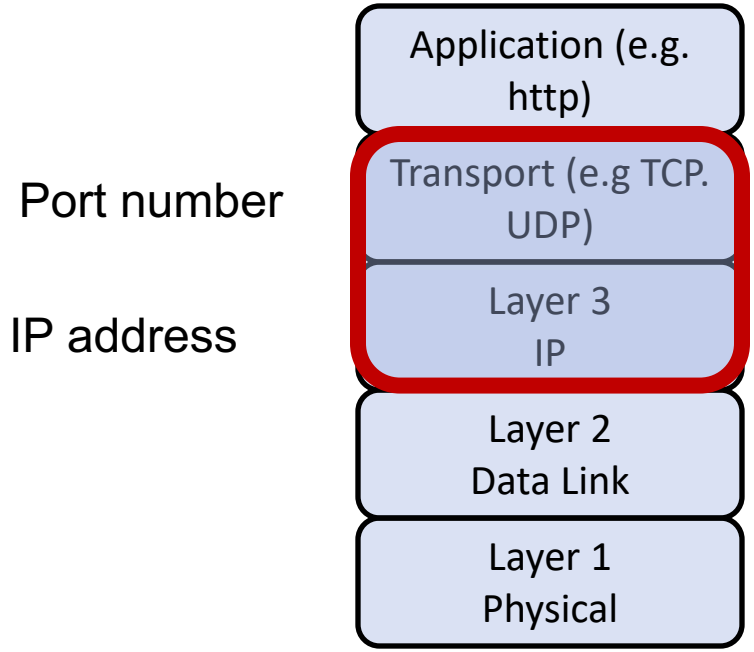
Data likely would go through multiple hops. Intermediate nodes could be owned by different semi-trusted third parties, e.g. Internet service provider (ISP), company's firewall. Intermediate nodes might change header information, translate the address etc, typically up to layer 3. Nonetheless, some intermediate nodes might change data in layer 4 and even application layer data.



Challenges in Network Security

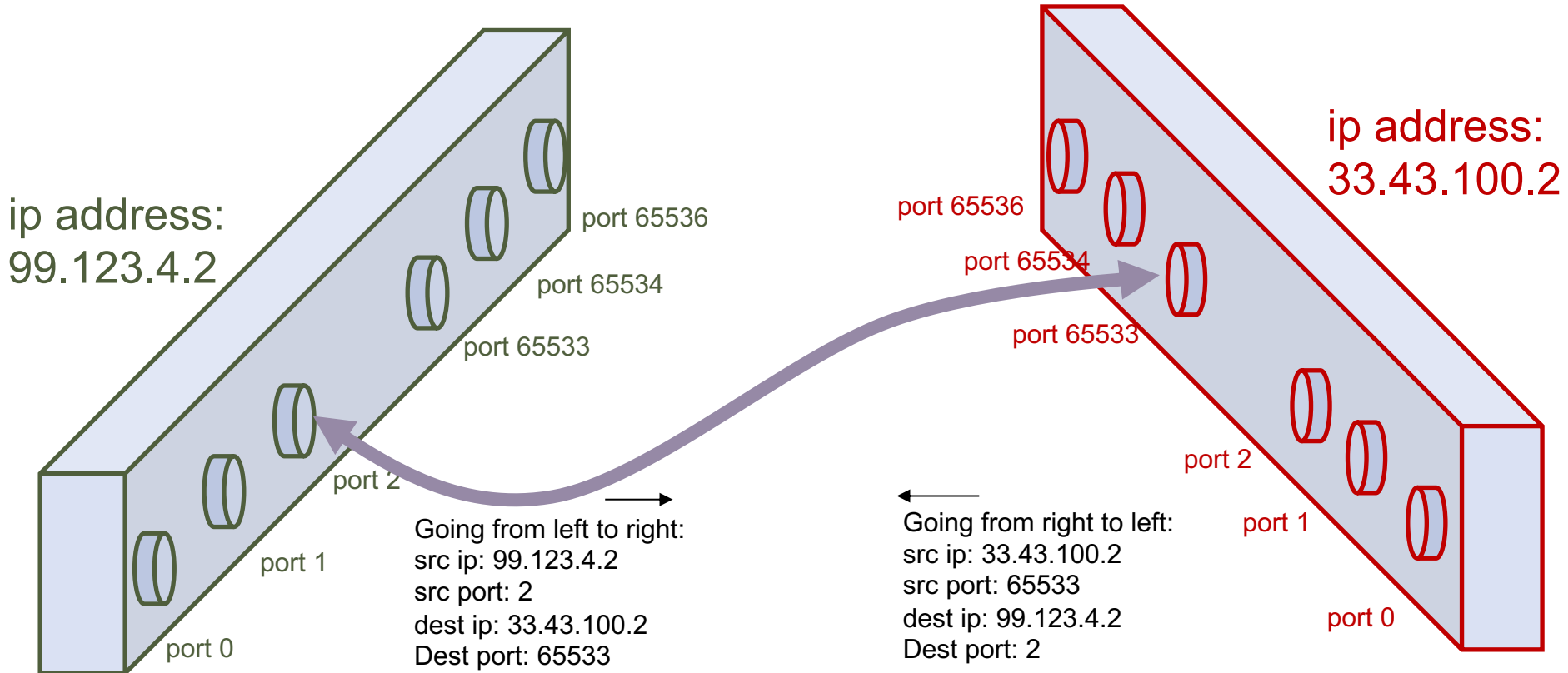
- (Complexity) Nodes are own by many different semi-trusted parties.
  - Intermediate node has access to both the header and the payload, and can modify (authenticity), read (confidentiality), drop (availability). An attacker at a certain layer can access all info in and below the layer.
- (Security Requirements) Many different security requirements.
  - In particular, availability can't be handled by crypto alone. Other requirements: anonymity, accountability, routing integrity, etc.
- (Legacy & security tradeoff) Initial design of many networking protocols did not consider intentional attacks.
  - For e.g., source ip-address in the IP header. Without additional protection mechanisms, a malicious sender can send packets with spoofed source ip-address.
  - For better performance and usability, many services do not employ strong protection mechanisms (e.g. network printer, DNS).
- (Management) There is a need to isolate and control information flow.

Remarks on TCP/IP and UDP/IP



Transport + IP layer

- Very often, the transport layer and IP layer are treated as one single layer. In this combined layer, the address of a communicating entity in a particular channel is an ***ip-address*** and a ***port***.
- Each node in the network has 65535 ports.
- A communication channel between two nodes is established by connecting a port in each node. In the e.g. between 99.123.4.2:***2*** and 33.43.100.2:***65533***.



UDP/IP

- If an application/program wants to invoke the UDP/IP protocol to send a message, the library call (depending on the programming languages) is typically of the form:

```
DatagramSend (  2, "33.43.100.2", 65533, message)
```

src ip is implicit and thus no need to specify

src port

dest ip

dest port

- The library call would construct an *IP datagram/packet*, and sends it using data-link layer protocol.

- There is limit on the size of message, at most ~65,000 bytes.
- The library call does not return a result indicating whether the destination has indeed received the packet. There is a possibility that the packet is lost! This is the property of UDP protocol. It is
  - *an unreliable, and*
  - *connectionless communication.*

TCP/IP: *reliable* communication

- In contrast, TCP/IP is ***reliable***.
- An application/program would typically make the library calls (depending on programming languages) of the form and in the following order:

```
-   P= open_connect (2, "33.43.100.2", 65533)
-        send (P, out_message)
-        read (P, in_message)
-   close_connection(P)
```

There could be multiple rounds of send/read.

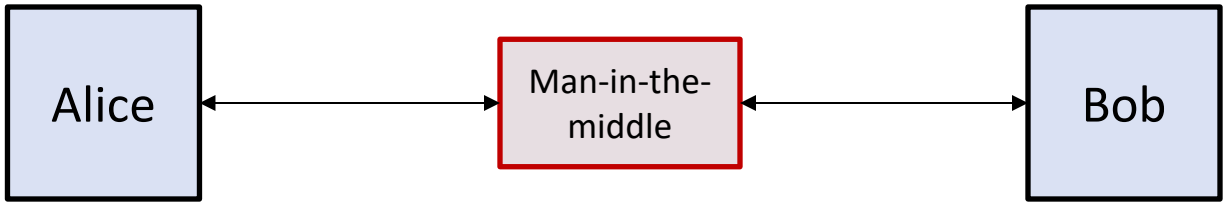
- `open_connect` would carry out some form of hand-shake protocol (known as TCP 3-way handshake) between the two nodes.
- `send` would construct *ip packets* of the following form and pass them to the datalink layer. In case the message is too long, multiple ip packets will be formed. The protocol also employs some mechanism of re-sending, re-ordering, acknowledgement to verify that the destination has indeed received the full message in the correct order.

Reliability does not imply Security

- TCP/IP is reliable but not “secure”. Intermediate nodes along the communication route can still modify data in the header and payload.

- For example, a malicious intermediate node can
  - spoof an IP packet to inform one node to close the connection, while still communicating with the other node.
  - change information on the packets ordering, so that dest reconstruct a scrambled message.

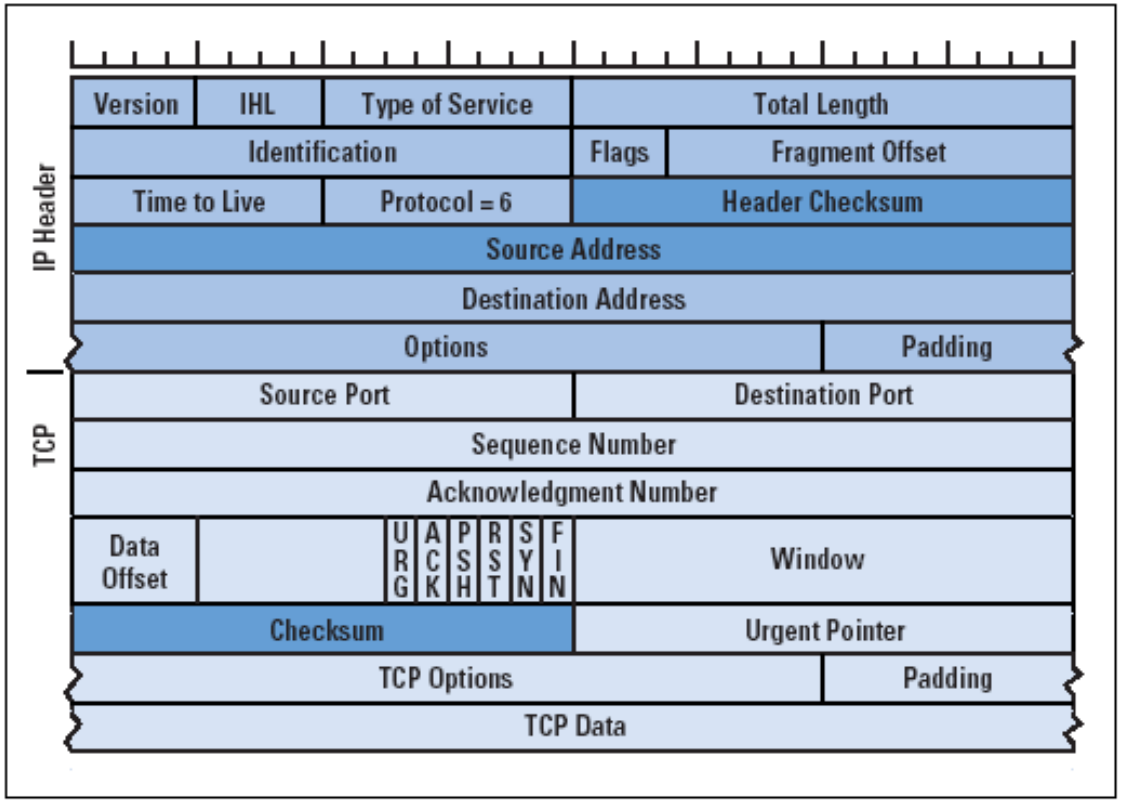
- The intermediate nodes can act as a *man-in-the-middle* in the ip layer.



Optional

- Image from https://www.cisco.com/c/en/us/about/press/internet-protocol-journal/back-issues/table-contents-29/anatomy.html

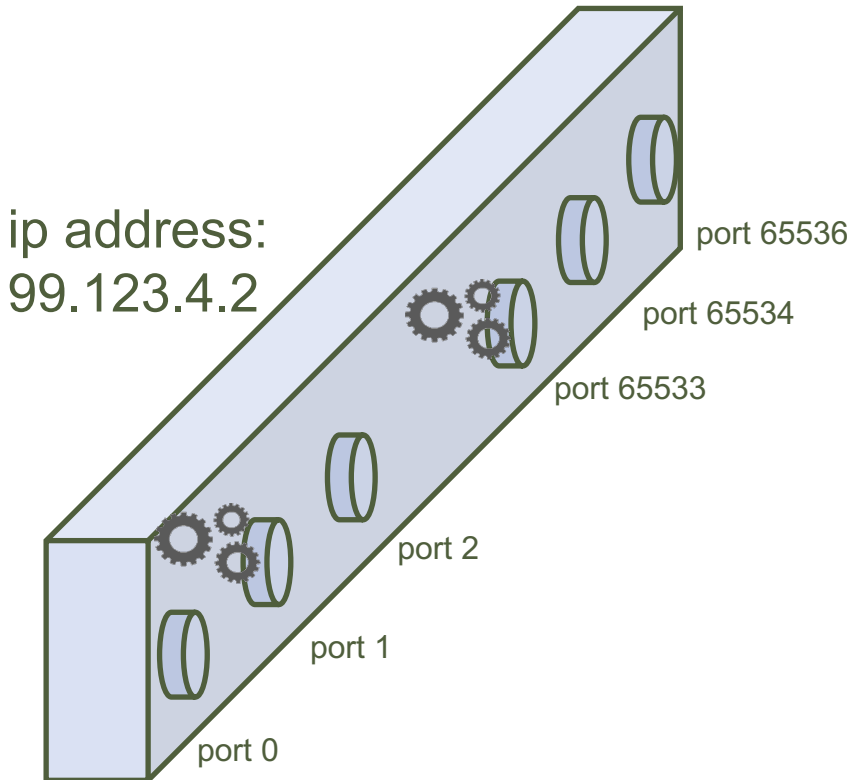
Figure 1: TCP/IP Header Fields Altered by NATs (Outgoing Packet)



Listening Port

What do we mean by “listening to a port”, “closed port”?

- We can imagine that behind certain ports (e.g. 1, 65533 in the e.g.), there are applications waiting to process data coming via the respective port. In such cases, we say that the node/process is “listening” to the port, and the port is a “listening port”. If the port is not listening, then it is a “closed port”.
- Data sent to a closed port will be dropped.



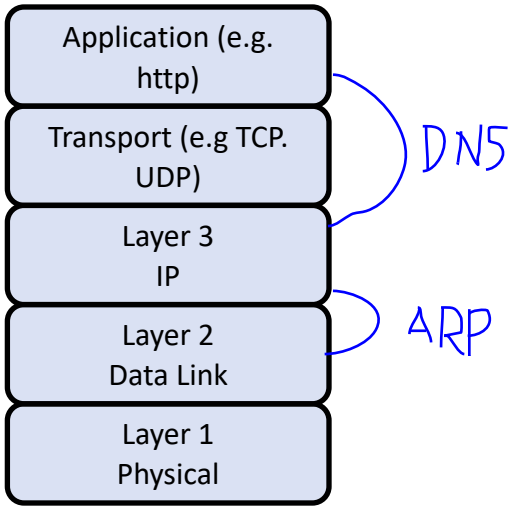
- There are security implications! We will revisit this in firewall design.
- Certain well-known services use widely agreed port. E.g. web server (HTTP) listen to 80, and hence the web server process is ready to process any request coming through 80.

5.2 Name resolution and attacks

- Each peer entity has a name. In a single node, at different layer, the name can be different.

Port number plays little role in name resolution attack

www.comp.nus.edu.sg	Domain name
80	port
132.127.12.3	IP address
01-02-03-04-05-06	mac address



- For a peer entity to use the virtual connection provided by layers below, it needs to find the corresponding name. E.g. finding the associated ip address for the domain name. Method of finding the name is called "*resolution*" protocol.
  - **DNS (Domain Name System):** resolution of Domain name to IP address
  - **ARP (Address Resolution Protocol)**: resolution of IP address to mac address
- Many initial design of the resolution protocol didn't take security into account, and thus easy for attacker to manipulate the outcome.

- ARP attack targets at the association of ip-addr with mac-addr.
- DNS attack targets at the association of domain name with ip addr.

In this module, we only consider a basic type of DNS attack, and ARP poisoning.

www.comp.nus.edu.sg Domain name

~~ARP (Address Resolution Protocol)~~

132.127.12.3 IP address

~~DNS (Domain Name System)~~

01-02-03-04-05-06 mac address

DNS (Domain Name System)

Given a domain name (e.g. www.comp.nus.edu.sg), its ip address can be found by looking up a locally stored table, or by querying a remote DNS server. The process is known as *resolution.* The client who initiates the query is called the *resolver*. If the address is found, we say that the domain name is *resolved.*

Demo:

```
$ nslookup www.comp.nus.edu.sg
Server:         192.168.1.1
Address:        192.168.1.1#53

Non-authoritative answer:
www.comp.nus.edu.sg    canonical name =
www0.comp.nus.edu.sg.
Name:   www0.comp.nus.edu.sg
Address: 137.132.80.57

$
```

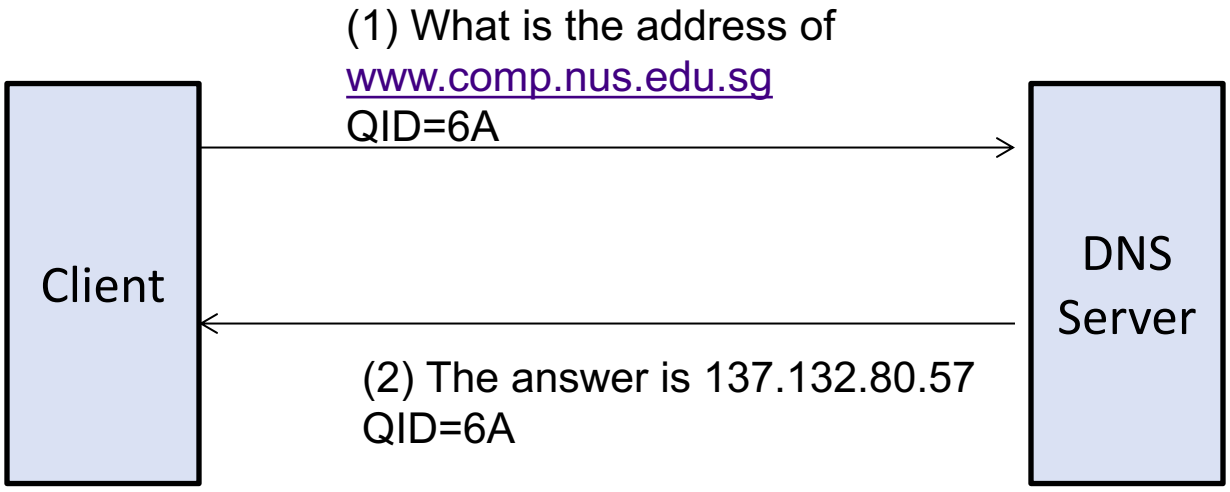
The domain name to lookup

Address of the DNS server

result of the query

DNS query and answer

- Current DNS protocol does not protect (confidentiality and authenticity) the query nor the answer.



traffic is all sent in clear

Some technical details:

- The query contains a 16-bit number, known as QID (query ID).
- The response from the server must also contains a QID.
- If the QID in the response doesn't match the QID in the query, the client rejects the answer. The design consideration of having QID probably is to match the query result to multiple queries sent out by the client. Nonetheless, this can be treated as a form of "light-weight" authentication.

DNS spoofing: Attack Scenario

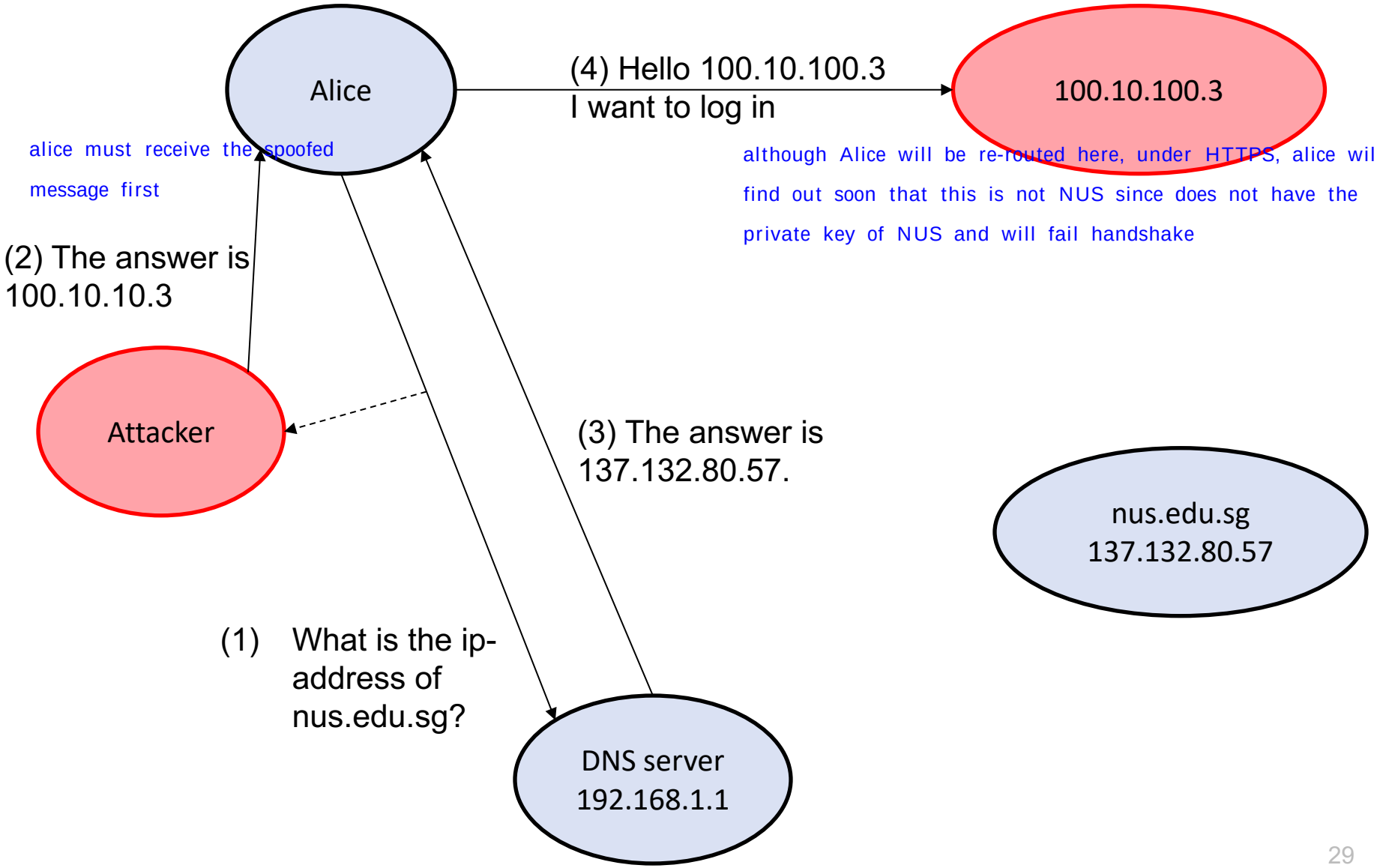
- Alice is using a café free wifi to surf the web.
- Alice wants to visit and login to nus.edu.sg
- She types the domain name into the browser address bar.
- The browser makes a query to a DNS server to determine the ip address. (e.g. by executing nslookup)
- After the browser obtained the ip address, it connects to the ip address.

Attack:

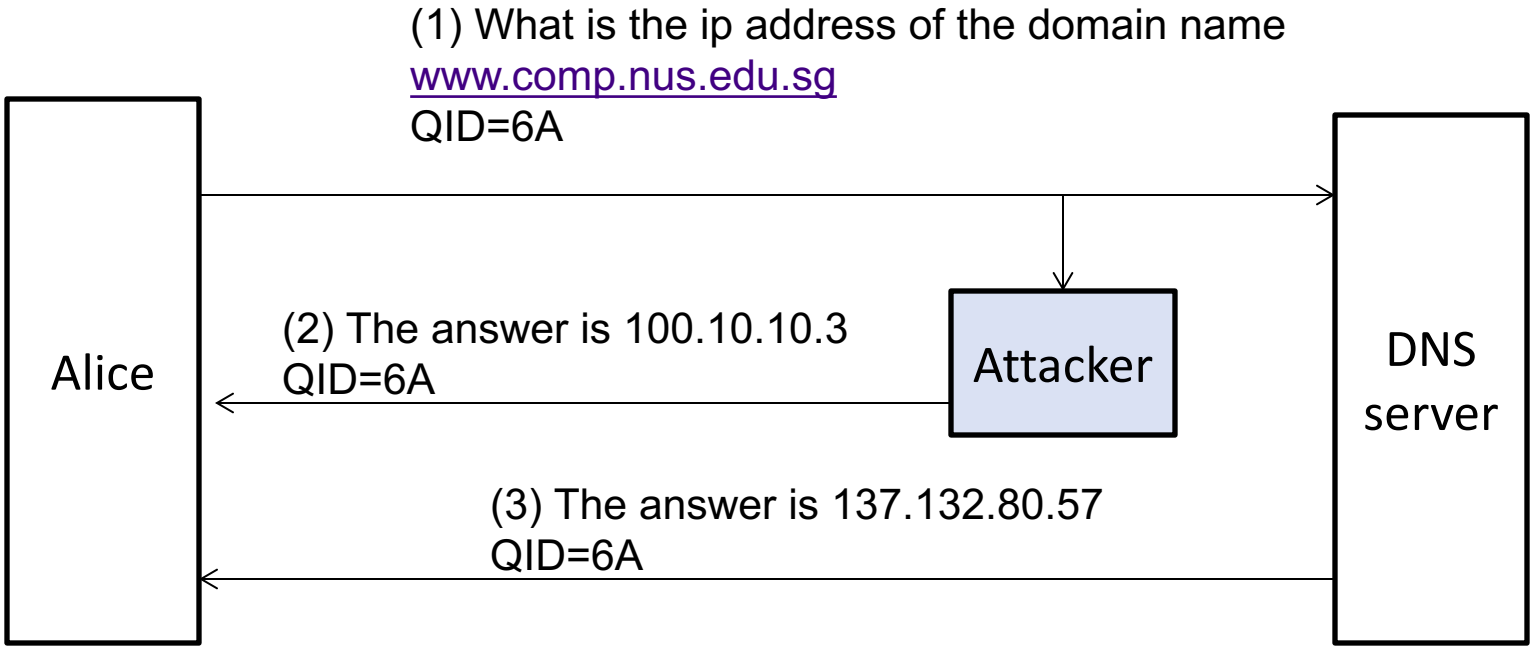
- We consider an attacker who is also in the café. Since the wifi is not protected, the attacker can
  - sniff data from the communication channel.
  - Inject spoofed data into the communication channel.

  However, the attacker can't remove/modify data sent by Alice.

  (the attacker sits in the physical layer).
- Attacker owns a webserver at 100.10.10.3 which is a spoofed NUS website.


Alice
(4) Hello 100.10.100.3
I want to log in
100.10.100.3
alice must receive the spoofed message first
although Alice will be re-routed here, under HTTPS, alice will find out soon that this is not NUS since does not have the private key of NUS and will fail handshake
(2) The answer is 100.10.10.3
Attacker
(3) The answer is 137.132.80.57.
nus.edu.sg
137.132.80.57
(1) What is the ip-address of nus.edu.sg?
DNS server
192.168.1.1

The attack



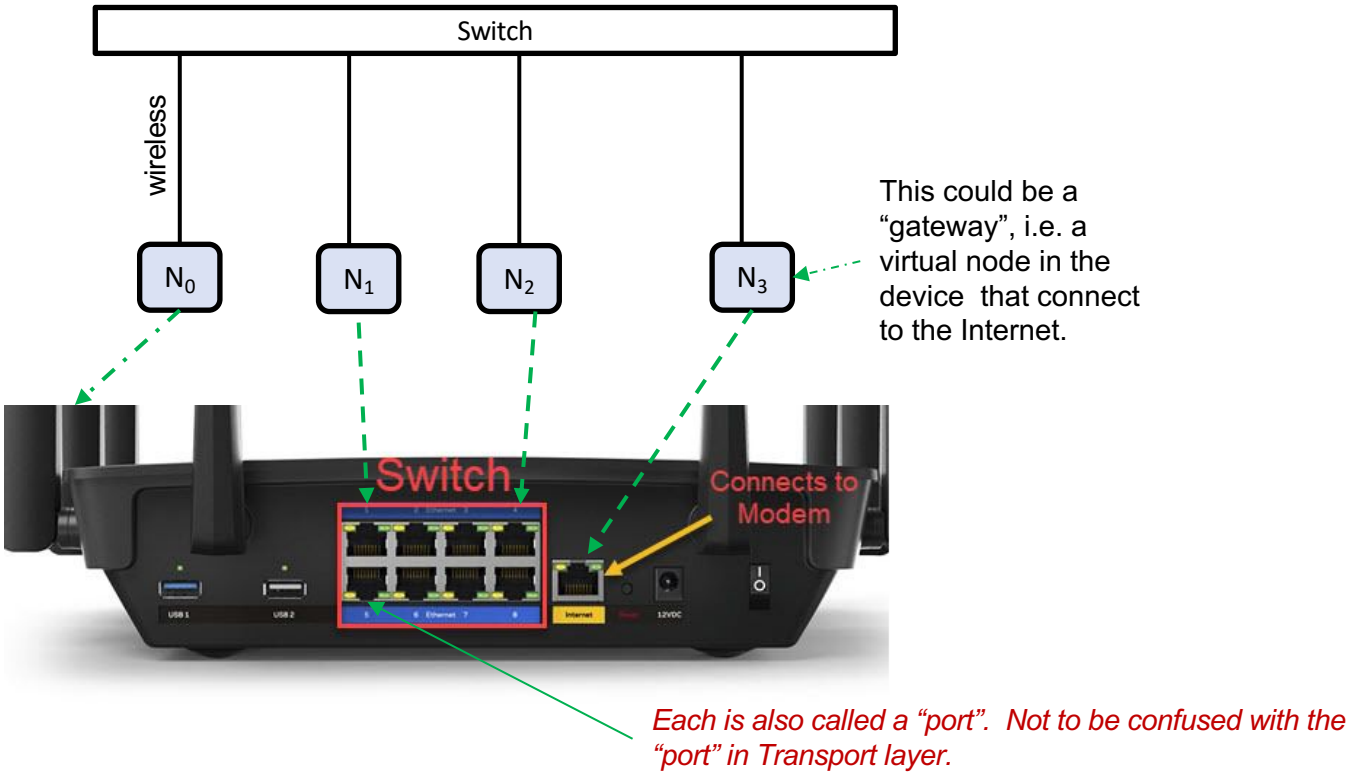
Step (1) Alice asks for the address.
Step (2) Attacker sniffs and knows about it. Attacker quickly spoofs a reply with the same QID.
Step (3) DNS server also sends a reply. Since Attacker is closer to Alice, Attacker's reply likely to reach Alice first.
Alice takes the first reply as answer, and connect to 100.10.10.3

- DNS is an important component as it resolves the domain name. Hence, an DNS server can be a “single-point-of-failure” of the network.
- A denial of service (DOS) attacks on a web service, instead of directly attack the web server, could conduct DOS to the DNS server instead. When DNS server is downed, the web service is not longer reachable.

- E.g. see attack on wikiLeak (http://www.independent.co.uk/life-style/gadgets-and-tech/news/twitter-down-is-it-not-working-wikileaks-ddos-us-election-japan-a7402081.html and [PF6.5]pg 414, [Pf]page 485).

Poisoning attack on ARP table

- A switch connects a few nodes. (Note that *switch* handles mac-addresses, *router* handles ip-addresses.)



- E.g. our home wifi "router", although often called as a "router", it also functions as a switch.

- The role of the switch is similar to the telephone switchboard shown earlier. It connects two “ports”.
- Switch doesn’t understand ip-addresses and doesn’t store ip-addresses. It connect ports based on mac-addresses.
- The switch keeps a table that associates the port to the mac-addresses.
- Resolution of ip-address to mac-address is done by the nodes (e.g. desktop, mobile phone). Each node keeps a table that associate ip-address to mac-addresses.
- The nodes update each others using some protocols, regarding info on the ip-addresses and mac addresses.

- ***ARP poisoning*** is an attack that modifies (aka “poisons”) the tables so as to gain Man-In-The-Middle access.

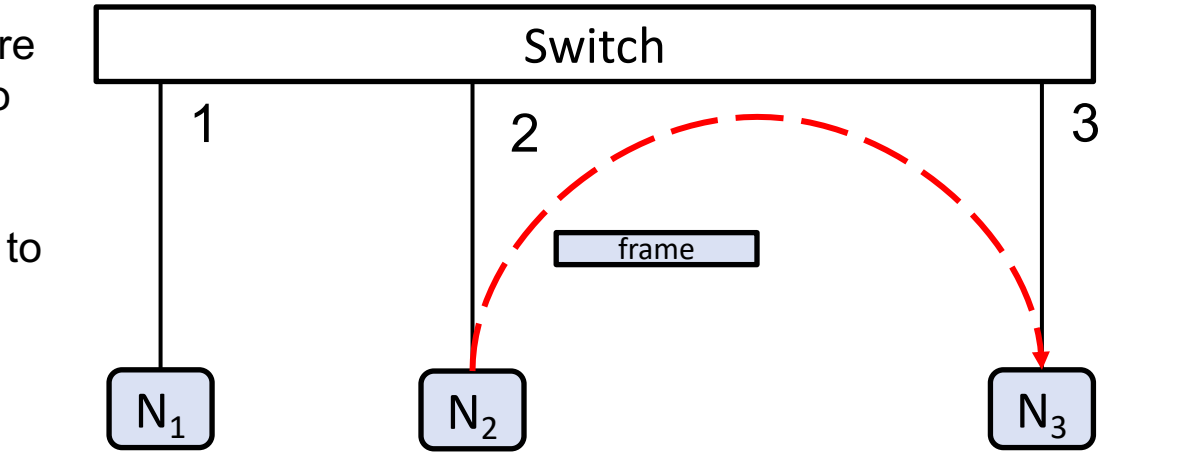
When N_2 want to send to ip address 10.0.1.4

T0

Switch's port	Mac-address
1	fa:16:3e:d5:e0:14
2	fa:16:3e:f3:ea:4c
3	fa:16:3e:ed:05:e4

Under normal circumstances, these are carried out when N_2 sends a packet to 10.0.1.4

1. N_2 looks up the table **T2**. Resolve to fa:16:3e:ed:05:e4
2. N_2 sends the frame to the switch, specifying destination fa:16:3e:ed:05:e4
3. Switch looks up the table **T0**, redirect the frame to port 3.



Ip-address	Mac-address
10.0.3.13	fa:16:3e:d5:e0:14
10.0.1.4	fa:16:3e:ed:05:e4

T2

Ip-address	Mac-address
10.0.3.13	fa:16:3e:d5:e0:14
10.0.3.5	fa:16:3e:f3:ea:4c

T3

Note:

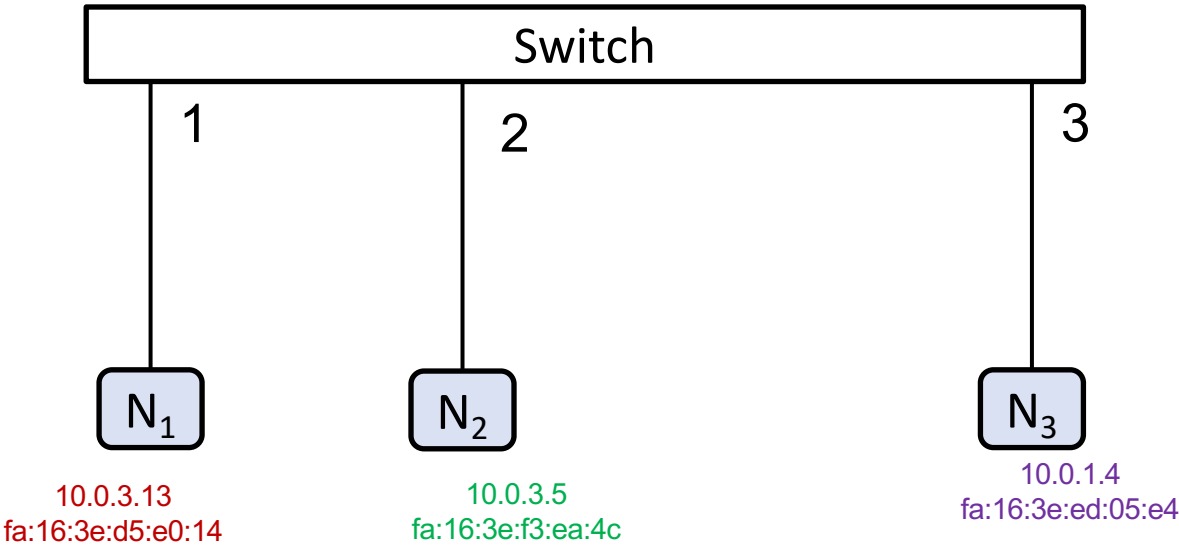
- *T0 stored in switch.*
- *T2 stored in N_2*
- *T3 stored in N_3*

Attack: N_1 wants to be MITM between 10.0.3.5 and 10.0.1.4

T0

Switch's port	Mac-address
1	fa:16:3e:d5:e0:14
2	fa:16:3e:f3:ea:4c
3	fa:16:3e:ed:05:e4

1. N_1 informs N_2 that mac address of 10.0.1.4 is fa:16:3e:d5:e0:14
2. N_1 informs N_3 that mac address of 10.0.3.5 is fa:16:3e:d5:e0:14



Ip-address	Mac-address
10.0.3.13	fa:16:3e:d5:e0:14
10.0.1.4	fa:16:3e:ed:05:e4

T2

Ip-address	Mac-address
10.0.3.13	fa:16:3e:d5:e0:14
10.0.3.5	fa:16:3e:f3:ea:4c

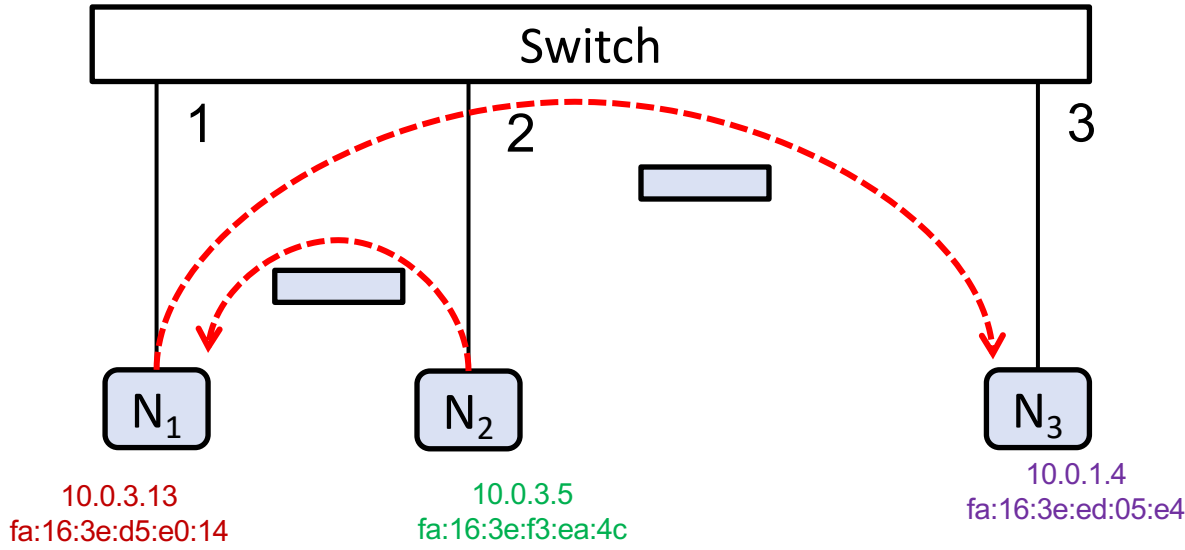
T3

Attack: N_1 wants to be MITM between 10.0.3.5 and 10.0.1.4

- After the tables are poisoned, all frames will be sent to N_1.
- N_1 can relay the frames, or modify the frames before relaying.
- Hence, N_1 become the MITM in layer 2.

T0

Switch's port	Mac-address
1	fa:16:3e:d5:e0:14
2	fa:16:3e:f3:ea:4c
3	fa:16:3e:ed:05:e4



T2

Ip-address	Mac-address
10.0.3.13	fa:16:3e:d5:e0:14
10.0.1.4	fa:16:3e:d5:e0:14

T3

Ip-address	Mac-address
10.0.3.13	fa:16:3e:d5:e0:14
10.0.3.5	fa:16:3e:d5:e0:14

5.3 Denial of Service Attack

to mitigate is just to increase the size

-like in cloud services is elastic, can expand size to handle incoming services as and when

-or to see incoming packets and determine how to handle them based on determining their purpose, can drop or put on low priority

can use to disrupt a DNS service

DOS is an attack on availability.

Availability: The property of being accessible and usable upon demand by an authorized entity.

Denial of service (DOS): The prevention of authorized access to resources or the delaying of time-critical operations.

just to disrupt

Many successful DOS attacks simply flood the victims with overwhelming requests/data.

Example of DOS attack

- Simply flood a web-server with http requests.

E.g. MyDoom worm which targeted SCO's website. Attacks starts on Feb 12, 2004.

- Sending large number of DNS requests to the DNS server.

For DOS to be effective, large number of attackers are required. (a single attacker can send requests only at a low rate).

When DOS is carried out by a large number of attackers, this is called ***DDOS: Distributed Denial of Service.***

Reflection and Amplification attack

- Reflection attack is a type of DOS in which the attackers send requests to intermediate nodes, which in turn send overwhelming traffic to the victim.

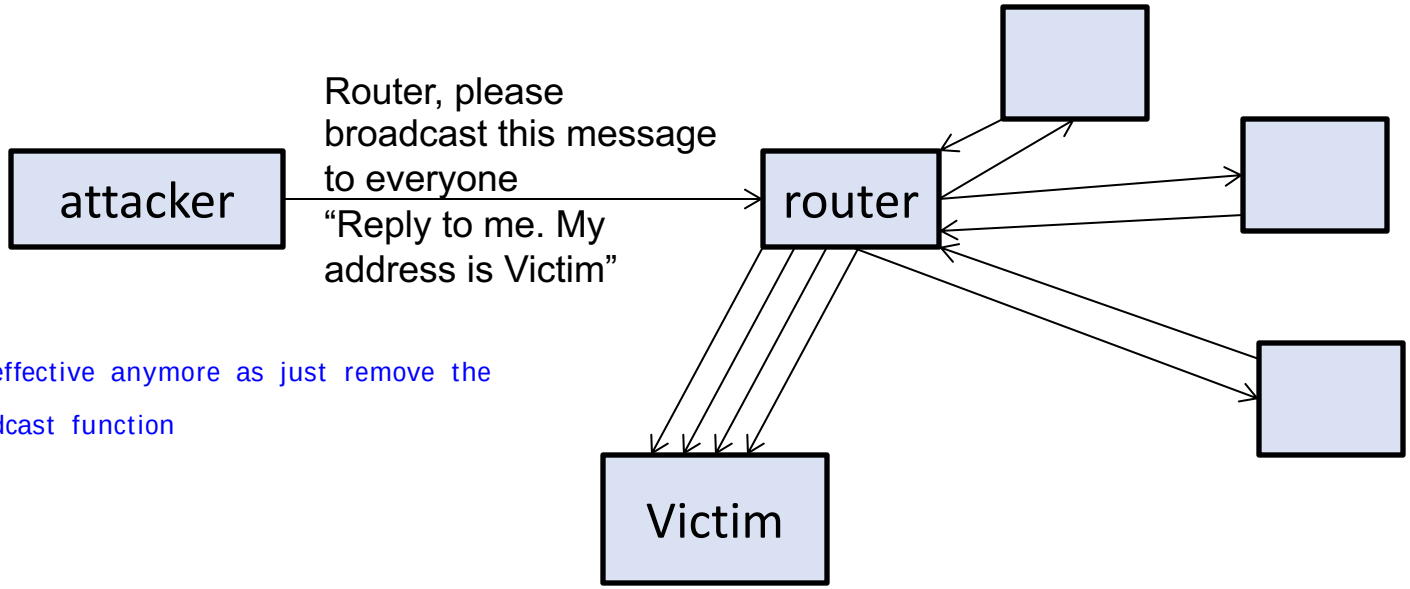
- Indirect, and thus more difficult to trace.

- Very often, the reflected traffic could be amplified (a single request could trigger multiple responses from the intermediate nodes). Hence, these are also known as *Amplification attacks*.

Eg of Reflection attacks: ICMP/Smurf flood [PF] page 404

- Step 1. An attacker sends the request "ICMP PING" to a router, instructing the router to broadcast this request. The source ip-address of this request is spoofed with the victim ip address.
- Step 2. The router broadcasts this request.
- Step 3. Each entity who has received this request, replies to it by sending an "echo reply" to the source, which is the victim.

The victim's network is overwhelmed with the "echo reply".



not effective anymore as just remove the broadcast function

Smurf flood preventive measure.

- This attack is no longer effective. Most router are now configured not to broadcast.
- To prevent attack, this measure simply disabled a feature that previously thought to be useful.

See IP broadcasting, http://en.wikipedia.org/wiki/Broadcast_address

Other examples of Reflection attack

could be an amplification attack also, where the request is short and the reply is super long (which is chosen)

- DNS reflection attack.

"During a DNS amplification attack, the perpetrator sends out a DNS query with a forged IP address (the victim's) to an open DNS resolver, prompting it to reply back to that address with a DNS response. With numerous fake queries being sent out, and with several DNS resolvers replying back simultaneously, the victim's network can easily be overwhelmed by the sheer number of DNS responses."

https://security.stackexchange.com/questions/93820/dns-reflection-attack-vs-dns-amplification-attack

What was the largest DDOS attacks (as of Nov 2018)?

Targeted at Github using Memcache on 5 March 2018. Generated data at a rate of 1.7 Terabits per second.

UDP-based Amplification Attacks

Protocol	Bandwidth Amplification Factor
Memcache	50000
NTP	556.9
CharGen	358.8
DNS	up to 179 [50]
QOTD	140.3
Quake Network Protocol	63.9
BitTorrent	4.0 - 54.3 [51]
SSDP	30.8
Kad	16.3
SNMPv2	6.3
Steam Protocol	5.5
NetBIOS	3.8

https://en.wikipedia.org/wiki/Denial-of-service_attack

Botnet

- A ***bot*** (aka *zombie*) is a compromised machine.
- A ***botnet*** (aka *zombie army*) is a large collection of connected bots, communicating via covert channels.
- A botnet has a command-and-control mechanism, and thus can be control by an individual to carry out DDOS.
- Possible usages of a botnet:
  - DDoS flooding, vulnerability scanning, anonymizing HTTP proxy, email address harvesting, cipher breaking!

Question: Why covert channels are used by a botnet?

this is to prevent the owner of the bot from finding out that it is being used.

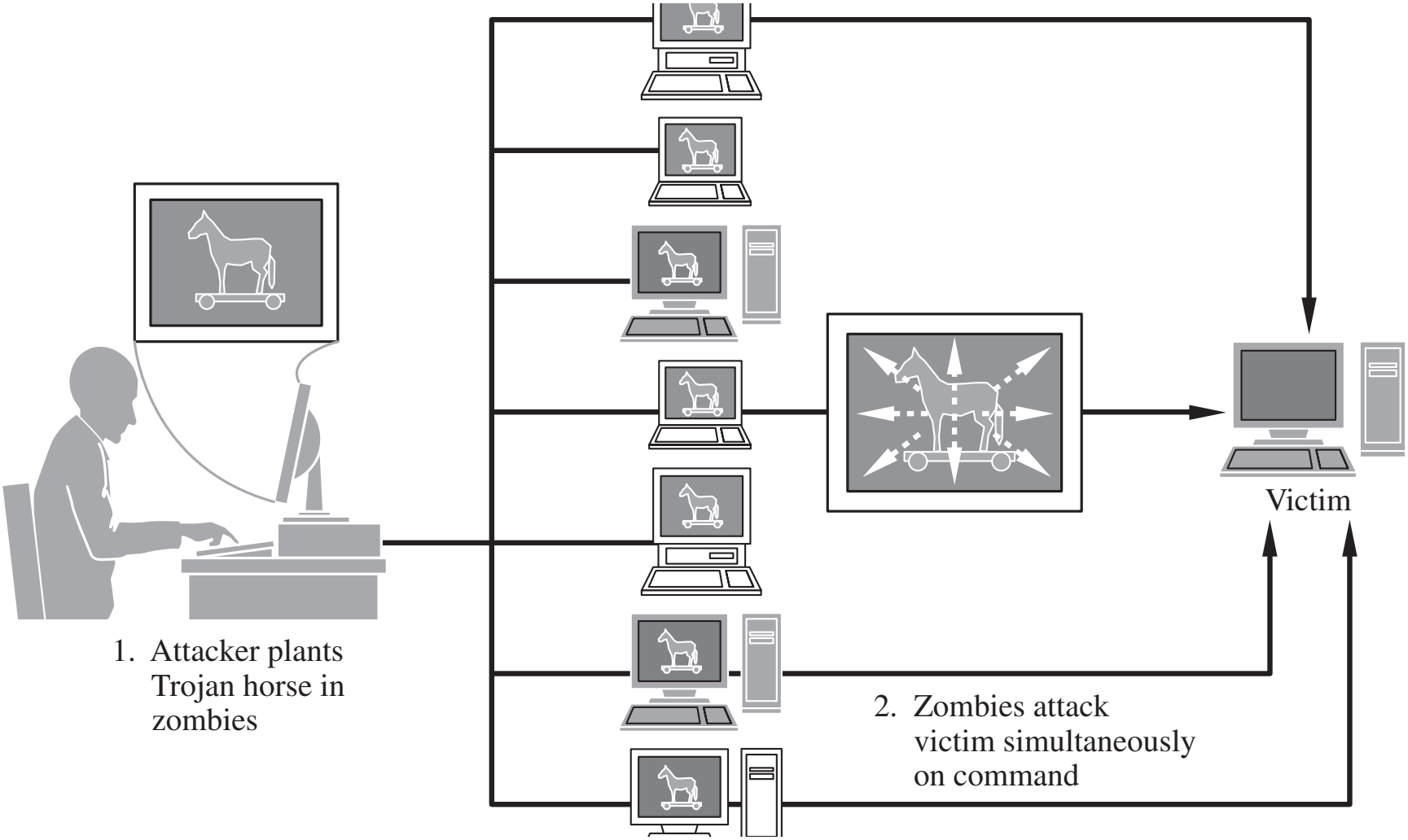
and also to make it harder to track

Botnet

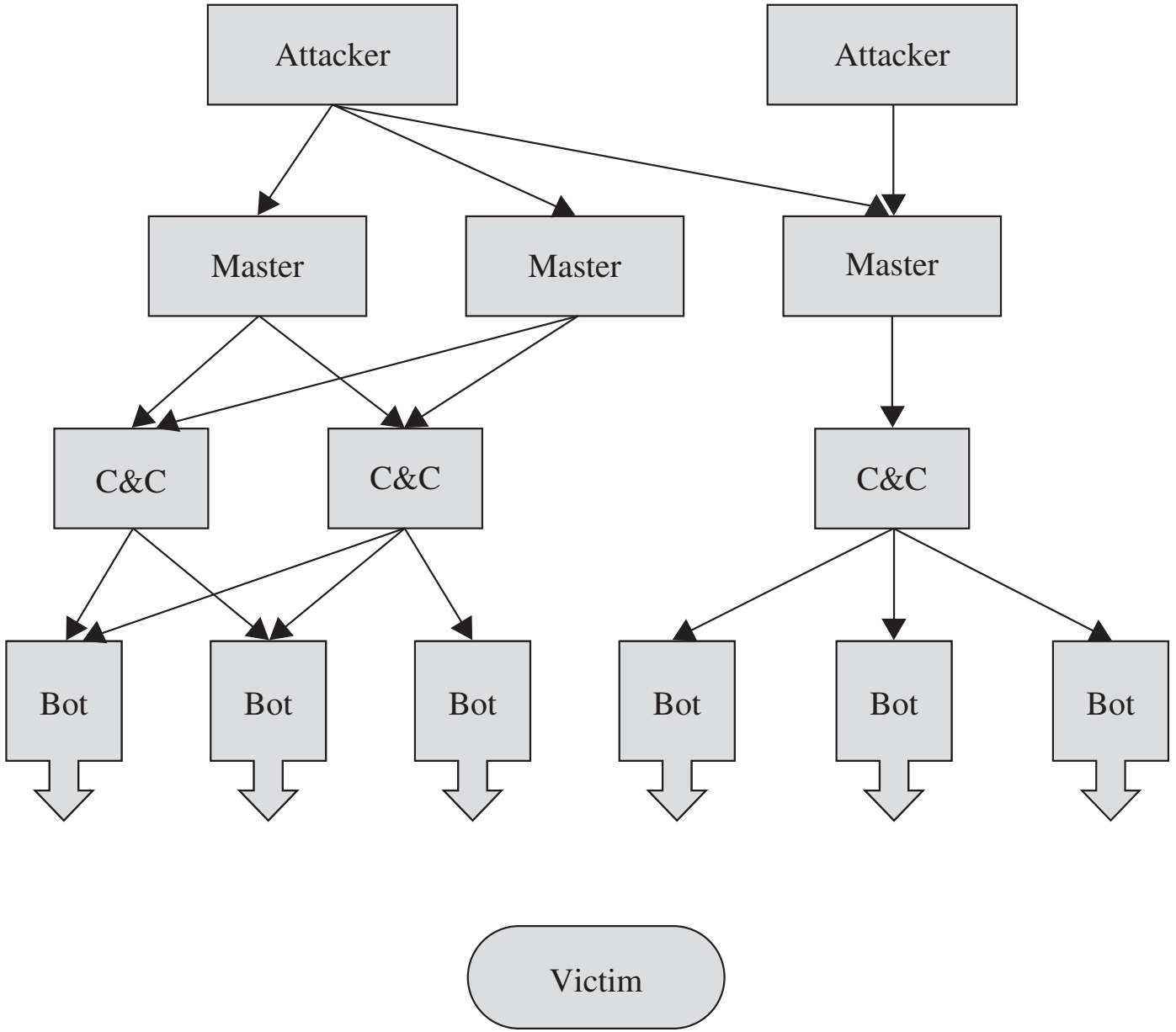
- Size of known botnets. http://en.wikipedia.org/wiki/Botnet

Date created	Date dismantled	Name	Estimated no. of bots	Spam capacity (bn/day)	Aliases
2009 (May)	November 2010 (not complete)	BredoLab	30,000,000[51]	3.6	Oficla
2008 (around)	2009-Dec	Mariposa	12,000,000[46]		
2008 (November)		Conficker	10,500,000+[47]	10	DownUp, DownAndUp, DownAdUp, Kido
		Marina Botnet	6,215,000[37]	92	Damon Briant, BOB.dc, Cotmonger, Hacktool.Spammer, Kraken
2010 (around)		TDL4	4,500,000[56]		TDSS, Alureon
		Zeus	3,600,000 (US only)[57]		Zbot, PRG, Wsnpoem, Gorhax, Kneber
2011 or earlier	2015-02	Ramnit	3,000,000[58]		
2007 (around)		Cutwail	1,500,000[42]	74	Pandex, Mutant (related to: Wigon, Pushdo)

Distributed Denial of Service (DDoS) using botnet



Botnet



DDoS Attacks trend

- There is a new trend of using “non-PC”, such as IoT devices, as bots in launching DDOS. A well-known example is the Mirai attack.
- List of well-known DDOS:
  - ***4 March, 2018***. Victim Github. 1.7 tera bits per second (tbps). Memcached. Record breaking.
  - ***February 28, 2018***. Victim Github: 1.35 tbps. Memcached. Record breaking.
  - ***October, 2016***. Using Mirai to coordinate a botnet of IoT devices. A series of attacks. Victim Dyn (a DNS service providers), French web host OVH (~1 tpbs).
  - ***March 2015***, Victim Github. Believed to be ordinated from China. Javascript injection by “Great Firewall”.
  - ***2013***, Victim Spamhaus. 0.3 tpbs. Record breaking. See https://blog.cloudflare.com/the-ddos-that-almost-broke-the-internet/
  - ***27 April, 2007***, Victim Estonia’s government services. Believe to be politically motivated (state sponsored attack?)
  - ***January, 2004.*** Mydoom. Infected machines sent https request to the victim, SCO’s websites `www.sco.com`. Spread infection by email. Estimated to generate 1 in every 5 emails at its peak.

5.4 Useful tools

Wireshark (packets analyzer)

usually capture at the connection of the network card

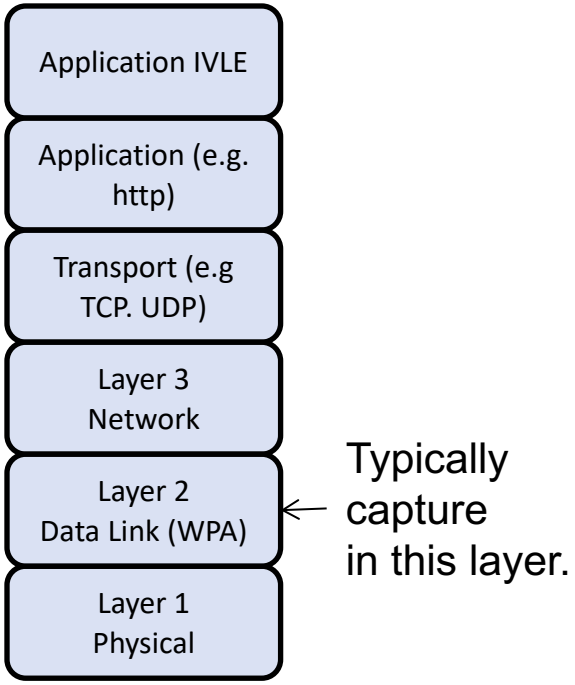
Wireshark: a free open-sourced packets analyzer.

https://www.wireshark.org/

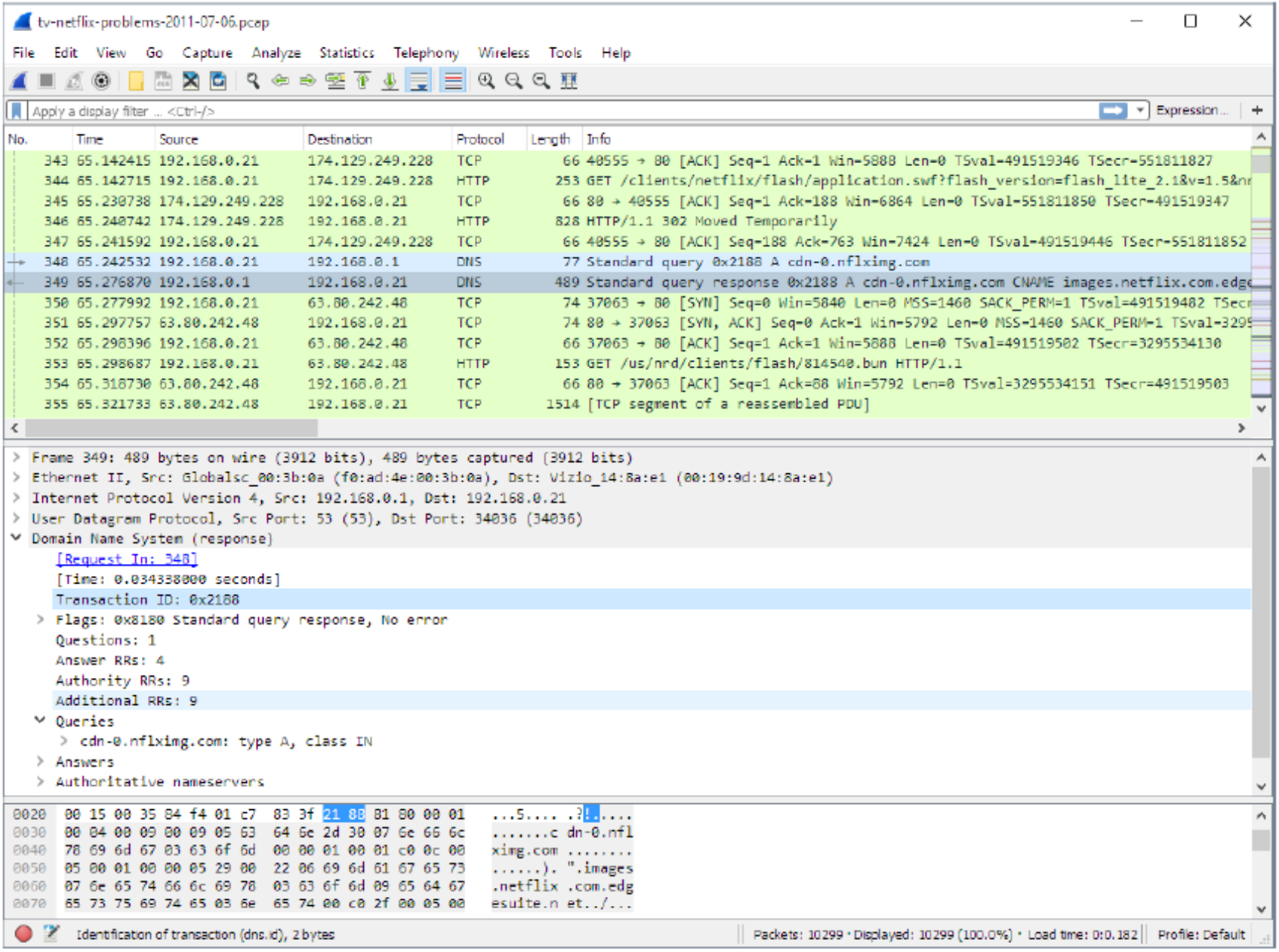
Exactly what does wireshark capture?

- Wireshark listens to "interactions" between the OS and the network card driver. (In other words, it is a MITM between OS and network card).
- Hence, header added by the network card, or modification made by the network card, may not be captured by Wireshark. This depends on the OS and the hardware.
- see the following FAQ for more info.

https://ask.wireshark.org/questions/22956/where-exactly-wireshark-does-captures-packets

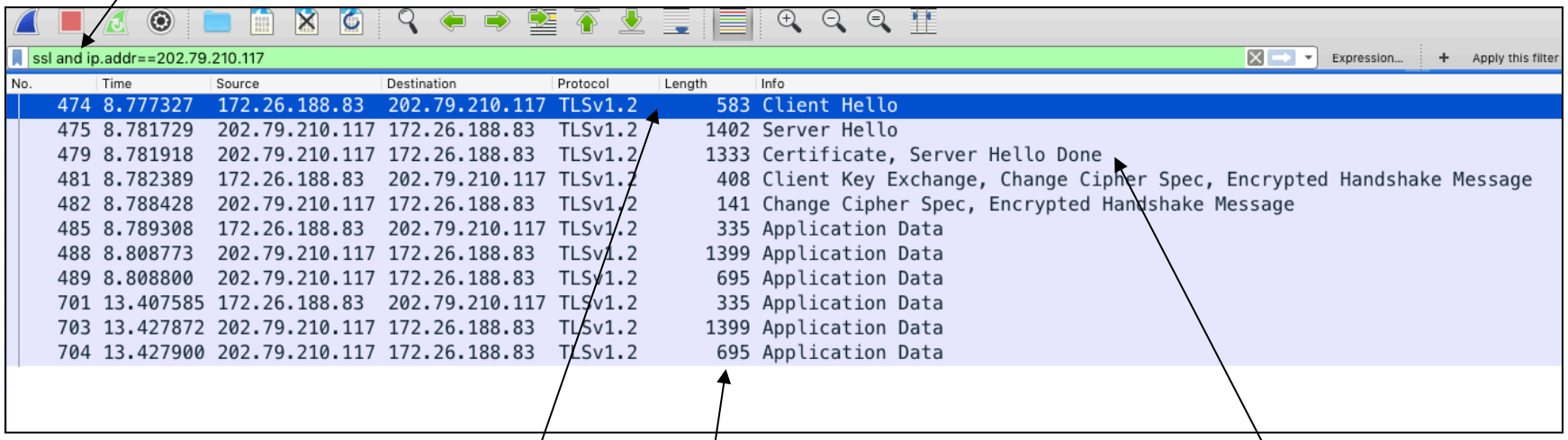


(demo: Wireshark)

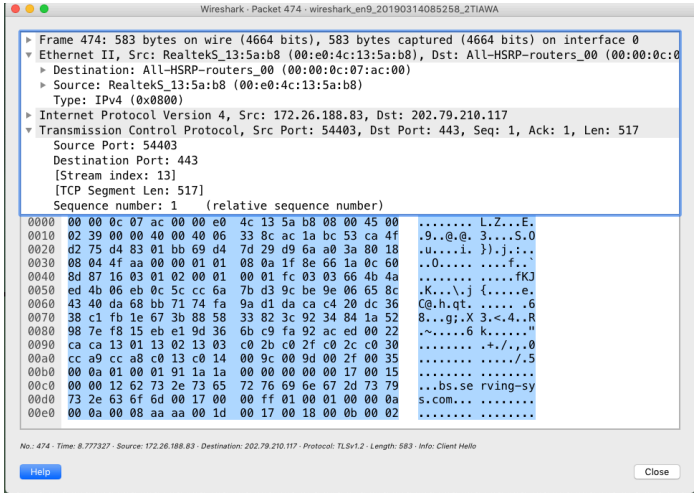

tv-netflix-problems-2011-07-06.pcap
File Edit View Go Capture Analyze Statistics Telephony Wireless Tools Help
Apply a display filter ... <Ctrl-/>
Expression...
No. Time Source Destination Protocol Length Info
343 65.142415 192.168.0.21 174.129.249.228 TCP 66 40555 → 80 [ACK] Seq=1 Ack=1 Win=5888 Len=0 TSval=491519346 TSecr=551811827
344 65.142715 192.168.0.21 174.129.249.228 HTTP 253 GET /clients/netflix/flash/application.swf?flash_version=flash_lite_2.1&v=1.5&nr
345 65.230738 174.129.249.228 192.168.0.21 TCP 66 80 → 40555 [ACK] Seq=1 Ack=188 Win=6864 Len=0 TSval=551811850 TSecr=491519347
346 65.240742 174.129.249.228 192.168.0.21 HTTP 828 HTTP/1.1 302 Moved Temporarily
347 65.241592 192.168.0.21 174.129.249.228 TCP 66 40555 → 80 [ACK] Seq=188 Ack=763 Win=7424 Len=0 TSval=491519446 TSecr=551811852
348 65.242532 192.168.0.21 192.168.0.1 DNS 77 Standard query 0x2188 A cdn-0.nflximg.com
349 65.276870 192.168.0.1 192.168.0.21 DNS 489 Standard query response 0x2188 A cdn-0.nflximg.com CNAME images.netflix.com.edge
350 65.277992 192.168.0.21 63.80.242.48 TCP 74 37063 → 80 [SYN] Seq=0 Win=5840 Len=0 MSS=1460 SACK_PERM=1 TSval=491519482 TSecr
351 65.297757 63.80.242.48 192.168.0.21 TCP 74 80 → 37063 [SYN, ACK] Seq=0 Ack=1 Win=5792 Len=0 MSS=1460 SACK_PERM=1 TSval=3295
352 65.298396 192.168.0.21 63.80.242.48 TCP 66 37063 → 80 [ACK] Seq=1 Ack=1 Win=5888 Len=0 TSval=491519502 TSecr=3295534130
353 65.298687 192.168.0.21 63.80.242.48 HTTP 153 GET /us/nrd/clients/flash/814540.bun HTTP/1.1
354 65.318730 63.80.242.48 192.168.0.21 TCP 66 80 → 37063 [ACK] Seq=1 Ack=88 Win=5792 Len=0 TSval=3295534151 TSecr=491519503
355 65.321733 63.80.242.48 192.168.0.21 TCP 1514 [TCP segment of a reassembled PDU]
Frame 349: 489 bytes on wire (3912 bits), 489 bytes captured (3912 bits)
Ethernet II, Src: Globalsc_00:3b:0a (f0:ad:4e:00:3b:0a), Dst: Vizio_14:8a:e1 (00:19:9d:14:8a:e1)
Internet Protocol Version 4, Src: 192.168.0.1, Dst: 192.168.0.21
User Datagram Protocol, Src Port: 53 (53), Dst Port: 34036 (34036)
Domain Name System (response)
[Request In: 348]
[Time: 0.034338000 seconds]
Transaction ID: 0x2188
Flags: 0x8180 Standard query response, No error
Questions: 1
Answer RRs: 4
Authority RRs: 9
Additional RRs: 9
Queries
cdn-0.nflximg.com: type A, class IN
Answers
Authoritative nameservers
0020 00 15 00 35 84 f4 01 c7 83 3f 21 88 81 80 00 01 ...5.... .?!.....
0030 00 04 00 09 00 09 05 63 64 6e 2d 30 07 6e 66 6c ....c dn-0.nfl
0040 78 69 6d 67 03 63 6f 6d 00 00 01 00 01 c0 0c 00 ximg.com ....
0050 05 00 01 00 00 05 29 00 22 06 69 6d 61 67 65 73 ......). ".images
0060 07 6e 65 74 66 6c 69 78 03 63 6f 6d 09 65 64 67 .netflix .com.edg
0070 65 73 75 69 74 65 03 6e 65 74 00 c0 2f 00 05 00 esuite.n et../...
Identification of transaction (dns.id), 2 bytes
Packets: 10299 · Displayed: 10299 (100.0%) · Load time: 0:0.182
Profile: Default

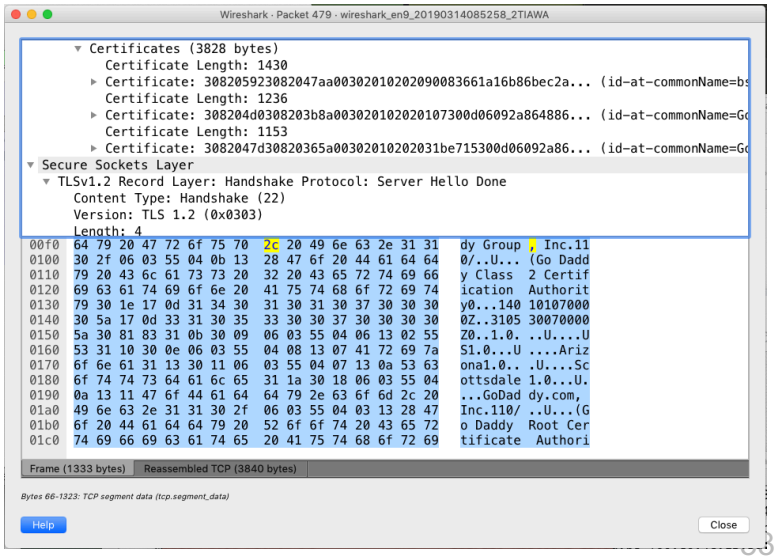
E.g. on SSL/TLS

Display filter. Note: there are two types of filter in wireshark: display and capture filter. (don't get confused).



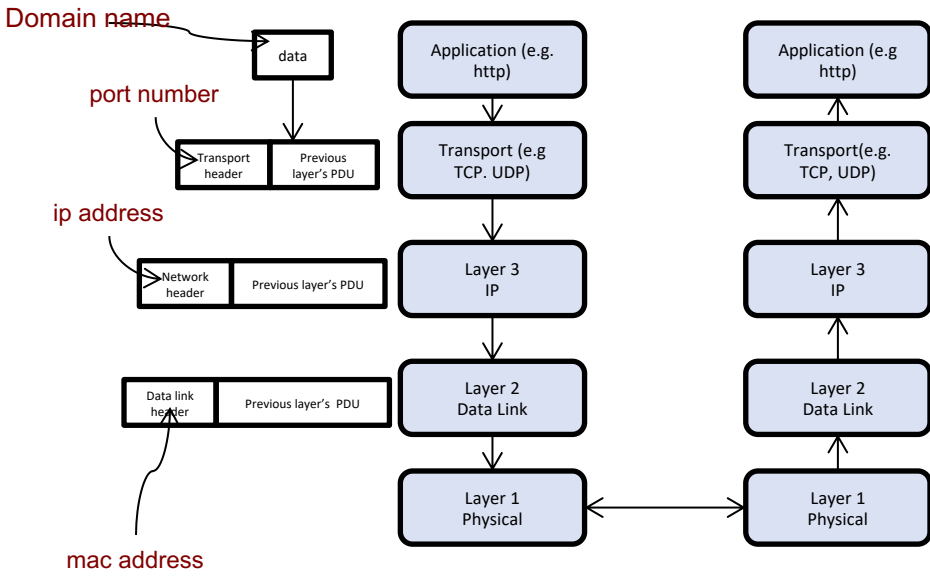
Encrypted data





Useful Tools: Nmap (port scanning)

- Why port scanning?
- There are multiple processes in running in a server. When the server receives a packet, base on the port number, it will decide which process handle that packet. So, by saying that a process/service is "***listening***" to a particular ***port***, we mean that the process is running and ready to handle arriving packets with that particular port number.
- When a port is "***open***", there exist such a process running in the server. When a port is "***closed***", no process is listening to that port.
- If a port is ***"closed",*** attacker is unable to feed malicious data to that port.
- see https://en.wikipedia.org/wiki/List_of_TCP_and_UDP_port_numbers#Well-known_ports for well-known port number.



69	Assigned	Yes	Official	Trivial File Transfer Protocol (TFTP)[10][37][38][39]
70	Yes	Assigned	Official	Gopher protocol[40]
71–74	Yes	Yes	Official	NETRJS protocol[41][42][43]
79	Yes	Assigned	Official	Finger protocol[10][44][45]
80	Yes, and SCTP[11]	Assigned	Official	Hypertext Transfer Protocol (HTTP)[10][46][47][48]
	No	Yes	Unofficial	Quick UDP Internet Connections (QUIC), a transport protocol over UDP (still in draft as of July 2018), using stream multiplexing, encryption by default with TLS, and currently supporting HTTP/2.[49]
81	Yes		Unofficial	TorPark onion routing[*verification needed*]
82		Yes	Unofficial	TorPark control[*verification needed*]
88	Yes	Assigned	Official	Kerberos[10][50][51] authentication system
90	Yes	Yes	Unofficial	PointCast (dotcom)[1][*third-party source needed*]
101	Yes	Assigned	Official	NIC host name[52]
102	Yes	Assigned	Official	ISO Transport Service Access Point (TSAP) Class 0 protocol;[53][54]
104	Yes	Yes	Official	Digital Imaging and Communications in Medicine (DICOM; also port 11112)
105	Yes	Yes	Official	CCSO Nameserver[55]
107	Yes	Yes	Official	Remote User Telnet Service (RTelnet)[56]
108	Yes	Yes	Official	IBM Systems Network Architecture (SNA) gateway access server
109	Yes	Assigned	Official	Post Office Protocol, version 2 (POP2)[57]
110	Yes	Assigned	Official	Post Office Protocol, version 3 (POP3)[10][58][59]
111	Yes	Yes	Official	Open Network Computing Remote Procedure Call (**ONC RPC**, sometimes referred to as **Sun RPC**)

- Port scanning: The process of determining which ports are open in a network.

- Port scanner: A tool for port scanning. E.g. Nmap.

- Port scanner is a useful tool for attacker, and network administrator to scan for vulnerabilities.

- Is port scanning illegal?

(Read if you want to use it) https://nmap.org/book/legal-issues.html

(demo: Nmap)

Nmap scan report on my desktop.

> nmap -v -p 1-65535 -sV -O -sS -T4 172.26.[redacted]

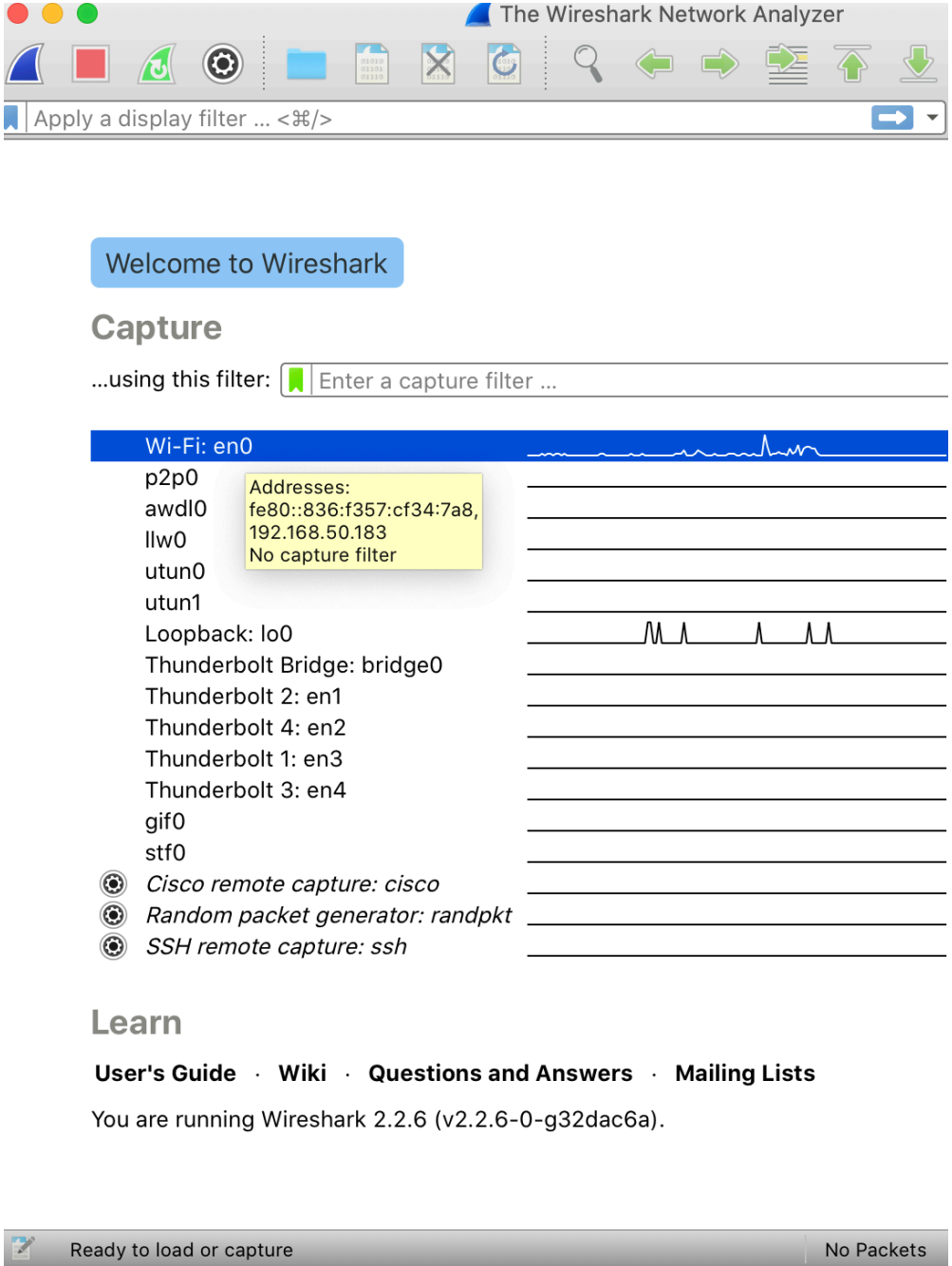
```
Starting Nmap 7.60 ( https://nmap.org ) at 2019-03-13 16:31 +08
NSE: Loaded 42 scripts for scanning.
Initiating ARP Ping Scan at 16:31
Scanning 172.26.[redacted] [1 port]
Completed ARP Ping Scan at 16:31, 0.01s elapsed (1 total hosts)
Initiating Parallel DNS resolution of 1 host. at 16:31
Completed Parallel DNS resolution of 1 host. at 16:31, 0.00s elapsed
Initiating SYN Stealth Scan at 16:31
Scanning [redacted] [65535 ports]
Discovered open port 139/tcp on 172.26[redacted]
Discovered open port 135/tcp on 172.26.[redacted]
Discovered open port 445/tcp on 172.26.[redacted]
Discovered open port 10600/tcp on 172.26.[redacted]
Discovered open port 49154/tcp on 172.26.[redacted]
SYN Stealth Scan Timing: About 22.53% done; ETC: 16:33 (0:01:47
remaining)
Discovered open port 17500/tcp on 172.26.[redacted]
Discovered open port 49155/tcp on 172.26.[redacted]
SYN Stealth Scan Timing: About 56.84% done; ETC: 16:32 (0:00:46
remaining)
Discovered open port 49153/tcp on 172.26.[redacted]
Discovered open port 2869/tcp on 172.26.[redacted]
Completed SYN Stealth Scan at 16:32, 91.72s elapsed (65535 total
ports)
Initiating Service scan at 16:32
Scanning 9 services on changec-d9010.d2.comp.nus.edu.sg
(172.26.188.231)
Completed Service scan at 16:33, 58.54s elapsed (9 services on 1
host)
Initiating OS detection (try #1) against changec-[redacted]
NSE: Script scanning 172.26[redacted].
Initiating NSE at 16:33
Completed NSE at 16:33, 7.09s elapsed
Initiating NSE at 16:33
Completed NSE at 16:33, 0.02s elapsed
Nmap scan report for [redacted]
(172.26.[redacted])
Host is up (0.00064s latency).
```

```
Not shown: 65526 filtered ports
PORT      STATE SERVICE       VERSION
135/tcp   open  msrpc         Microsoft Windows RPC
139/tcp   open  netbios-ssn   Microsoft Windows netbios-ssn
445/tcp   open  microsoft-ds?
2869/tcp  open  http          Microsoft HTTPAPI httpd 2.0 (SSDP/UPnP)
10600/tcp open  ssl/http      Microsoft HTTPAPI httpd 2.0 (SSDP/UPnP)
17500/tcp open  ssl/db-lsp?
49153/tcp open  msrpc         Microsoft Windows RPC
49154/tcp open  msrpc         Microsoft Windows RPC
49155/tcp open  msrpc         Microsoft Windows RPC
MAC Address: B8:CA:3A:B5:0B:E0 (Dell)
Warning: OSScan results may be unreliable because we could not find at least 1
open and 1 closed port
Device type: general purpose|phone
Running: Microsoft Windows 2008|8.1|7|Phone|Vista
OS CPE: cpe:/o:microsoft:windows_server_2008:r2 cpe:/o:microsoft:windows_8.1
cpe:/o:microsoft:windows_7::-:professional cpe:/o:microsoft:windows_8
cpe:/o:microsoft:windows cpe:/o:microsoft:windows_vista::-
cpe:/o:microsoft:windows_vista::sp1
OS details: Microsoft Windows Server 2008 R2 or Windows 8.1, Microsoft Windows 7
Professional or Windows 8, Microsoft Windows Phone 7.5 or 8.0, Microsoft Windows
Vista SP0 or SP1, Windows Server 2008 SP1, or Windows 7, Microsoft Windows Vista
SP2, Windows 7 SP1, or Windows Server 2008
Uptime guess: 5.115 days (since Fri Mar  8 13:47:55 2019)
Network Distance: 1 hop
TCP Sequence Prediction: Difficulty=257 (Good luck!)
IP ID Sequence Generation: Incremental
Service Info: OS: Windows; CPE: cpe:/o:microsoft:windows


Read data files from: /opt/local/bin/../share/nmap
OS and Service detection performed. Please report any incorrect results at
https://nmap.org/submit/ .
Nmap done: 1 IP address (1 host up) scanned in 159.90 seconds
           Raw packets sent: 131169 (5.773MB) | Rcvd: 89 (4.238KB)
```

Wireshark Demo

(1) Choose the “network interface”



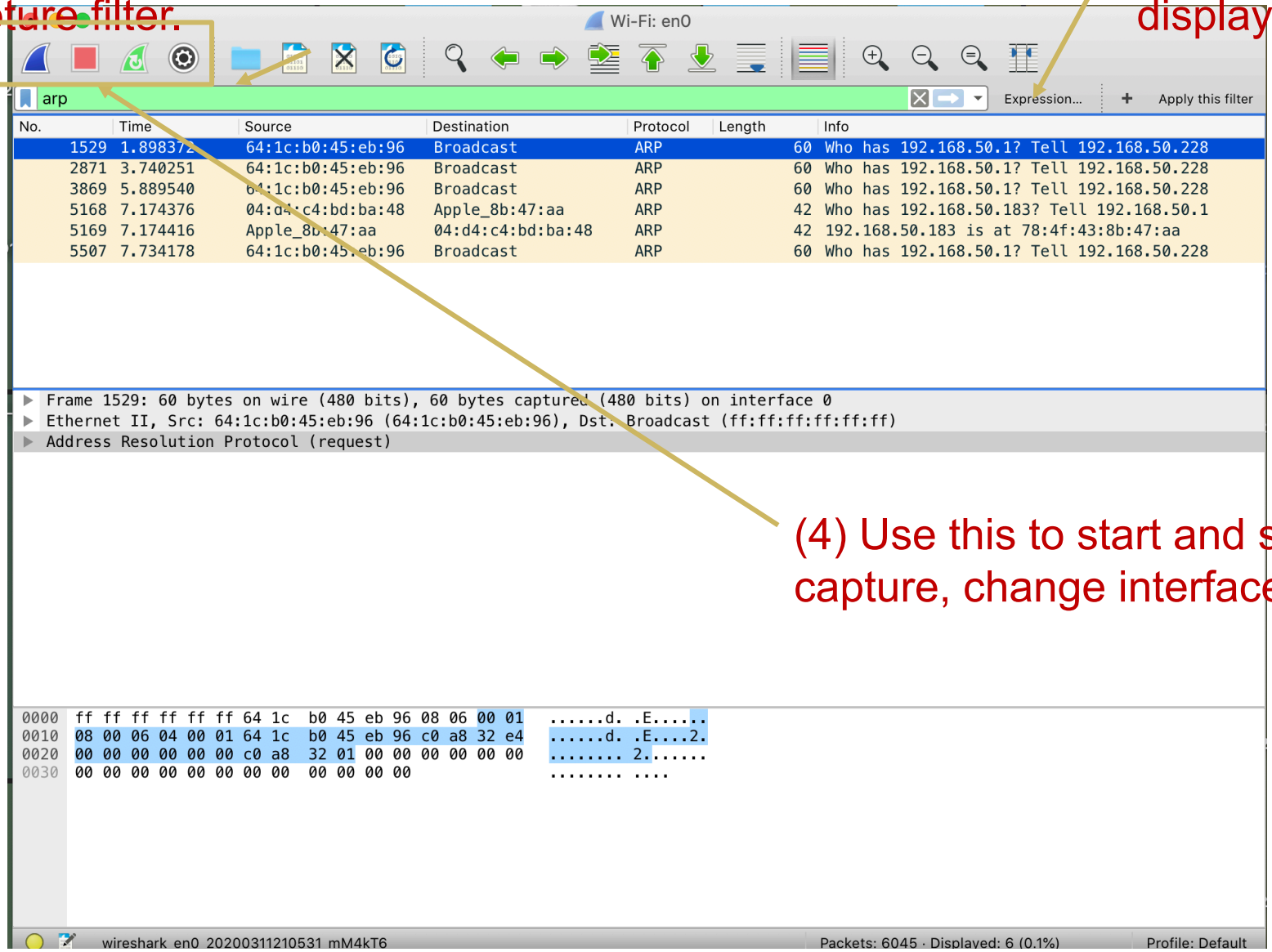
(2) Set a capture filter if required.
e.g simply leave it empty or “tcp”

This interface ip-address
Is 192.168.50.183.

Its mac address
(not shown in this screenshot)
Is 78:4f:43:8b:47:aa

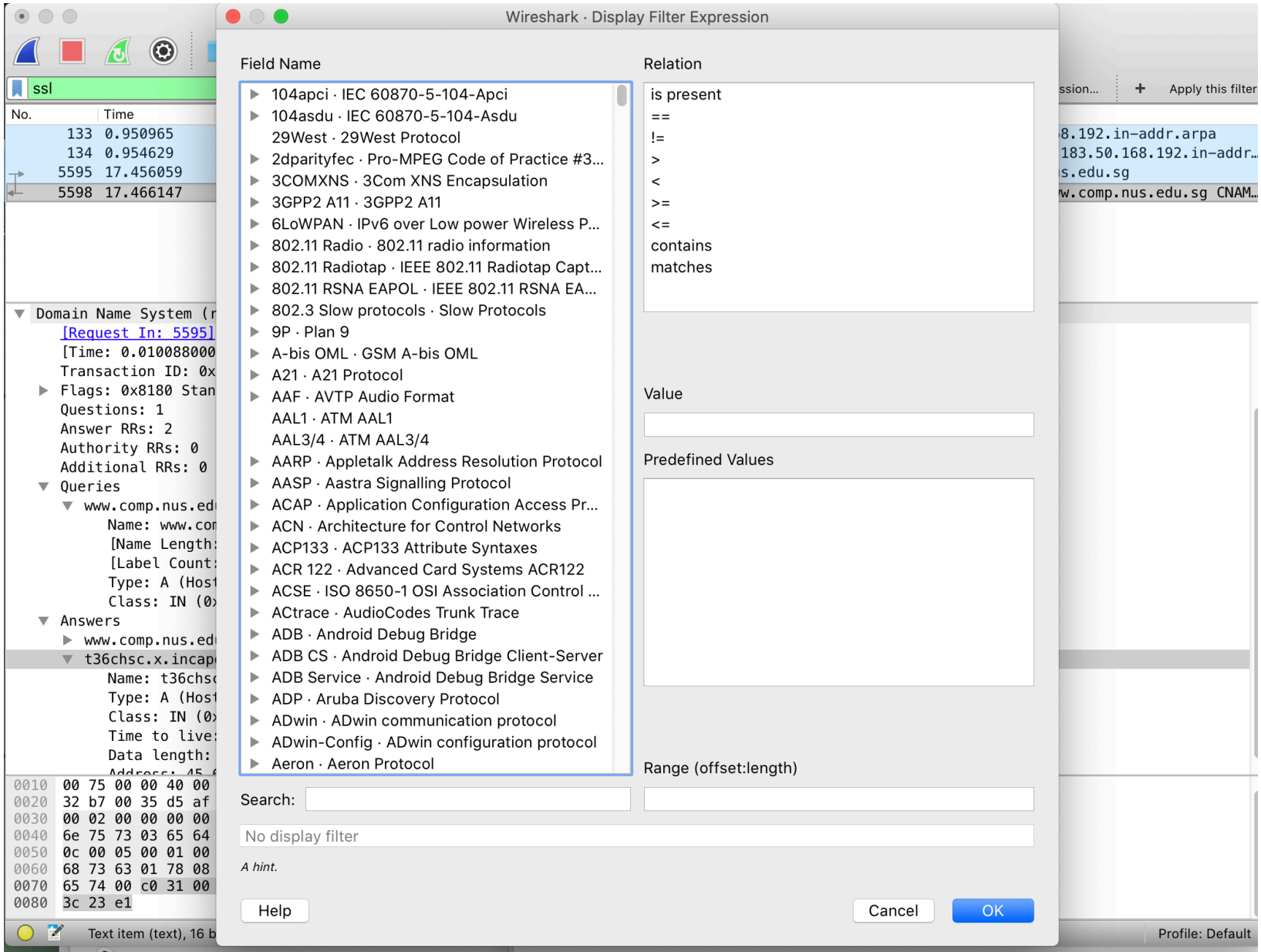
(3) Too many info. Use the display filter to select what to see. Note the difference between display and capture filter.

(4) Click here to see various options for display filter.

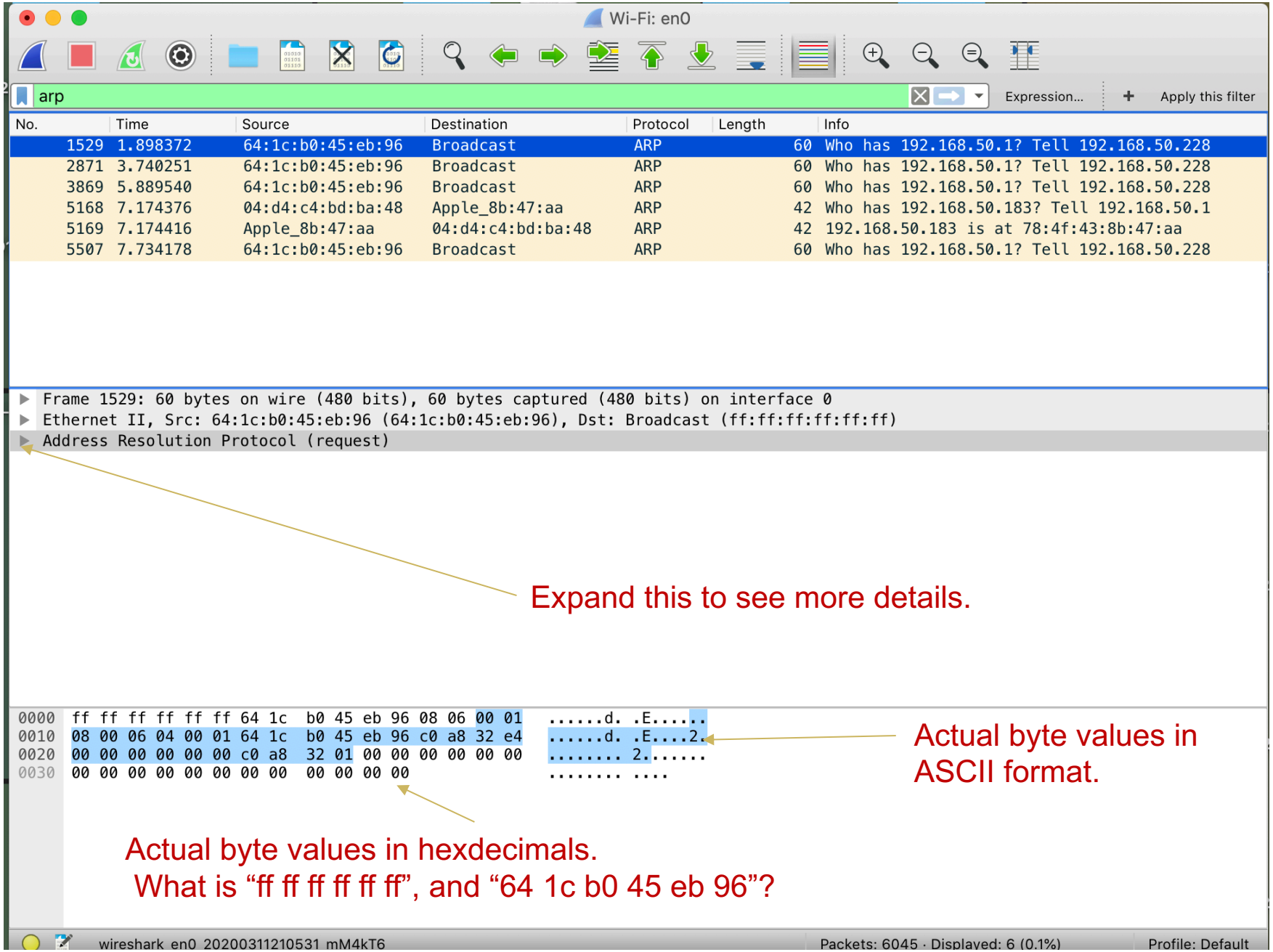


(4) Use this to start and stop capture, change interface.

Display filter.



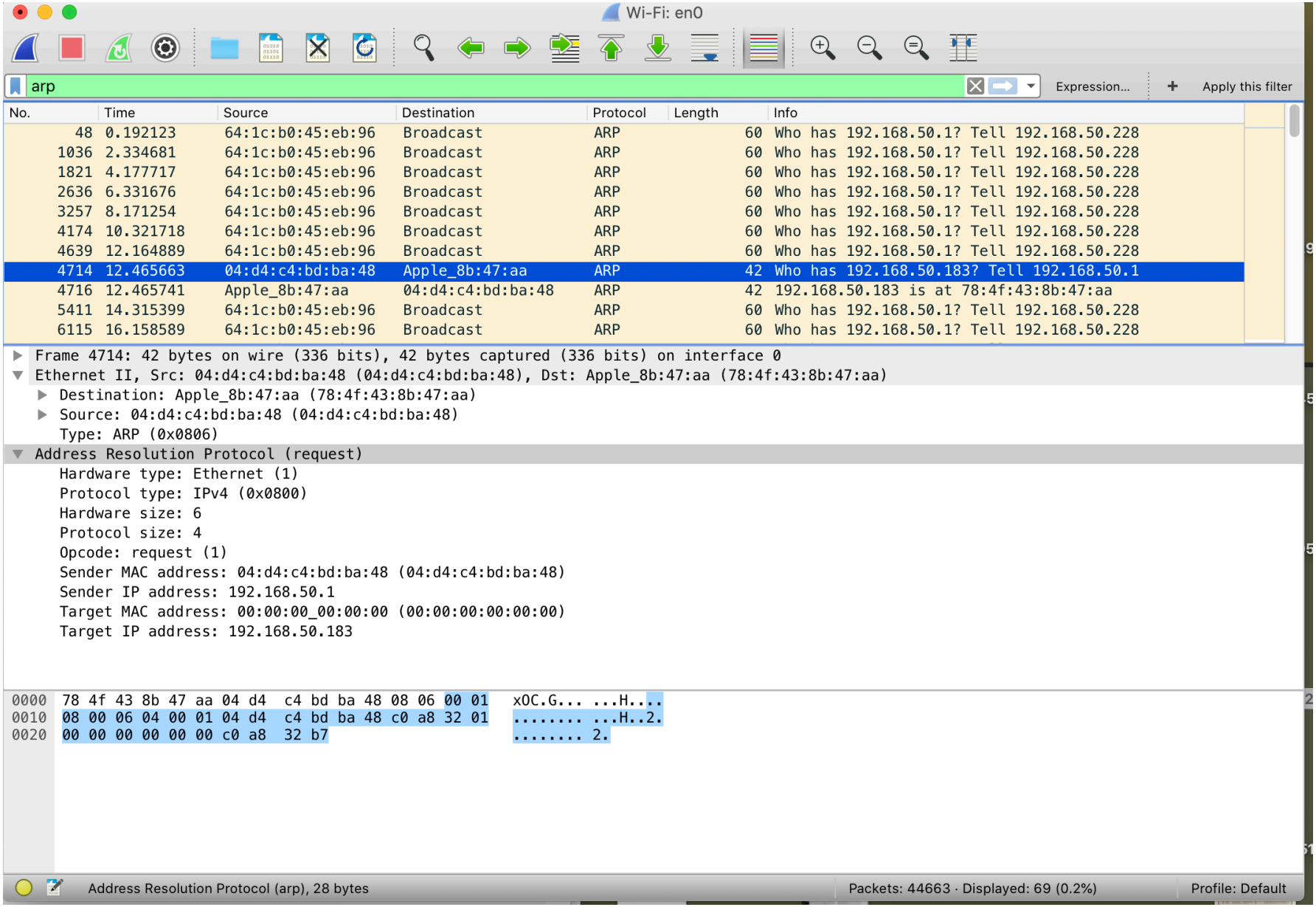
ARP: recall the query-answer in arp. What is the frame number 5168 and 5169?

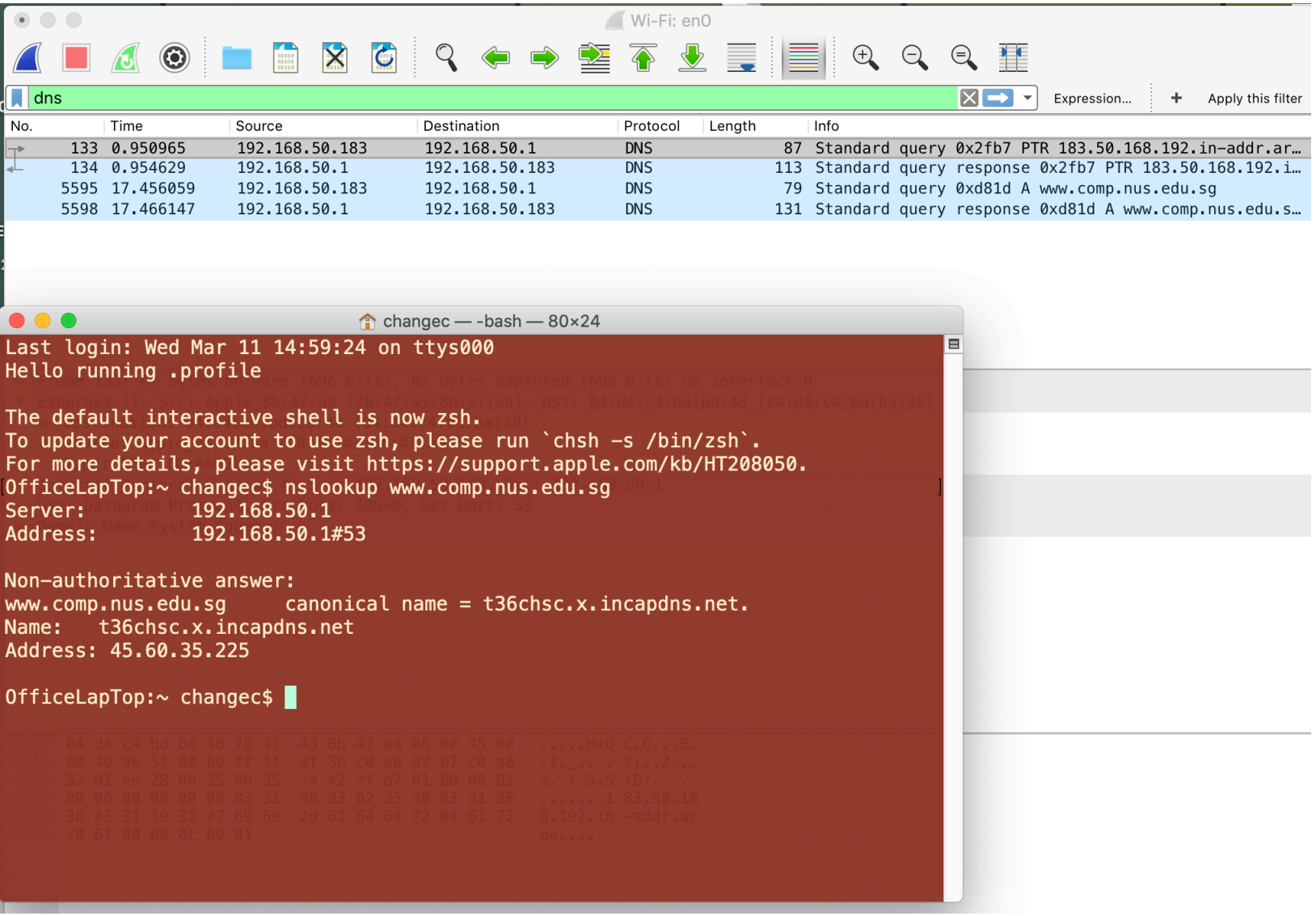


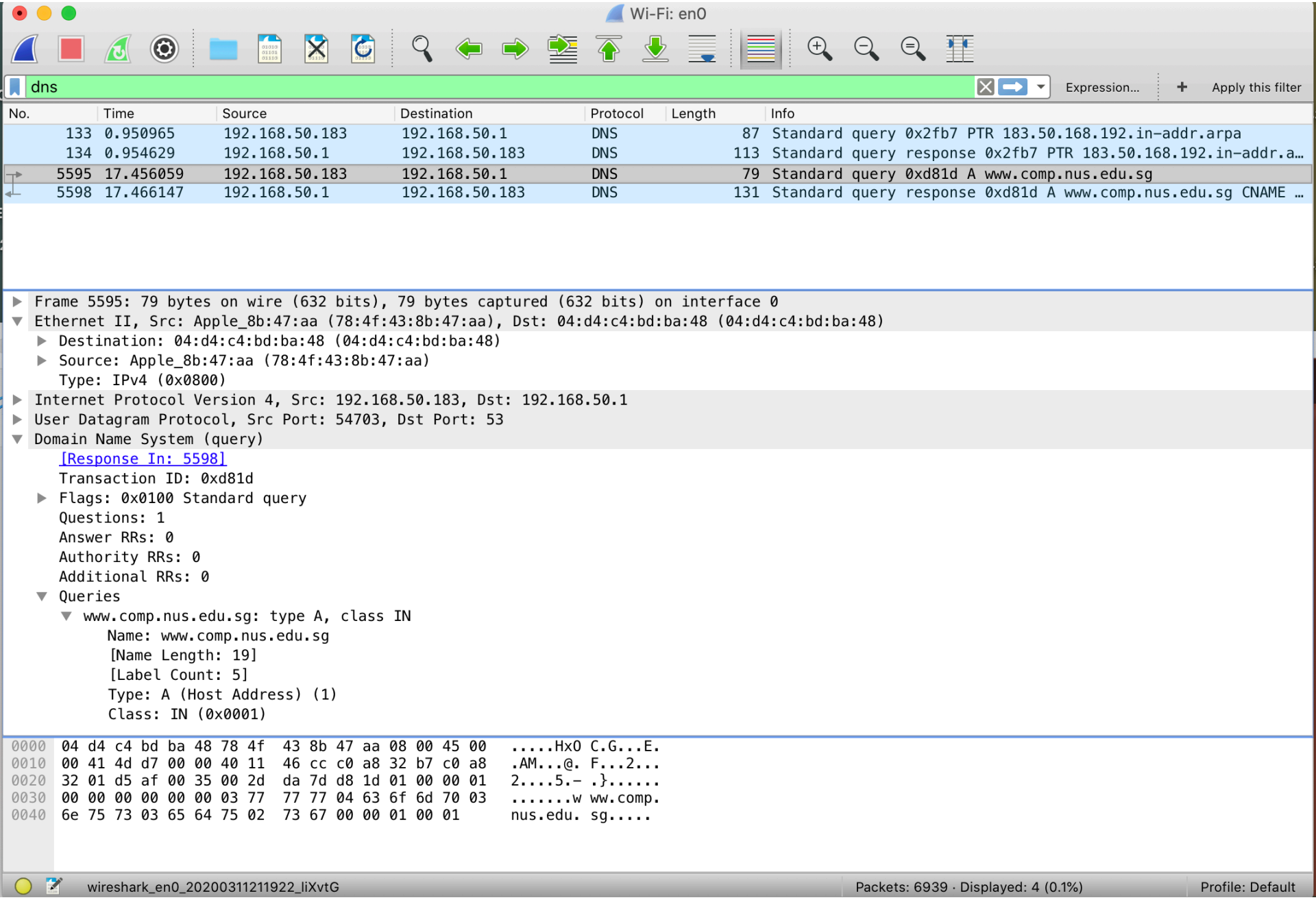
Expand this to see more details.

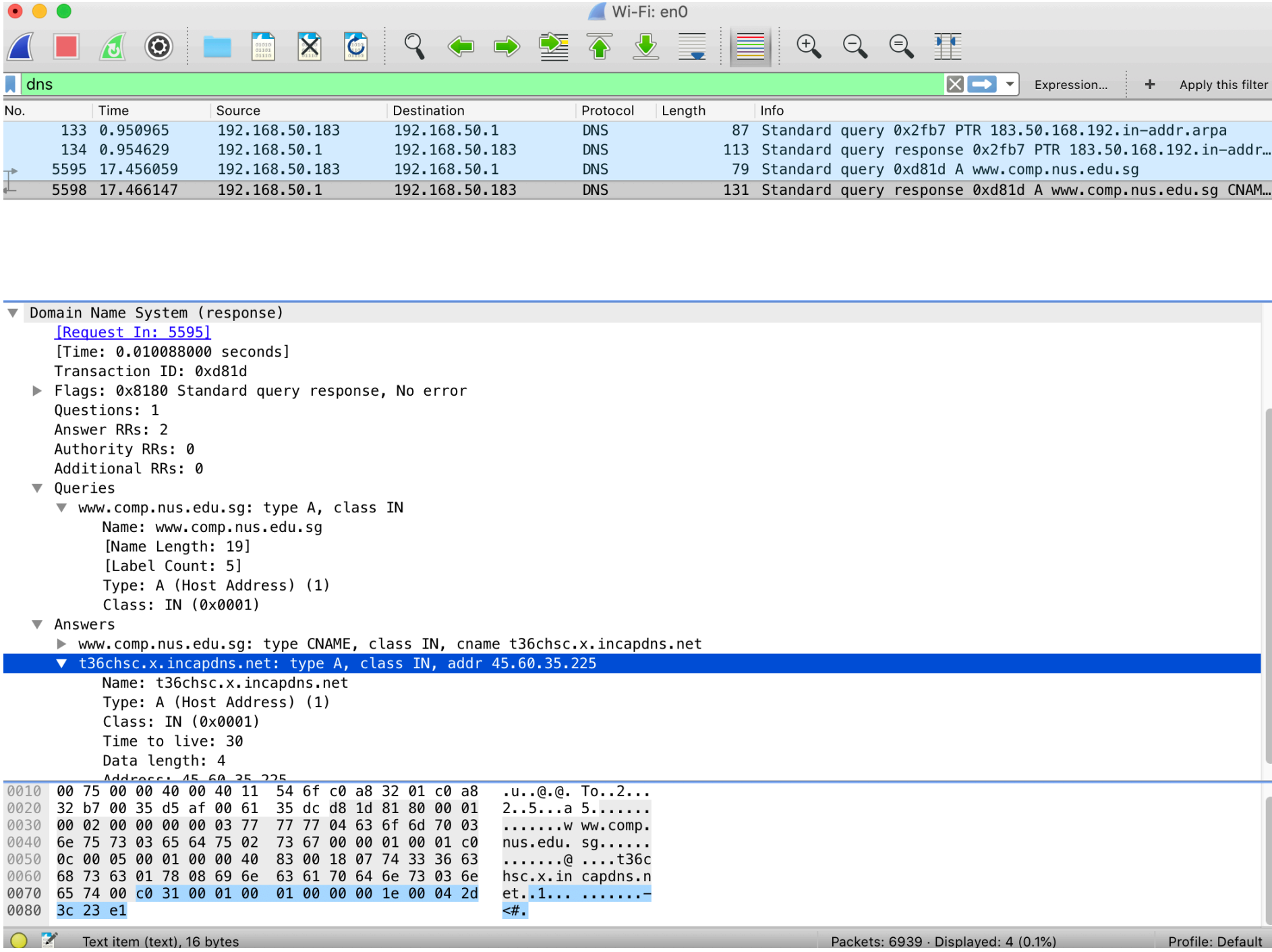
Actual byte values in ASCII format.

Actual byte values in hexdecimals.
What is “ff ff ff ff ff ff”, and “64 1c b0 45 eb 96”?

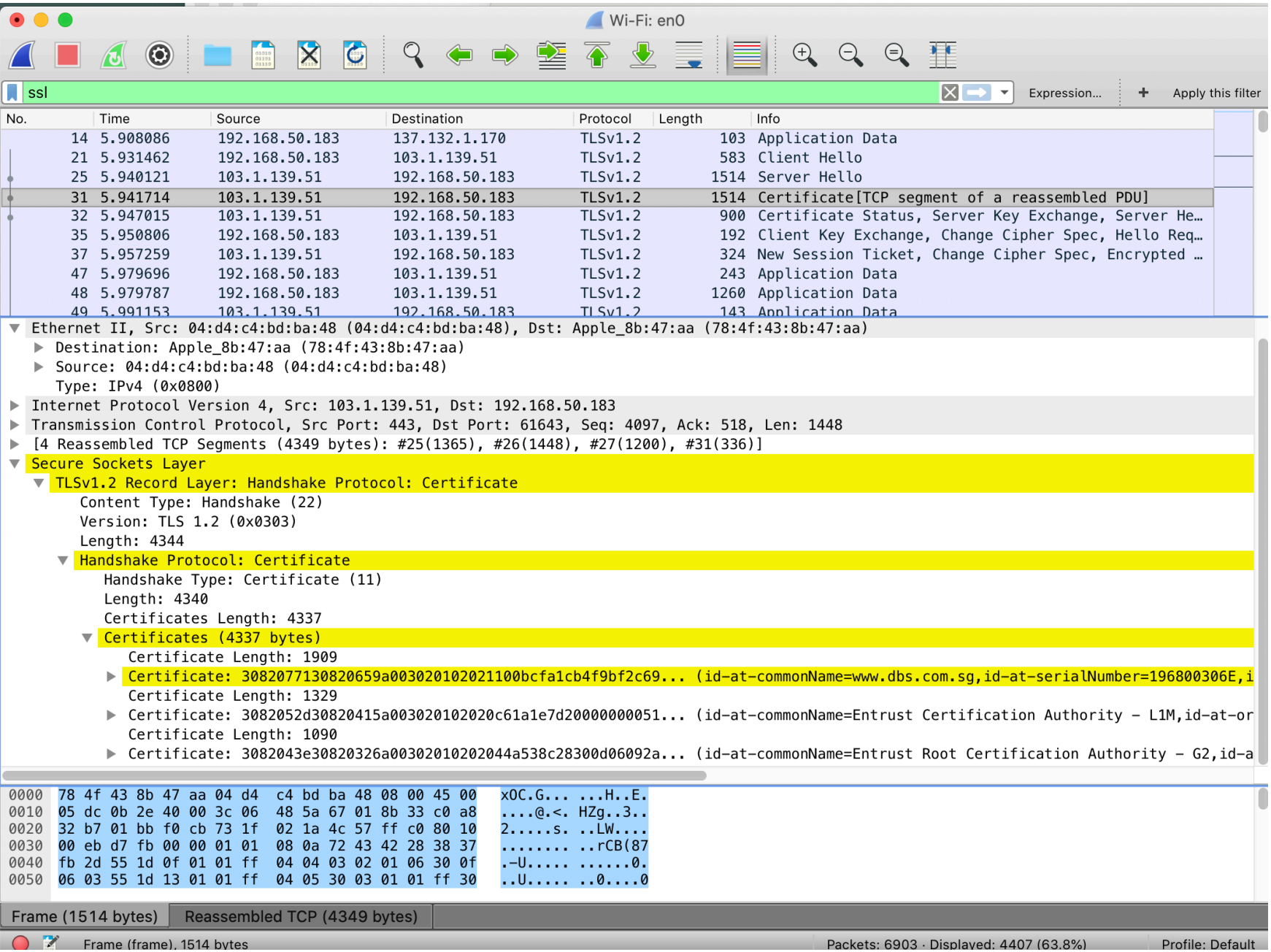

Wi-Fi: en0
arp
Expression...
Apply this filter
No. Time Source Destination Protocol Length Info
48 0.192123 64:1c:b0:45:eb:96 Broadcast ARP 60 Who has 192.168.50.1? Tell 192.168.50.228
1036 2.334681 64:1c:b0:45:eb:96 Broadcast ARP 60 Who has 192.168.50.1? Tell 192.168.50.228
1821 4.177717 64:1c:b0:45:eb:96 Broadcast ARP 60 Who has 192.168.50.1? Tell 192.168.50.228
2636 6.331676 64:1c:b0:45:eb:96 Broadcast ARP 60 Who has 192.168.50.1? Tell 192.168.50.228
3257 8.171254 64:1c:b0:45:eb:96 Broadcast ARP 60 Who has 192.168.50.1? Tell 192.168.50.228
4174 10.321718 64:1c:b0:45:eb:96 Broadcast ARP 60 Who has 192.168.50.1? Tell 192.168.50.228
4639 12.164889 64:1c:b0:45:eb:96 Broadcast ARP 60 Who has 192.168.50.1? Tell 192.168.50.228
4714 12.465663 04:d4:c4:bd:ba:48 Apple_8b:47:aa ARP 42 Who has 192.168.50.183? Tell 192.168.50.1
4716 12.465741 Apple_8b:47:aa 04:d4:c4:bd:ba:48 ARP 42 192.168.50.183 is at 78:4f:43:8b:47:aa
5411 14.315399 64:1c:b0:45:eb:96 Broadcast ARP 60 Who has 192.168.50.1? Tell 192.168.50.228
6115 16.158589 64:1c:b0:45:eb:96 Broadcast ARP 60 Who has 192.168.50.1? Tell 192.168.50.228
Frame 4714: 42 bytes on wire (336 bits), 42 bytes captured (336 bits) on interface 0
Ethernet II, Src: 04:d4:c4:bd:ba:48 (04:d4:c4:bd:ba:48), Dst: Apple_8b:47:aa (78:4f:43:8b:47:aa)
Destination: Apple_8b:47:aa (78:4f:43:8b:47:aa)
Source: 04:d4:c4:bd:ba:48 (04:d4:c4:bd:ba:48)
Type: ARP (0x0806)
Address Resolution Protocol (request)
Hardware type: Ethernet (1)
Protocol type: IPv4 (0x0800)
Hardware size: 6
Protocol size: 4
Opcode: request (1)
Sender MAC address: 04:d4:c4:bd:ba:48 (04:d4:c4:bd:ba:48)
Sender IP address: 192.168.50.1
Target MAC address: 00:00:00_00:00:00 (00:00:00:00:00:00)
Target IP address: 192.168.50.183
0000 78 4f 43 8b 47 aa 04 d4 c4 bd ba 48 08 06 00 01 xOC.G... ...H....
0010 08 00 06 04 00 01 04 d4 c4 bd ba 48 c0 a8 32 01 ....H..2.
0020 00 00 00 00 00 00 c0 a8 32 b7 .... 2.
Address Resolution Protocol (arp), 28 bytes
Packets: 44663 · Displayed: 69 (0.2%)
Profile: Default

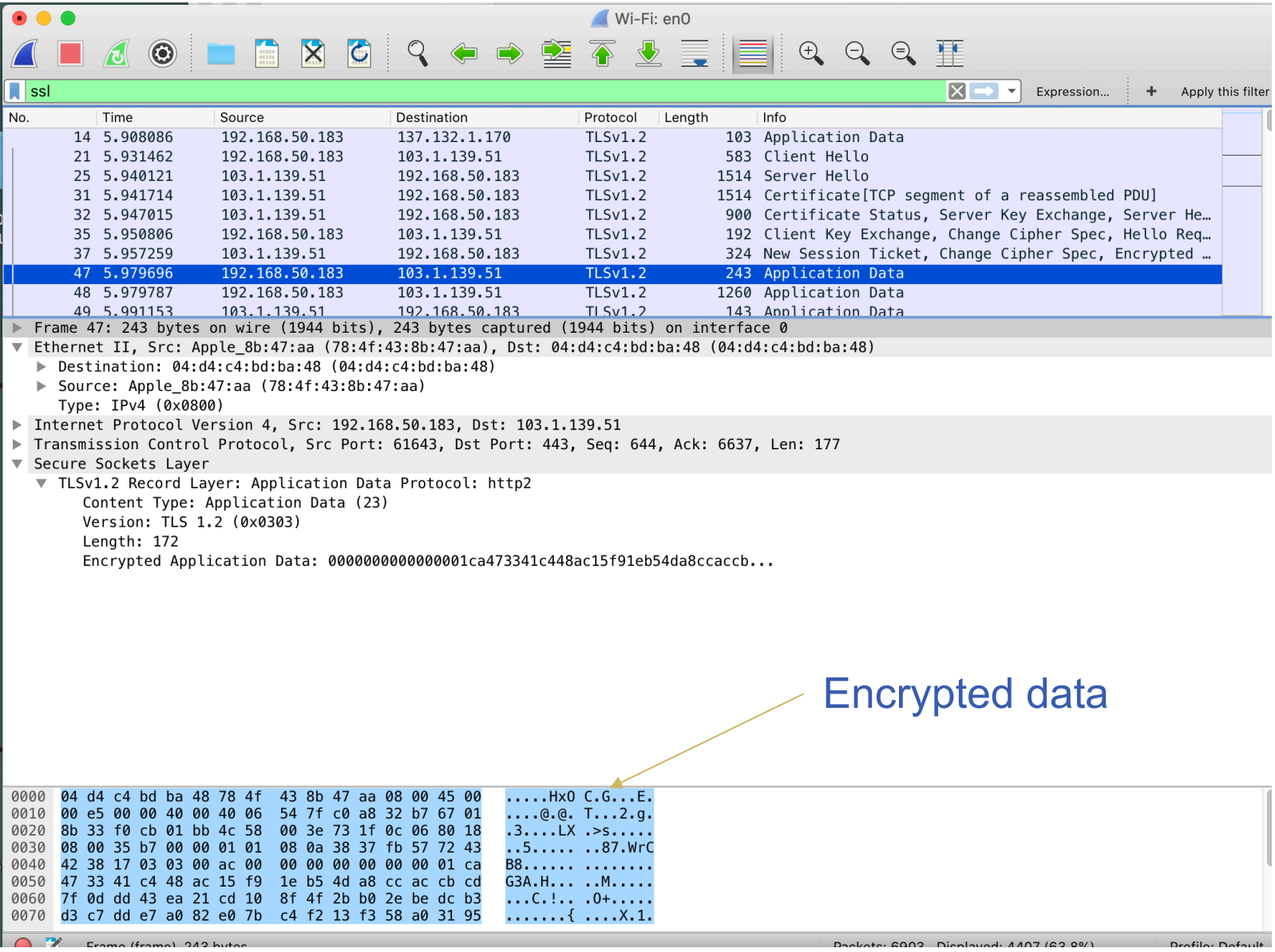

Wi-Fi: en0
dns
Expression...
Apply this filter
No. Time Source Destination Protocol Length Info
133 0.950965 192.168.50.183 192.168.50.1 DNS 87 Standard query 0x2fb7 PTR 183.50.168.192.in-addr.ar…
134 0.954629 192.168.50.1 192.168.50.183 DNS 113 Standard query response 0x2fb7 PTR 183.50.168.192.i…
5595 17.456059 192.168.50.183 192.168.50.1 DNS 79 Standard query 0xd81d A www.comp.nus.edu.sg
5598 17.466147 192.168.50.1 192.168.50.183 DNS 131 Standard query response 0xd81d A www.comp.nus.edu.s…
changec — -bash — 80×24
Last login: Wed Mar 11 14:59:24 on ttys000
Hello running .profile
The default interactive shell is now zsh.
To update your account to use zsh, please run `chsh -s /bin/zsh`.
For more details, please visit https://support.apple.com/kb/HT208050.
OfficeLapTop:~ changec$ nslookup www.comp.nus.edu.sg
Server: 192.168.50.1
Address: 192.168.50.1#53
Non-authoritative answer:
www.comp.nus.edu.sg canonical name = t36chsc.x.incapdns.net.
Name: t36chsc.x.incapdns.net
Address: 45.60.35.225
OfficeLapTop:~ changec$


Wi-Fi: en0
dns
Expression...
Apply this filter
No. Time Source Destination Protocol Length Info
133 0.950965 192.168.50.183 192.168.50.1 DNS 87 Standard query 0x2fb7 PTR 183.50.168.192.in-addr.arpa
134 0.954629 192.168.50.1 192.168.50.183 DNS 113 Standard query response 0x2fb7 PTR 183.50.168.192.in-addr.a…
5595 17.456059 192.168.50.183 192.168.50.1 DNS 79 Standard query 0xd81d A www.comp.nus.edu.sg
5598 17.466147 192.168.50.1 192.168.50.183 DNS 131 Standard query response 0xd81d A www.comp.nus.edu.sg CNAME …
Frame 5595: 79 bytes on wire (632 bits), 79 bytes captured (632 bits) on interface 0
Ethernet II, Src: Apple_8b:47:aa (78:4f:43:8b:47:aa), Dst: 04:d4:c4:bd:ba:48 (04:d4:c4:bd:ba:48)
Destination: 04:d4:c4:bd:ba:48 (04:d4:c4:bd:ba:48)
Source: Apple_8b:47:aa (78:4f:43:8b:47:aa)
Type: IPv4 (0x0800)
Internet Protocol Version 4, Src: 192.168.50.183, Dst: 192.168.50.1
User Datagram Protocol, Src Port: 54703, Dst Port: 53
Domain Name System (query)
[Response In: 5598]
Transaction ID: 0xd81d
Flags: 0x0100 Standard query
Questions: 1
Answer RRs: 0
Authority RRs: 0
Additional RRs: 0
Queries
www.comp.nus.edu.sg: type A, class IN
Name: www.comp.nus.edu.sg
[Name Length: 19]
[Label Count: 5]
Type: A (Host Address) (1)
Class: IN (0x0001)
0000 04 d4 c4 bd ba 48 78 4f 43 8b 47 aa 08 00 45 00 .....HxO C.G...E.
0010 00 41 4d d7 00 00 40 11 46 cc c0 a8 32 b7 c0 a8 .AM...@. F...2...
0020 32 01 d5 af 00 35 00 2d da 7d d8 1d 01 00 00 01 2....5.- .}......
0030 00 00 00 00 00 00 03 77 77 77 04 63 6f 6d 70 03 ....w ww.comp.
0040 6e 75 73 03 65 64 75 02 73 67 00 00 01 00 01 nus.edu. sg.....
wireshark_en0_20200311211922_liXvtG
Packets: 6939 · Displayed: 4 (0.1%)
Profile: Default


Wi-Fi: en0
dns
Expression...
Apply this filter
No. Time Source Destination Protocol Length Info
133 0.950965 192.168.50.183 192.168.50.1 DNS 87 Standard query 0x2fb7 PTR 183.50.168.192.in-addr.arpa
134 0.954629 192.168.50.1 192.168.50.183 DNS 113 Standard query response 0x2fb7 PTR 183.50.168.192.in-addr…
5595 17.456059 192.168.50.183 192.168.50.1 DNS 79 Standard query 0xd81d A www.comp.nus.edu.sg
5598 17.466147 192.168.50.1 192.168.50.183 DNS 131 Standard query response 0xd81d A www.comp.nus.edu.sg CNAM…
Domain Name System (response)
[Request In: 5595]
[Time: 0.010088000 seconds]
Transaction ID: 0xd81d
Flags: 0x8180 Standard query response, No error
Questions: 1
Answer RRs: 2
Authority RRs: 0
Additional RRs: 0
Queries
www.comp.nus.edu.sg: type A, class IN
Name: www.comp.nus.edu.sg
[Name Length: 19]
[Label Count: 5]
Type: A (Host Address) (1)
Class: IN (0x0001)
Answers
www.comp.nus.edu.sg: type CNAME, class IN, cname t36chsc.x.incapdns.net
t36chsc.x.incapdns.net: type A, class IN, addr 45.60.35.225
Name: t36chsc.x.incapdns.net
Type: A (Host Address) (1)
Class: IN (0x0001)
Time to live: 30
Data length: 4
0010 00 75 00 00 40 00 40 11 54 6f c0 a8 32 01 c0 a8 .u..@.@. To..2...
0020 32 b7 00 35 d5 af 00 61 35 dc d8 1d 81 80 00 01 2..5...a 5.......
0030 00 02 00 00 00 00 03 77 77 77 04 63 6f 6d 70 03 ....w ww.comp.
0040 6e 75 73 03 65 64 75 02 73 67 00 00 01 00 01 c0 nus.edu. sg......
0050 0c 00 05 00 01 00 00 40 83 00 18 07 74 33 36 63 ....@ t36c
0060 68 73 63 01 78 08 69 6e 63 61 70 64 6e 73 03 6e hsc.x.in capdns.n
0070 65 74 00 c0 31 00 01 00 01 00 00 00 1e 00 04 2d et..1... ....-
0080 3c 23 e1 <#.
Text item (text), 16 bytes
Packets: 6939 · Displayed: 4 (0.1%)
Profile: Default

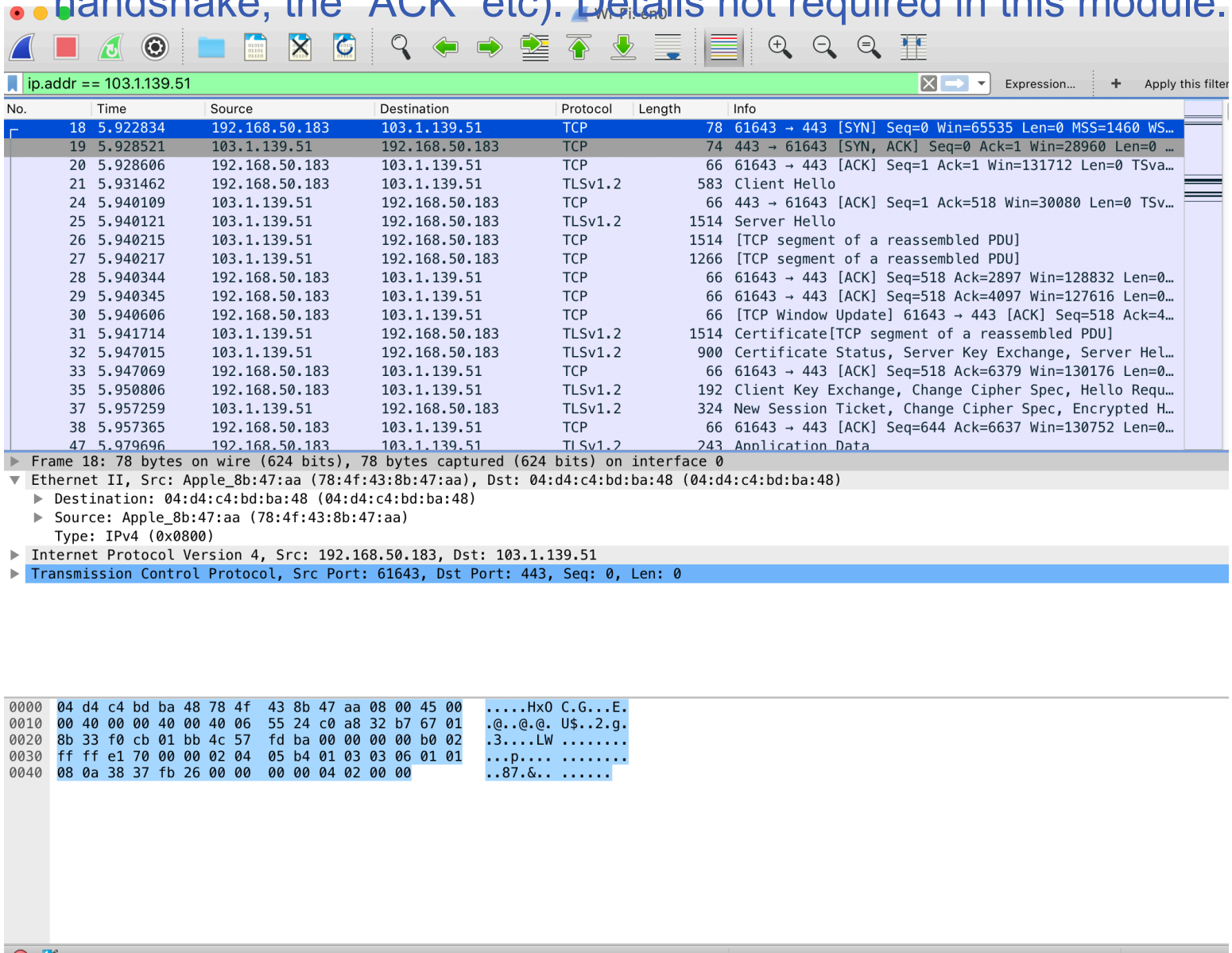
TLS: set display filter to “ssl”. Find the TLS handshake (authenticated key ex



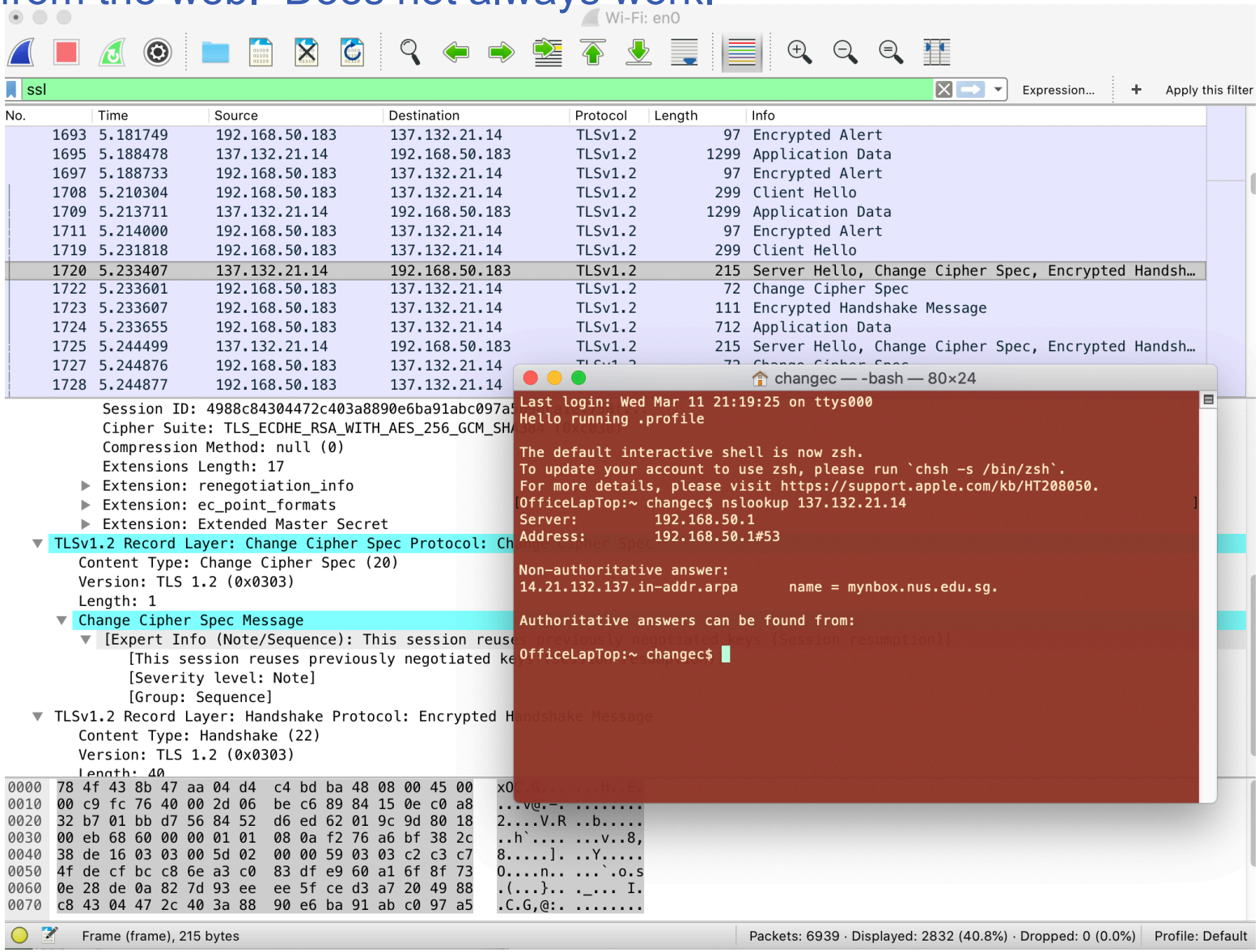

Wi-Fi: en0
ssl
Expression...
Apply this filter
No. Time Source Destination Protocol Length Info
14 5.908086 192.168.50.183 137.132.1.170 TLSv1.2 103 Application Data
21 5.931462 192.168.50.183 103.1.139.51 TLSv1.2 583 Client Hello
25 5.940121 103.1.139.51 192.168.50.183 TLSv1.2 1514 Server Hello
31 5.941714 103.1.139.51 192.168.50.183 TLSv1.2 1514 Certificate[TCP segment of a reassembled PDU]
32 5.947015 103.1.139.51 192.168.50.183 TLSv1.2 900 Certificate Status, Server Key Exchange, Server He…
35 5.950806 192.168.50.183 103.1.139.51 TLSv1.2 192 Client Key Exchange, Change Cipher Spec, Hello Req…
37 5.957259 103.1.139.51 192.168.50.183 TLSv1.2 324 New Session Ticket, Change Cipher Spec, Encrypted …
47 5.979696 192.168.50.183 103.1.139.51 TLSv1.2 243 Application Data
48 5.979787 192.168.50.183 103.1.139.51 TLSv1.2 1260 Application Data
49 5.991153 103.1.139.51 192.168.50.183 TLSv1.2 143 Application Data
Frame 47: 243 bytes on wire (1944 bits), 243 bytes captured (1944 bits) on interface 0
Ethernet II, Src: Apple_8b:47:aa (78:4f:43:8b:47:aa), Dst: 04:d4:c4:bd:ba:48 (04:d4:c4:bd:ba:48)
Destination: 04:d4:c4:bd:ba:48 (04:d4:c4:bd:ba:48)
Source: Apple_8b:47:aa (78:4f:43:8b:47:aa)
Type: IPv4 (0x0800)
Internet Protocol Version 4, Src: 192.168.50.183, Dst: 103.1.139.51
Transmission Control Protocol, Src Port: 61643, Dst Port: 443, Seq: 644, Ack: 6637, Len: 177
Secure Sockets Layer
TLSv1.2 Record Layer: Application Data Protocol: http2
Content Type: Application Data (23)
Version: TLS 1.2 (0x0303)
Length: 172
Encrypted Application Data: 0000000000000001ca473341c448ac15f91eb54da8ccaccb...
Encrypted data
0000 04 d4 c4 bd ba 48 78 4f 43 8b 47 aa 08 00 45 00 .....HxO C.G...E.
0010 00 e5 00 00 40 00 40 06 54 7f c0 a8 32 b7 67 01 ....@.@. T...2.g.
0020 8b 33 f0 cb 01 bb 4c 58 00 3e 73 1f 0c 06 80 18 .3....LX .>s.....
0030 08 00 35 b7 00 00 01 01 08 0a 38 37 fb 57 72 43 ..5..... ..87.WrC
0040 42 38 17 03 03 00 ac 00 00 00 00 00 00 00 01 ca B8...... ....
0050 47 33 41 c4 48 ac 15 f9 1e b5 4d a8 cc ac cb cd G3A.H... ..M.....
0060 7f 0d dd 43 ea 21 cd 10 8f 4f 2b b0 2e be dc b3 ...C.!.. .O+.....
0070 d3 c7 dd e7 a0 82 e0 7b c4 f2 13 f3 58 a0 31 95 ....{ ....X.1.

Looking at all IP packets from the ip.adder 103.1.139.51

Note that at TCP layer, there are many other more interactions (3 way-handshake, the “ACK” etc). Details not required in this module.



We can use nslookup to find out more about an ipaddress.
(the is called reverser DNS lookup where find the domain name from ip-address.) We can also find the geolocation by using some services from the web. Does not always work.



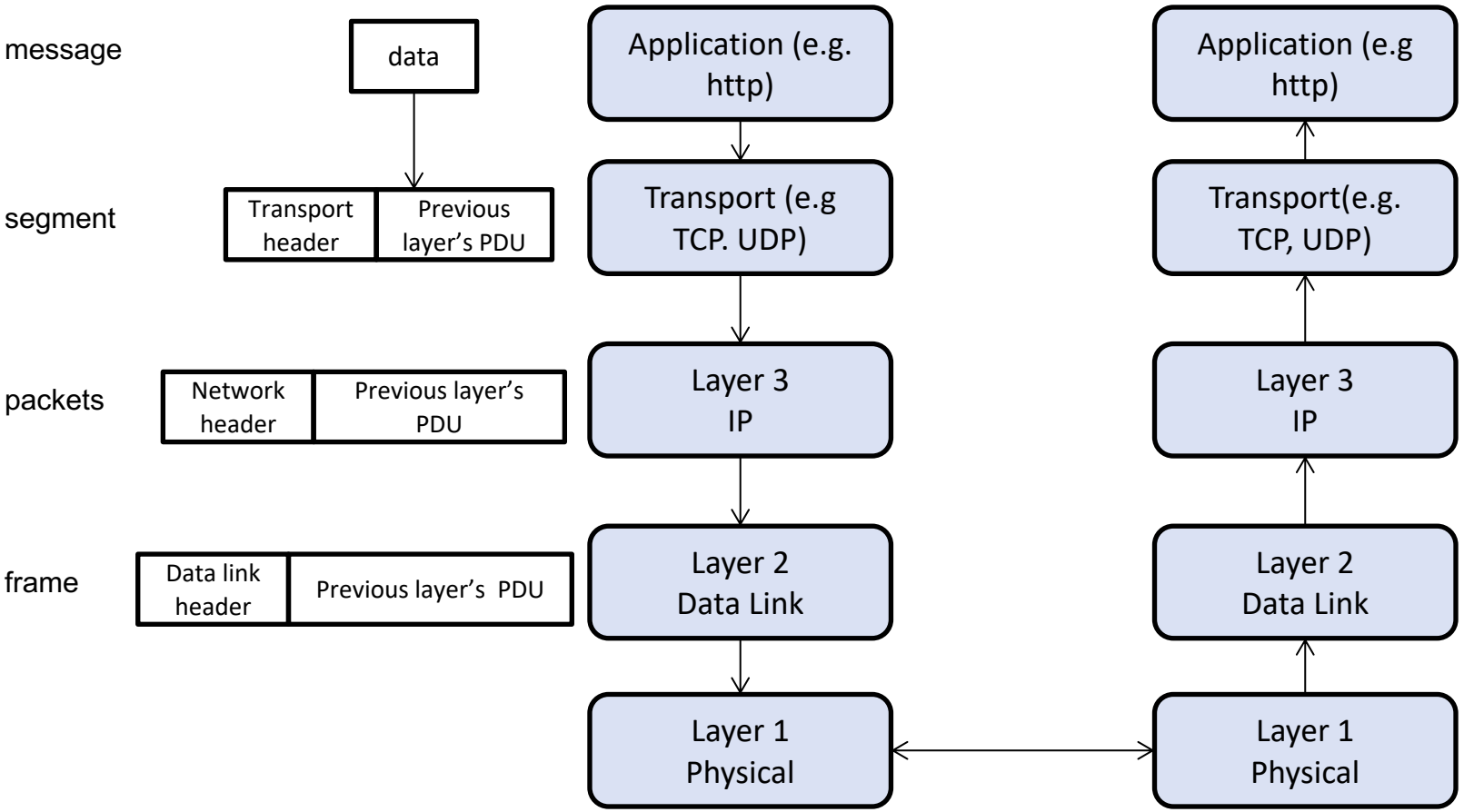
There are many more tools and features. (e.g. the “follow”, “Analyze”, “export” etc)
Explore to find out more.

5.5 Protection: Securing the communication channel using cryptography

In the past few lectures, we have illustrated that cryptography techniques can be deployed to achieve confidentiality (encryption) and authenticity (mac, PKI, strong authentication) over a public communication channel, even if the adversary can sniff & spoof data.

There are many security protocols achieving that, but operates at different “layers”.

- The well-known TLS/SSL, WPA, IPSEC protect different layers.



Remark on Layering

Very often, when referring to a security protocol, we indicate the "layer" the protocol targets to protect. (complication: some protections span across multiple layers, or do not provide full protection of the targeted layer.)

When analyzing an attack, it is also insightful to figure out at what layer the attacker resides. (complication: likewise, some attacks span across multiple layers. In such situations, trying hard to pin-point the layer could sometime be very confusing).

A security protocol that protects layer k, would protect information in that layer and above.

Hence, if an attacker resides at layer 1, and there is a security protocol that protect layer 3, then information generated in layer 3 and above will be protected, but information generated in layer 2 would not be protected by the security protocol

1. SSL/TLS

- The SSL/TLS sit on top of Transport layer.

- We can imagine that, when an application (say browser or email agent) wants to send data to the other end point, it first passes the data and the address (ip address) to SSL/TLS. Next SSL/TLS first “protects” the data using encryption (confidentiality) and mac (authenticity), and then instructs the transport layer to send the protected data.

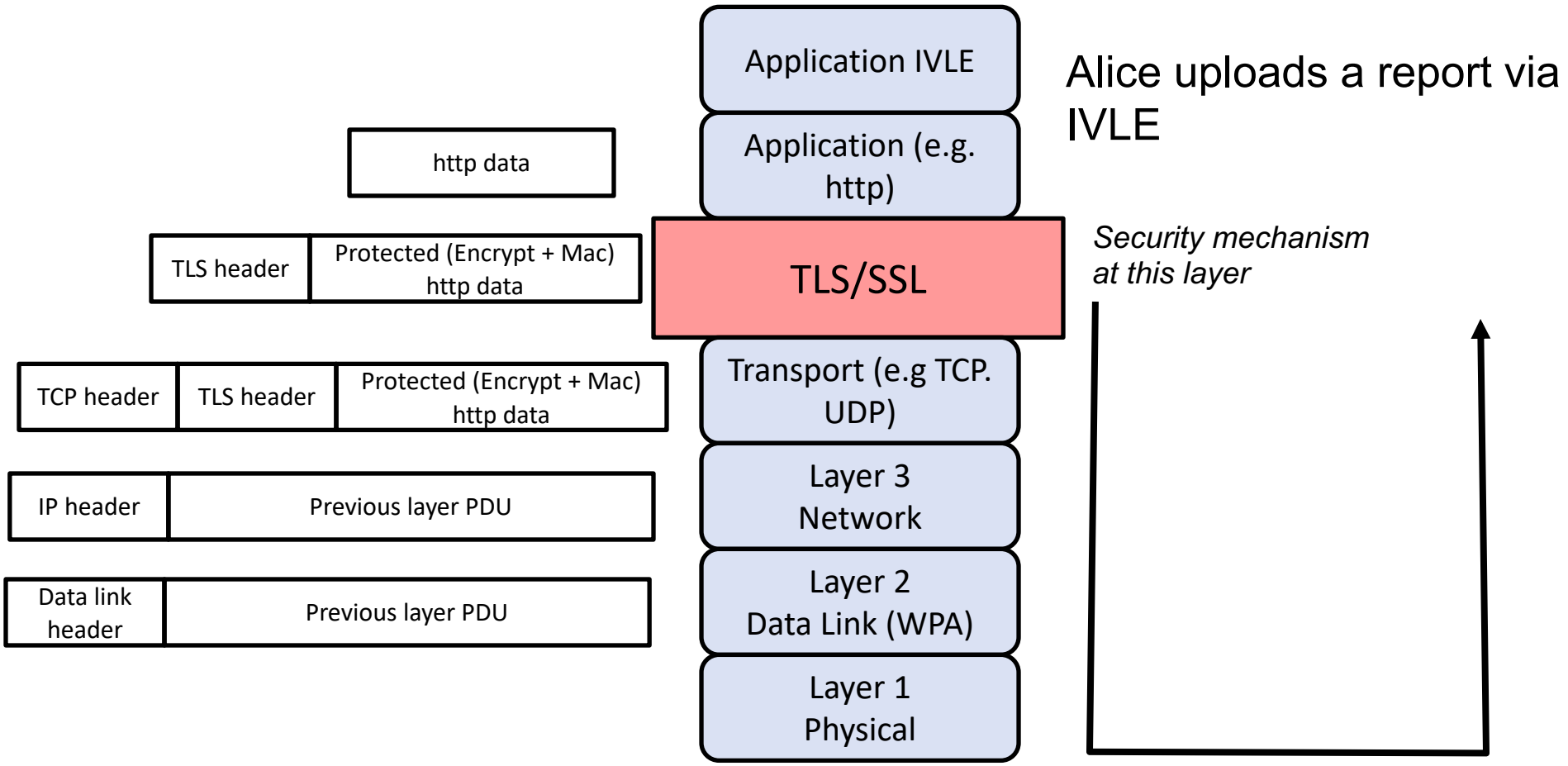
- E.g. Alice using IVLE to upload a report a.pdf to the IVLE server. Note that IVLE uses https, which in turn uses SSL/TLS.

Alice's machine carries the following:

1. The "IVLE" application passes the file a.pdf to https, and then to TLS.
2. TLS protects the data by encryption and mac.
3. TLS passes the protected data to the transport layer.

IVLE's server carries out the following:

1. The transport layer passes the protected data to TLS.
2. TLS decrypt the data and verify the mac for integrity.
3. TLS passes the decrypted data to IVLE's application.



The receiver end-point decrypts the received data at the corresponding layer.

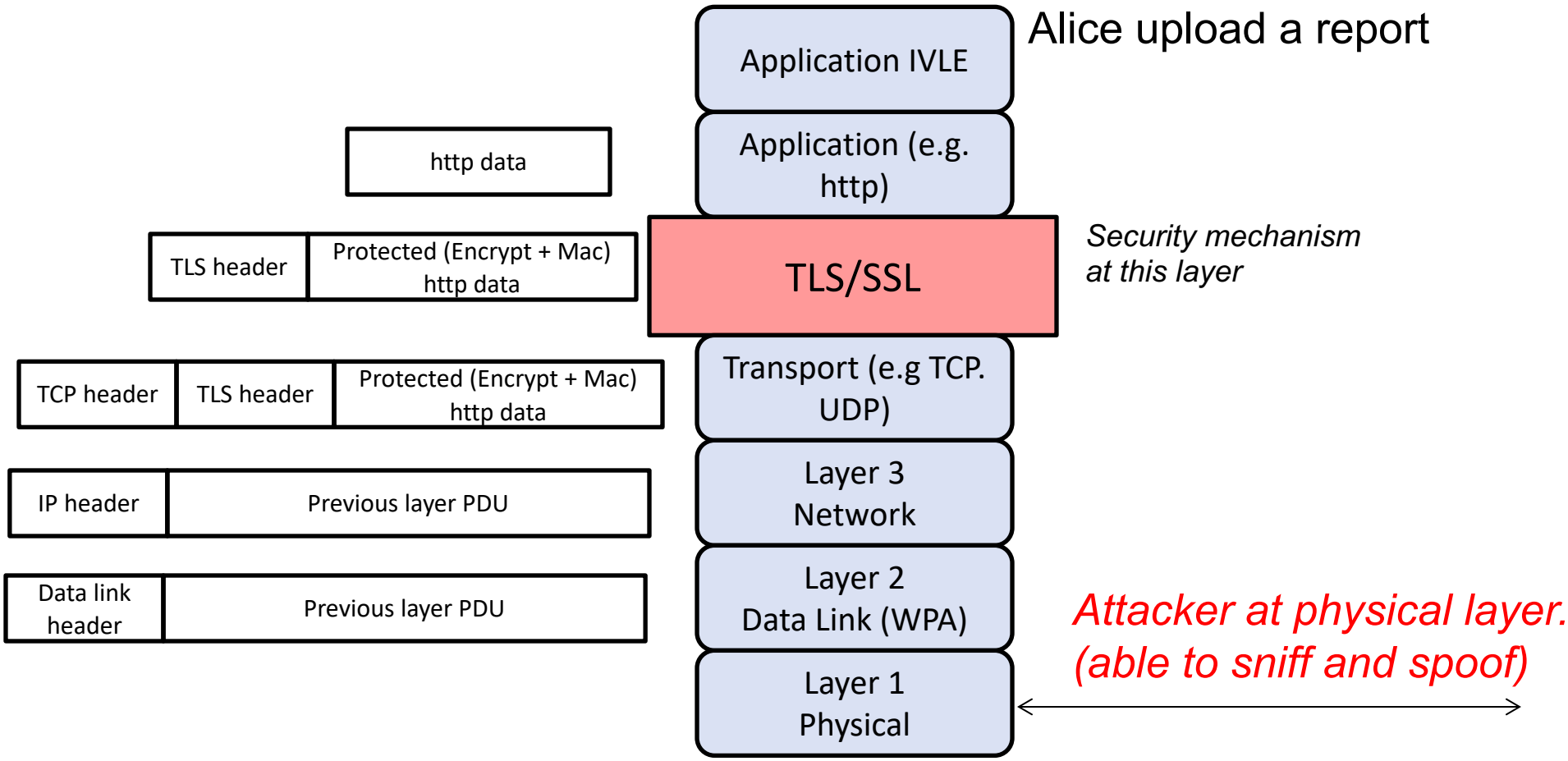
Scenario 1

- Suppose that there is an attacker in the physical layer who can sniff and spoof message at that layer (i.e. MITM in the physical layer). For example, Alice uploading her report in a cafe using free wifi (without WPA protection). Hence anyone in the café has access to the physical layer and thus can sniff and spoof messages in that layer.

- Question: Can the attacker learn
  1. Alice's report? no, because do not have the private key of luminus
  2. The fact that Alice is visiting IVLE website (i.e. can the attacker learn the ip-address)?

     yes, because that those headers are not encrypted

Attacker at physical layer.

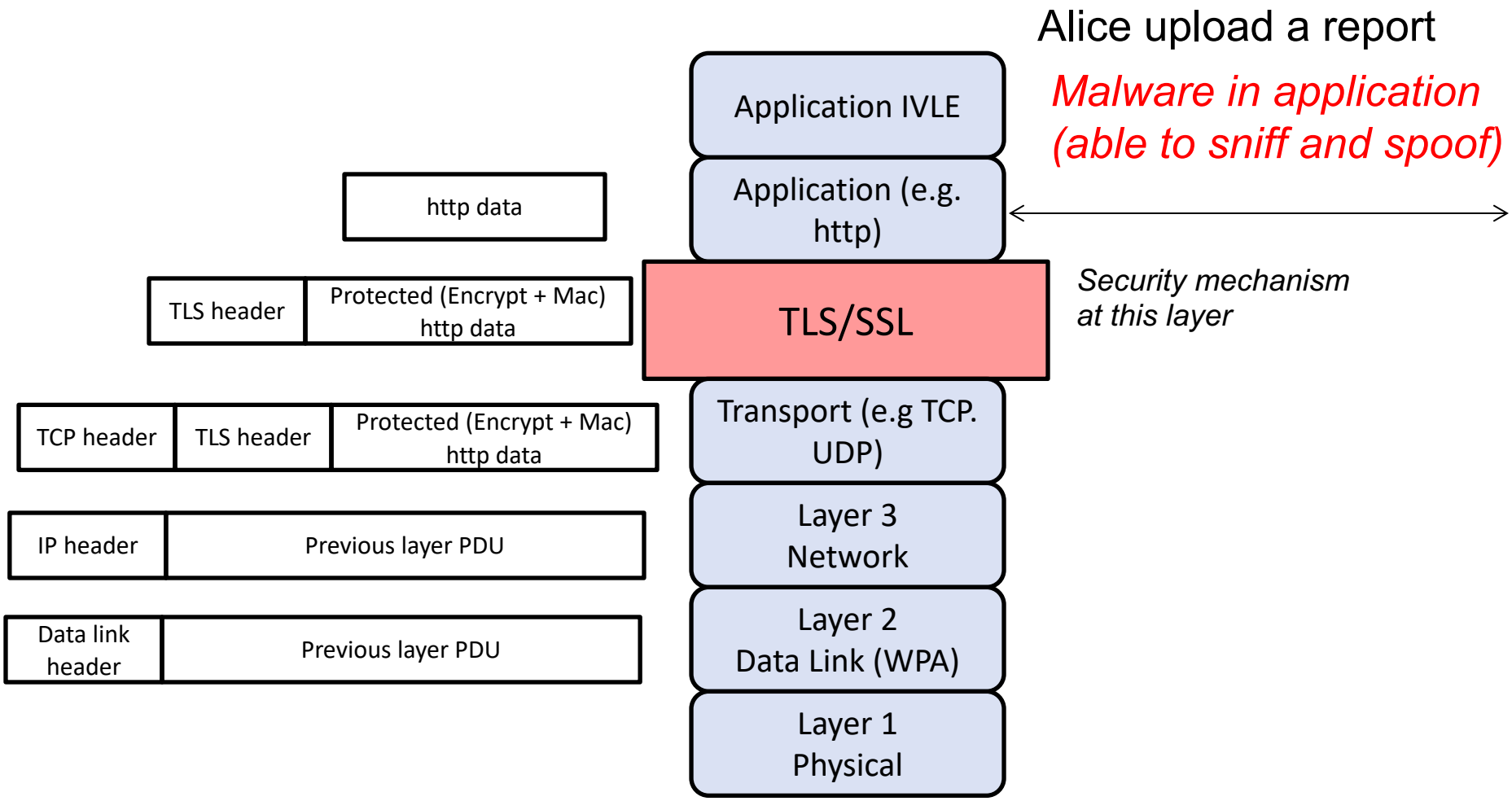


Scenario 2

- Suppose that there is an adversary in the application layer. For example, a malicious java script injected into IVLE and being executed by Alice's browser.

- Question: Can the malicious script learn
  1. Alice's report? no
  2. Alice's mac address? (yes and no)

Attacker at application layer (e.g. Malware in browser)



2. WPA2

Wifi Protected Access II (WPA2). A popular protocol employed in home Wifi access point.

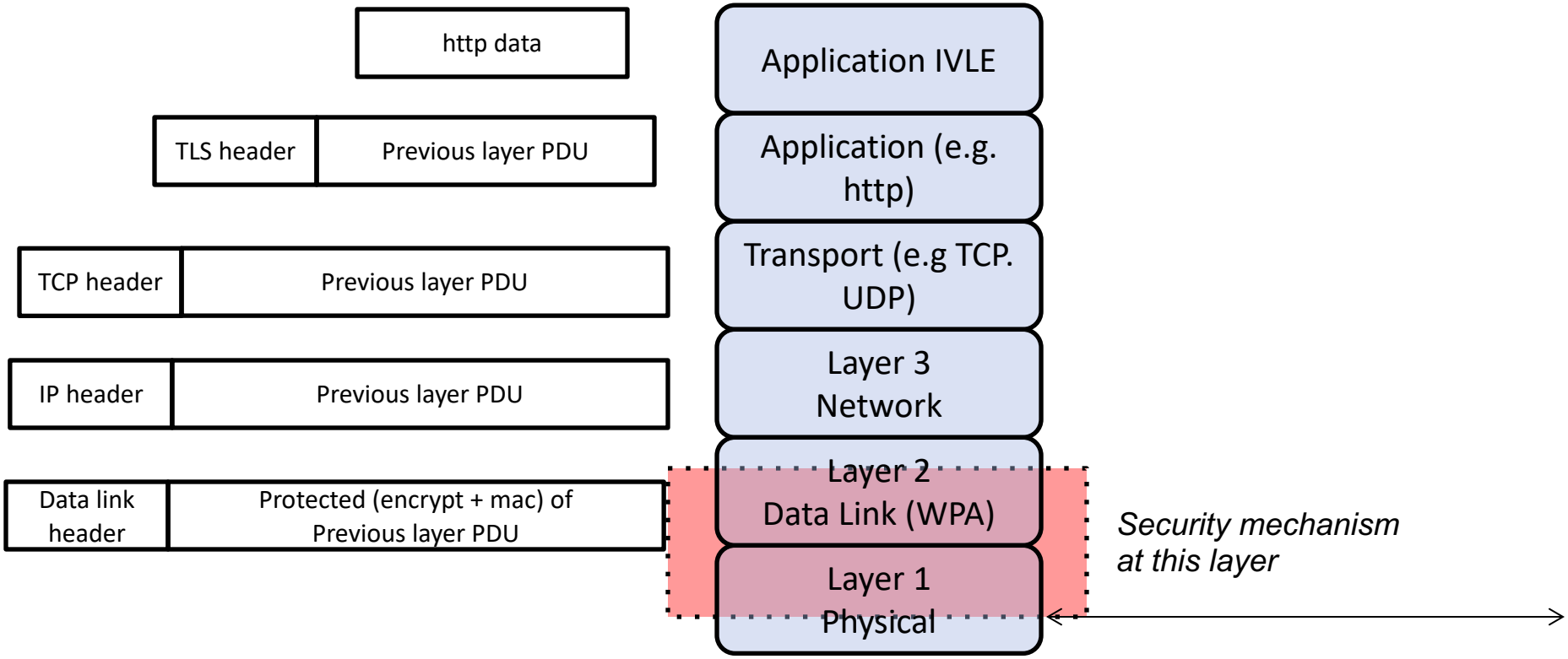
WPA2 provides protection at layer 2 (Link) and layer 1 (Physical). Not all information in layer 2 are protected.

See recent attack on WPA2.

Key Reinstallation Attacks: Breaking WPA2 by forcing nonce reuse
https://www.krackattacks.com/

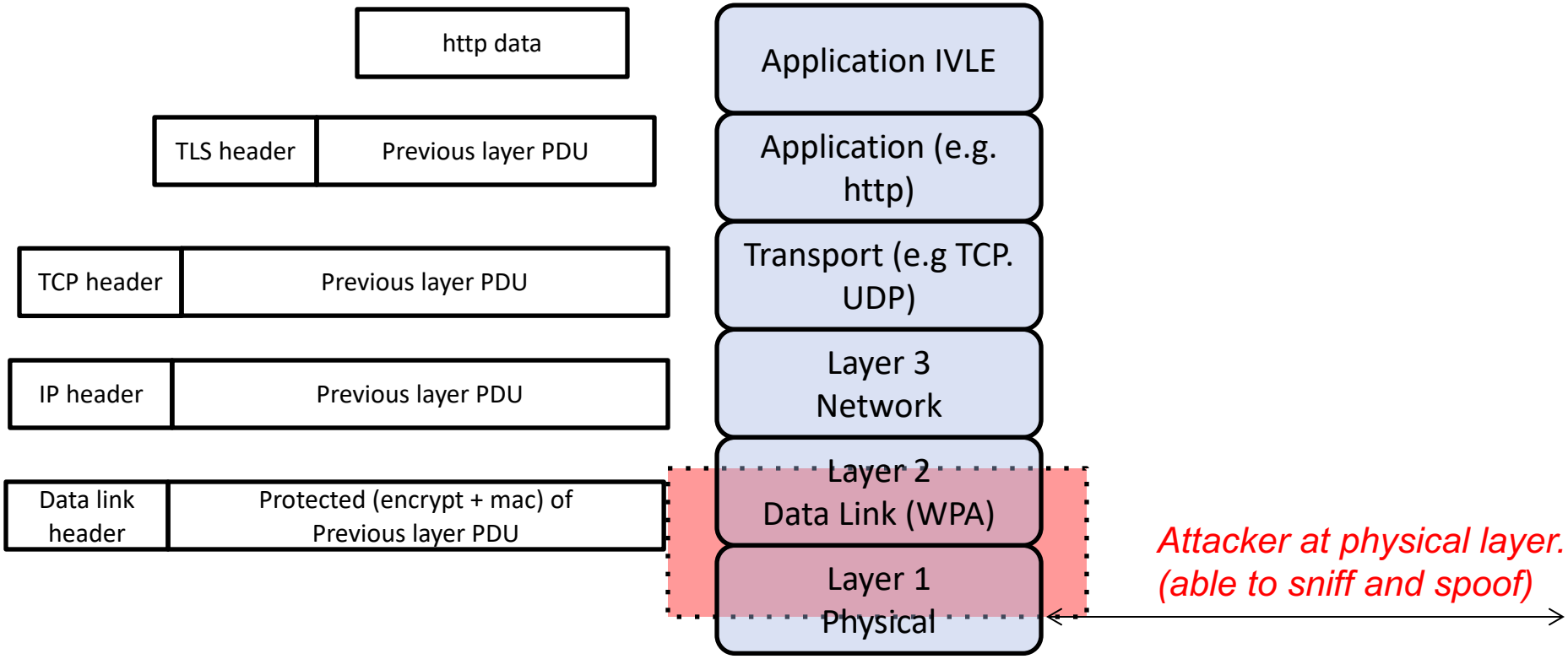
Research paper: https://papers.mathyvanhoef.com/ccs2017.pdf

Alice uploading a report



Attacker at physical layer

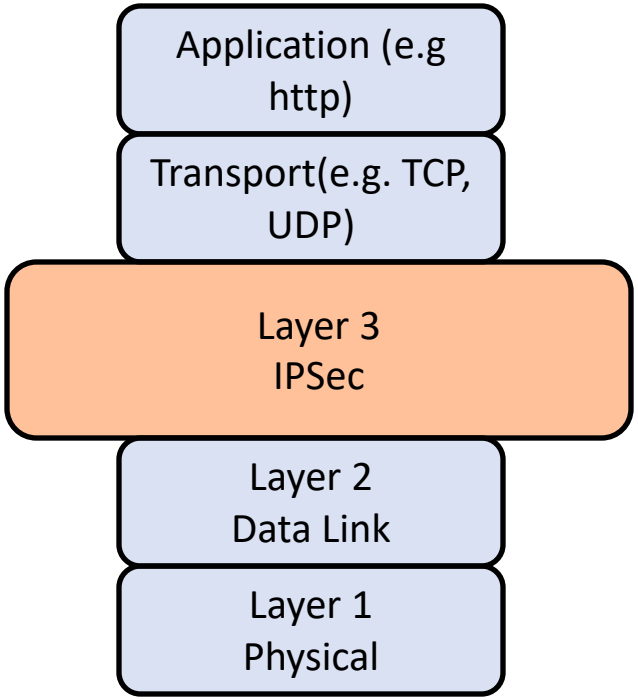
Alice uploading a report



Question: Can the attacker learn

1. *Alice's report?* no
2. *The fact that Alice is visiting IVLE website?* no
3. *The mac address (link layer)?* Not immediately clear from the figure above. Yes.

3. IPSec



E.g. IPSec provides “integrity/authenticity” protection of ip-address, but not confidentiality. Hence, attackers are unable to “spoof” the source ip-source, but can learn the source and destination ip-address of the sniffed packets.

Remarks

- IPSec is a mechanism whose goal is to protect the IP layer.

- "**Internet Protocol Security** (**IPsec**) is a protocol suite for securing Internet Protocol (IP) communications by authenticating and encrypting each IP packet of a communication session. IPsec includes protocols for establishing mutual authentication between agents at the beginning of the session and negotiation of cryptographic keys to be used during the session. IPsec can be used in protecting data flows between a pair of hosts (*host-to-host*), between a pair of security gateways (*network-to-network*), or between a security gateway and a host (*network-to-host*)."
- "Internet Protocol security (IPsec) uses cryptographic security services to protect communications over Internet Protocol (IP) networks. IPsec supports network-level peer authentication, data origin authentication, data integrity, data confidentiality (encryption), and replay protection."
- "IPsec is an end-to-end security scheme operating in the Internet Layer of the Internet Protocol Suite, while some other Internet security systems in widespread use, such as Transport Layer Security (TLS) and Secure Shell (SSH), operate in the upper layers at Application layer. Hence, only IPsec protects any application traffic over an IP network. Applications can be automatically secured by IPsec at the IP layer."

-wiki

5.6. Firewall

[ZCC] ED Zwicky, S Cooper, DB Chapman, **Building Internet Firewalls: Internet and Web Security,** 2000

(free from books.google.com

http://dbmanagement.info/Books/Others/O%27Reilly_Building_Internet_Firewalls_2nd_Edition.pdf)

- Consider the computer network in an organization.
  - Some nodes contain more sensitive information than other. Example, Student examination record database server, vs public workstations in lecture hall.
  - Some nodes might have unpatched vulnerabilities. Example, when a patch is available, it might take some time (e.g. days, weeks, months) to patch all the systems.
  - Certain nodes might be compromised (e.g. An unhappy student who has access to the lab's workstation).
  - Certain protocols do not have protection mechanisms, or only light-weight protection. For example, DNS, arp, network printer, etc. We need to prevent attackers from accessing such protocol.

- We need to divide the computer network into segments and deny unnecessary access. **(Principle of least privilege, compartmentalization)**

- Firewall, Intrusion detection system (IDS) are tools to control access to the network.

Remark: Principle of least privilege and compartmentalization

- The term "Principle of least privilege" was introduced in the design of OS, but was later adopted in other domain in security.
  - "The **principle of least privilege** (**PoLP**, also known as the **principle of minimal privilege** or the **principle of least authority**) requires that in a particular abstraction layer of a computing environment, every module (such as a process, a user, or a program, depending on the subject) must be able to access only the information and resources that are necessary for its legitimate purpose"
    https://en.wikipedia.org/wiki/Principle_of_least_privilege#Implementation

- Compartmentalization: There isn't a single well accepted definition. Generally, it refer to the notion of confining information within compartments.

Firewall

set of rules

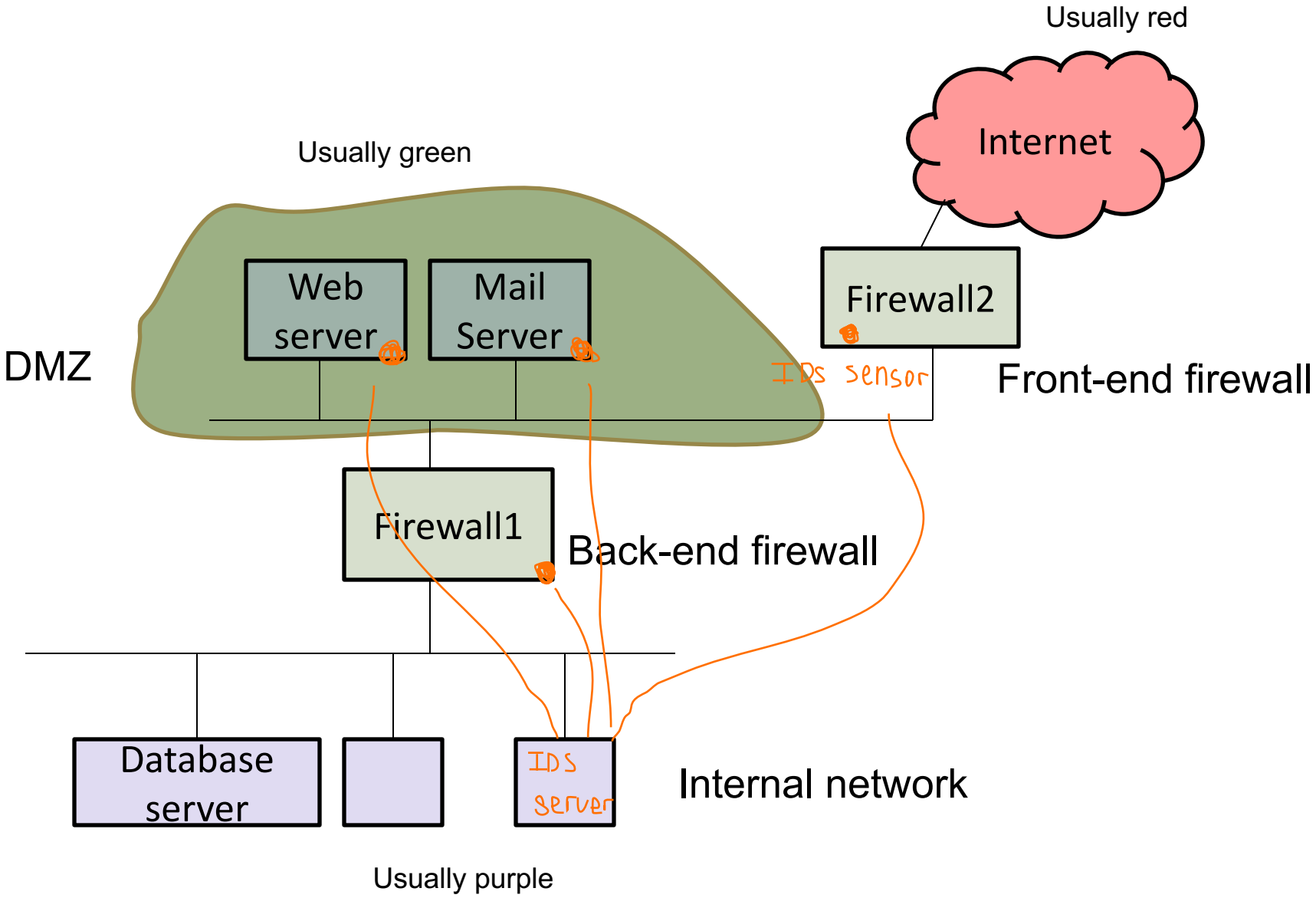
- Firewall: A Firewall controls what traffic is allowed to enter the network (***ingress*** filtering), or leave the network (***egress*** filtering).

- *Firewall are devices or programs that control the flow of network traffic between networks or hosts that employ differing security postures.*

  (from Guidelines on Firewalls and Firewall Policy, NIST, special publication 800-41 http://csrc.nist.gov/publications/nistpubs/800-41-Rev1/sp800-41-rev1.pdf)

- DMZ: Demilitarized zone. A sub-network that exposes the organization's external service to the (untrusted) Internet.

A typical 2-firewall setting.



Packet filtering/screening ([ZCC Section 5.2])

Firewall's controls are achieved by "packets filtering" (aka screening). Filtering may occur in router, gateway/bridge, host, etc.

Packet filtering inspects every packet, typically only on the IP packet's header information. (if the payload is inspected, we call it ***deep packet inspection (DPI)***). Action taken after inspection could be

- Allow the packet to pass
- Just drop the packet
- Reject the packet (i.e. drop and inform the sender)
- Log info
- Notify system admin
- Modify the packet (for more advanced device).

Example of firewall rules

- Drop packets with “source ip-address” not within the organization’s network. (*To stop attacks originated within the network*).

- Whitelist
  - Drop all packets except those specified in the white-list. (e.g. drop all except http, email protocol, and DNS)

- Blacklist
  - Accept all packets except those specified in the black-list. (e.g. allow https except ip-address in the black list).

Firewall design (see [ZCC] ch8.5-12)

A firewall enforces a set of rules provided by the network administrator.

Example on the 2-firewall setting:

- Rules for Firewall1.
  - Block: HTTP.
  - Allow internal to Mail Server: SMTP, POP3
- Rules for Firewall2
  - Allow from anywhere to Mail Server: SMTP only

port number usually very important
-http = 80
-email = 25

How the rules are to be specified differ on different devices and software. In this lecture, we consider a typical design (from [PF] pg 453)

usually arranged in a sequence

Rule	Type	Direction		Source Address	Destination Address	Destination Port	Action
1	TCP	in		*	192.168.1.*	25	Permit
2	TCP	in		*	192.168.1.*	69	Permit
3	TCP	out		192.168.1.*	*	80	Permit
4	TCP	in		*	192.168.1.18	80	Permit
5	TCP	in		*	192.168.1.*	*	Deny
6	UDP	in		*	192.168.1.*	*	Deny
last	*	*		*	*	*	Deny

Matching condition *action*

- The rules are processed sequentially starting from rule 1, 2, …. The first matching rule determines the action.
- The symbol "*" matches any value. This is a symbol in "regular expression".

Types of firewall

- NIST's document (NIST 800-41) groups the firewalls into 3 types:

1. Packet filters (Inspect packet header)
2. Stateful Inspection (Deep packet inspection)
3. Proxy (Modify packets)

Intrusion Detection System (IDS)

see slide 91

An IDS system consists of a set of "sensors" gathering data. Sensors could be in the host, or network router. The data are analyzed for intrusion. Three types of IDS:

- Attack signature Detection
  - The attack has specific, well-defined signature. For e.g. using certain port number, certain source ip address.
- Anomaly Detection
  - The IDS attempt to detect abnormal pattern. For e.g. a sudden surge of packets with certain port number.
- Behavior-based IDS
  - Can be viewed as a type of anomaly detection that focuses on human behavior. For e.g. The system might keep the profile of each user. It then tries to detect any user who deviates from the profile (e.g. start to download large files).

Popular open-source IDS: Snort. https://www.snort.org/

e.g. of snort rule (from https://blog.rapid7.com/2016/12/09/understanding-and-configuring-snort-rules/):

```
log tcp !192.168.0/24 any -> 192.168.0.33 (msg: "mounted access" ; )
```

Other tools.

TLS/SSL scan

- Checking known vulnerability of a server.

- https://www.ssllabs.com/ssltest/analyze.html?d=luminus.nus.edu.sg&hideResults=on

5.7 Management

- Management needed in order to monitor and adjust network characteristic.

- Detail omitted. Optional. see [PF6.9]

Some terminologies:

- Security Operations Center (SOC)
  - a centralized unit in an organization that monitors the IT systems and deals with security issues.

- Security Information and Event Management (SIEM)
  - pronounced as “SIM”. Approaches and tools for SOC.
  - A popular system: Splunk (https://www.splunk.com/)

ELK Stack-Elasticsearch and Kibana (open sourced)