Computer Organization and Networks

Chapter 9: Networking III

Winter 2021/2022

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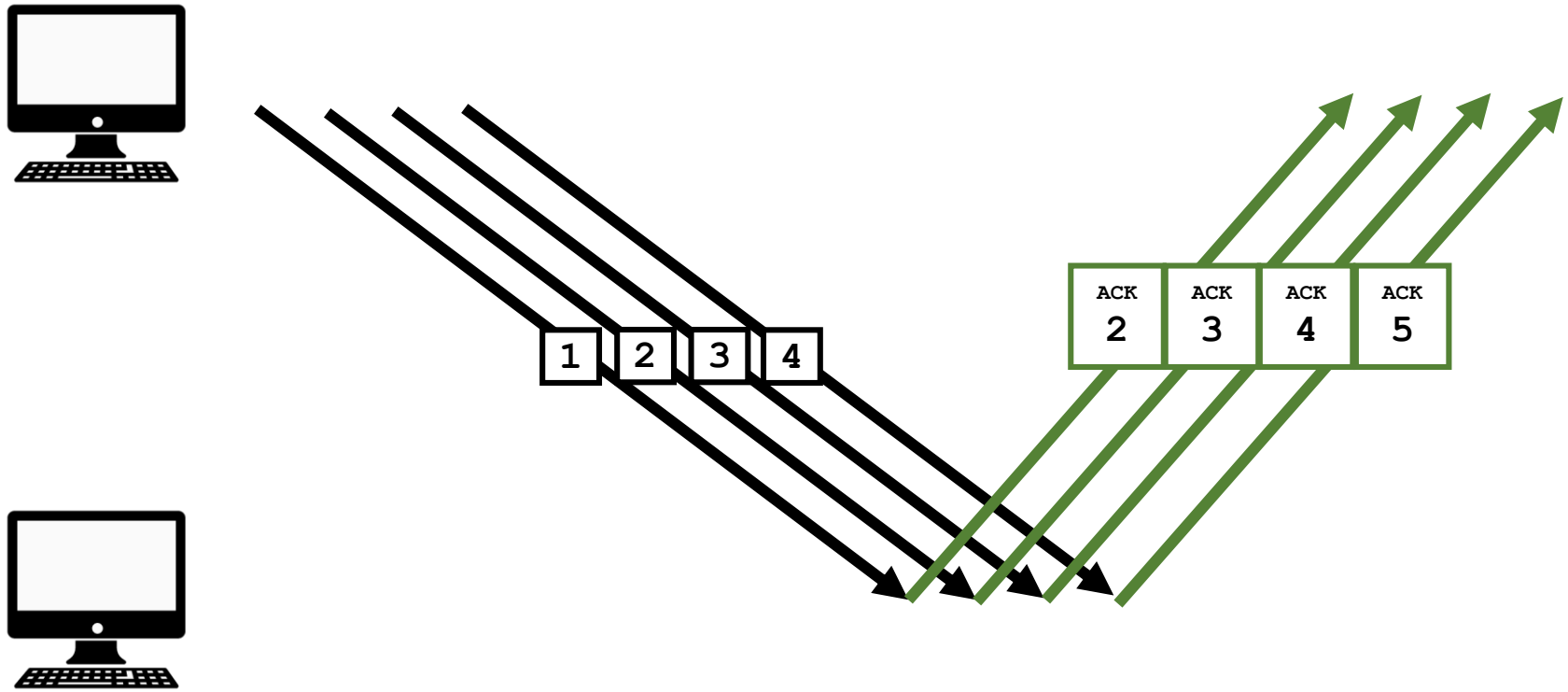
he/his

The Transport Layer

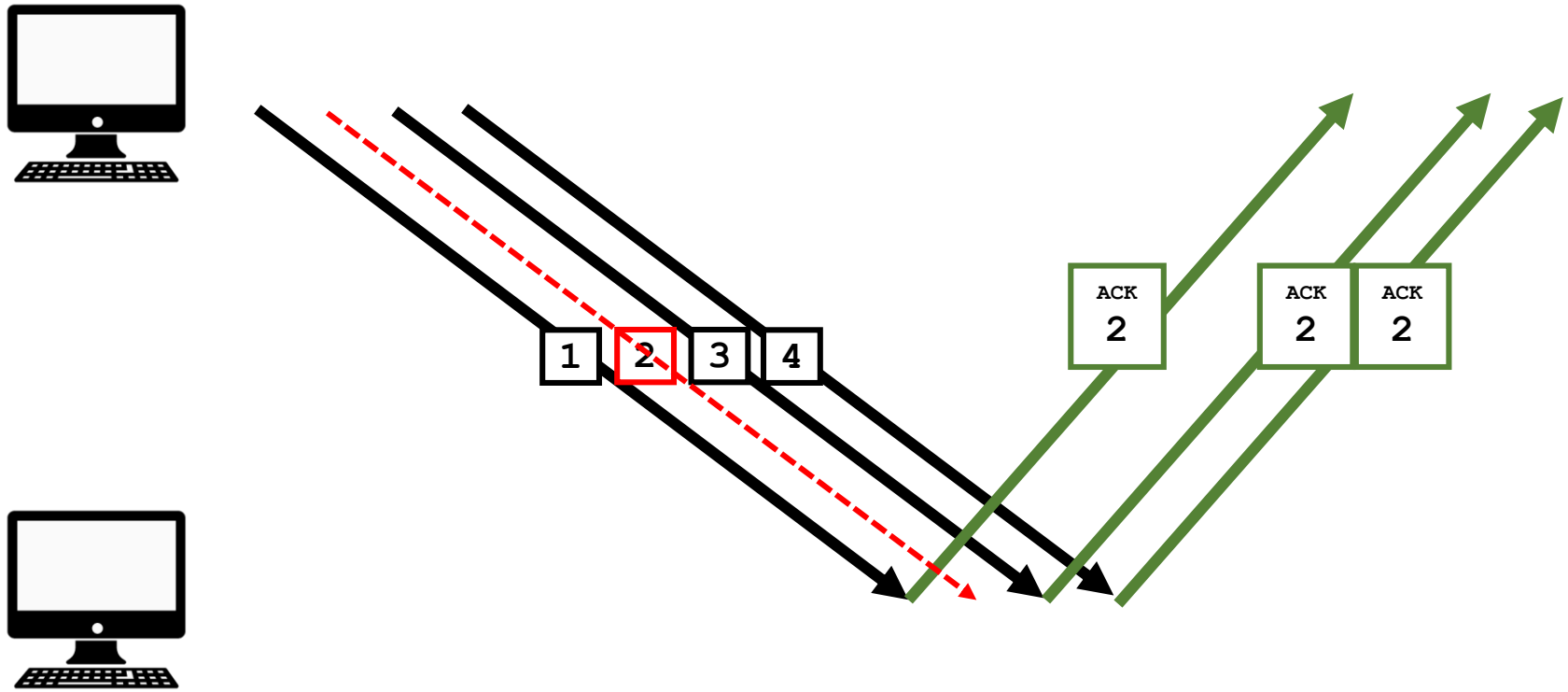
(again?)

TCP: Selective Acknowledgment



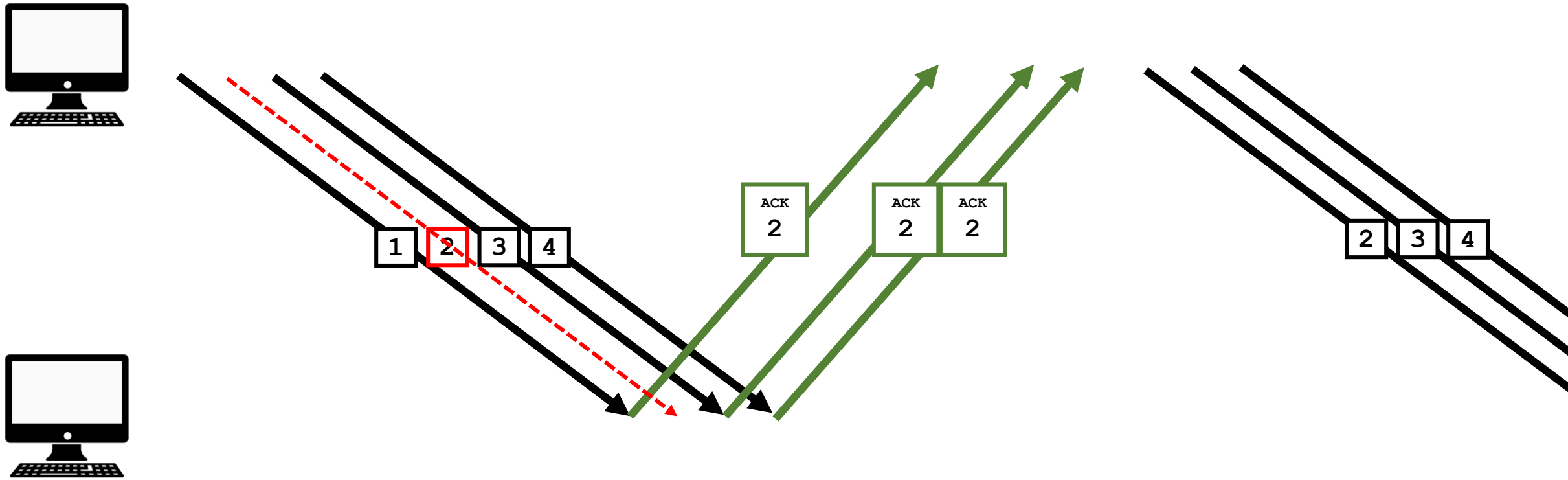
TCP: Selective Acknowledgment

- "Standard" TCP does not deal with packet loss efficiently



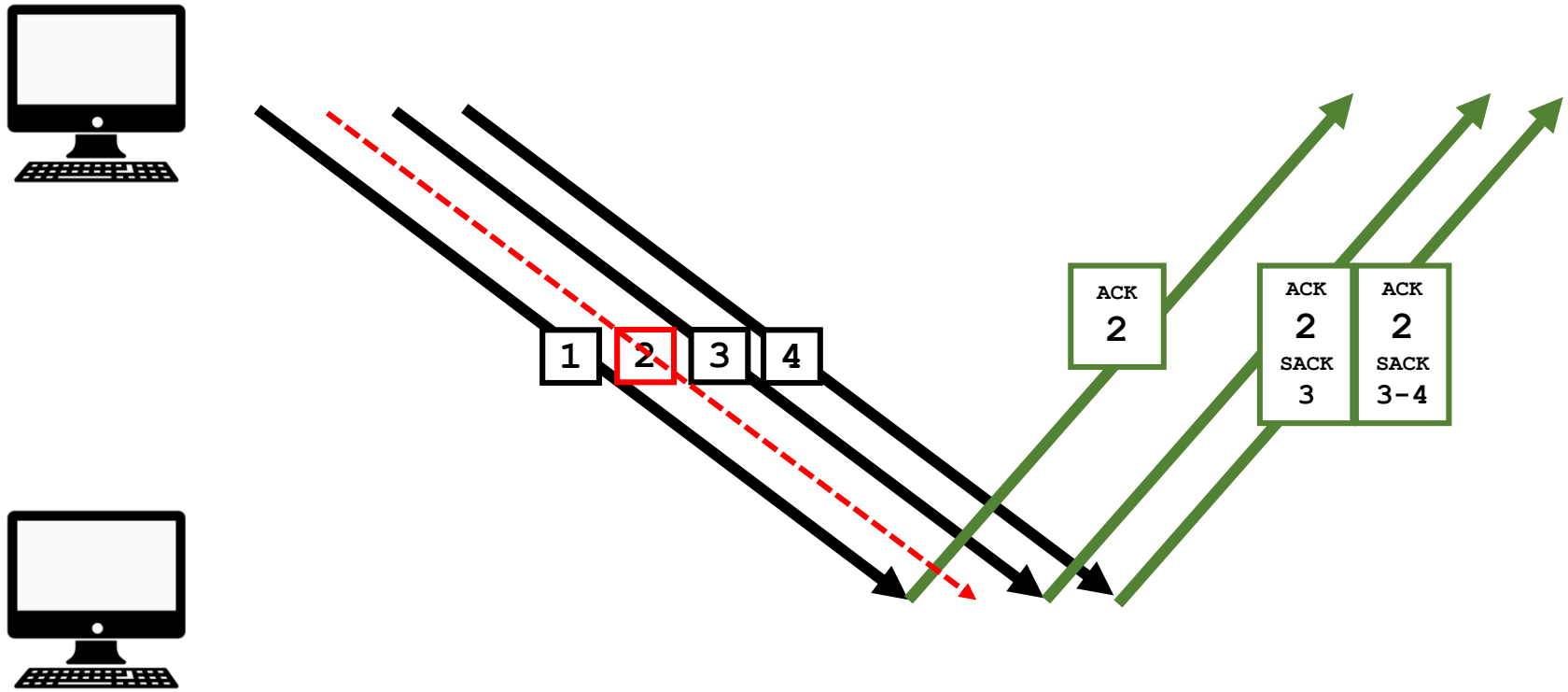
TCP: Selective Acknowledgment

- "Standard" TCP does not deal with packet loss efficiently
  - Superfluous data is re-sent, wasting time and bandwidth!



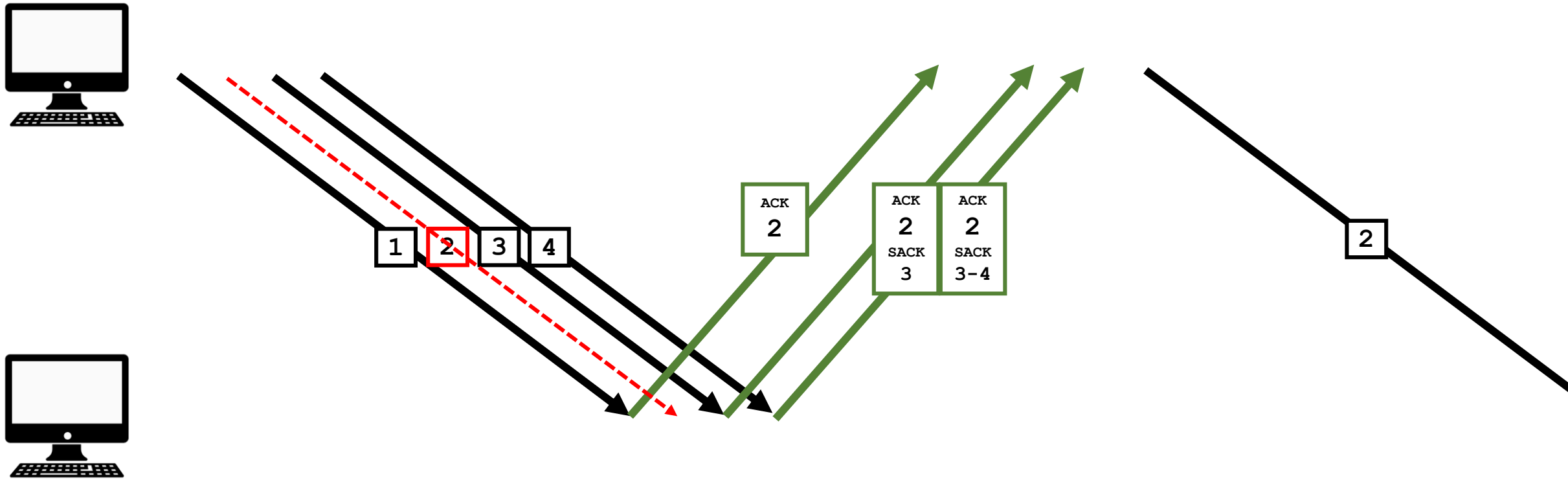
TCP: Selective Acknowledgment

- The SACK extension lets the recipient acknowledge further ranges



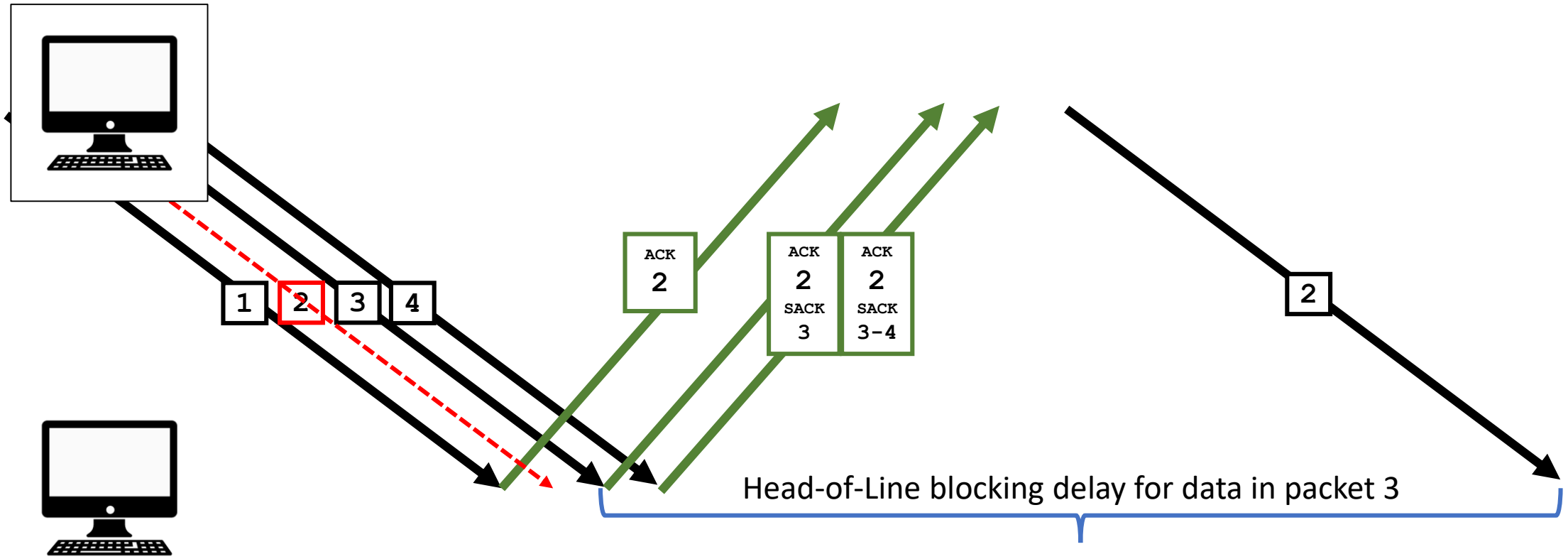
TCP: Selective Acknowledgment

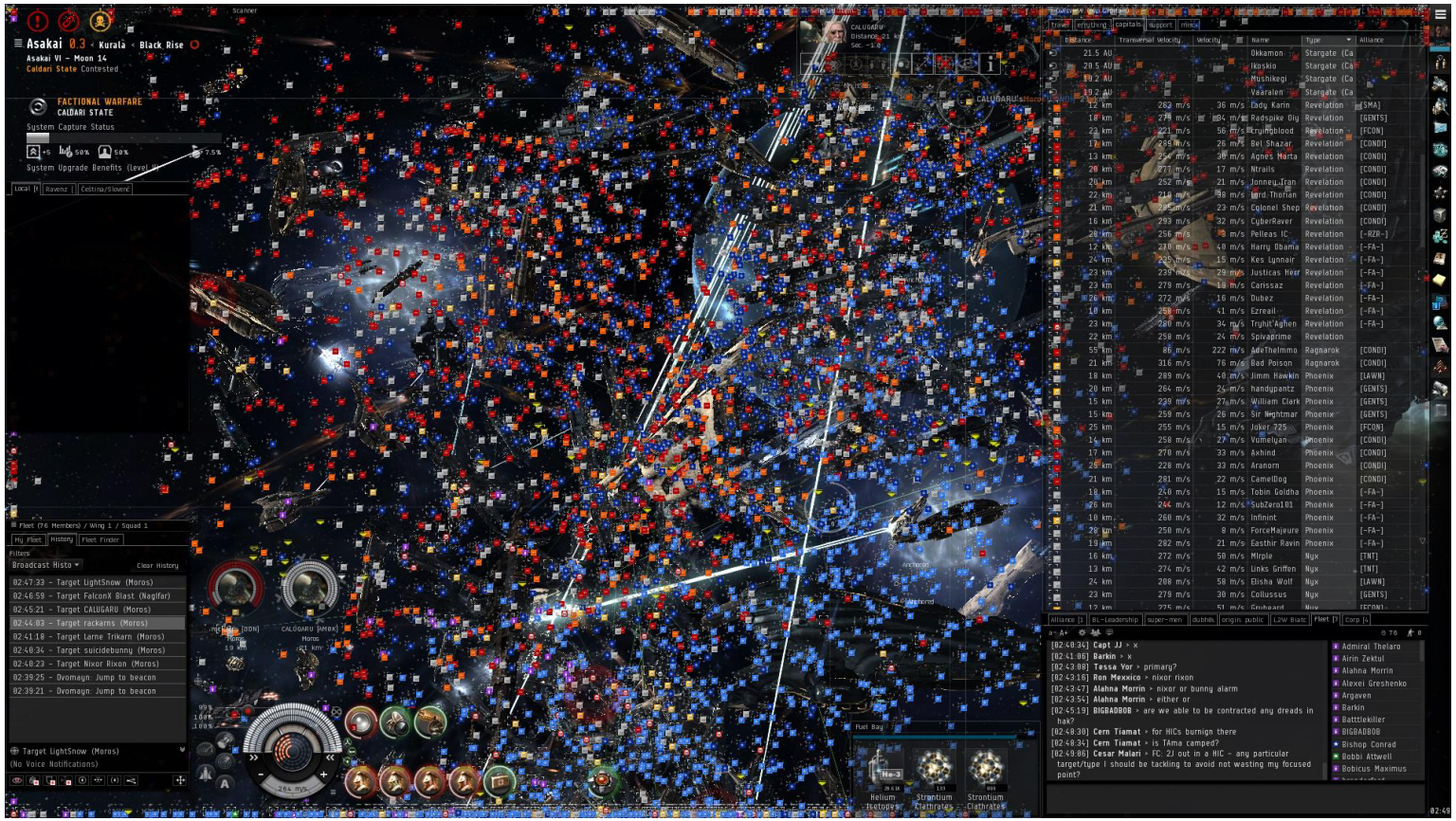
- The SACK extension lets the recipient acknowledge further ranges
  - These ranges do not need to be re-sent!



TCP: Head-of-Line blocking

- However, a TCP connection is still a single byte stream
  - While we wait for packet 2, we cannot process packets 3 and 4…





The Application Layer

(some select applications)

Recap

- **Data Link Layer**: send data to locally connected devices
  - Ethernet, Wi-Fi, Bluetooth, …
- **Network Layer:** send data to devices over the internet
  - IPv4, IPv6, …
- **Transport Layer:** structure the data into individual connections
  - TCP, UDP, …

- What's left?
  - Actually send useful data!

Domain Name System

- UDP port 53
- Transforms *host names* into IP addresses
  - **`online.tugraz.at`** ➠ **`129.27.2.210`**
- Hierarchical structure
  - **`.`** ➠ *root nameservers* (typically hardcoded)
  - **`at.`** ➠ ask **`127.30.48.1`** (**`dns.nic.at`**)
  - **`tugraz.at.`** ➠ ask **`129.27.2.3`** (**`ns1.tu-graz.ac.at`**)
  - **`online.tugraz.at.`** ➠ it's at **`129.27.2.210`**

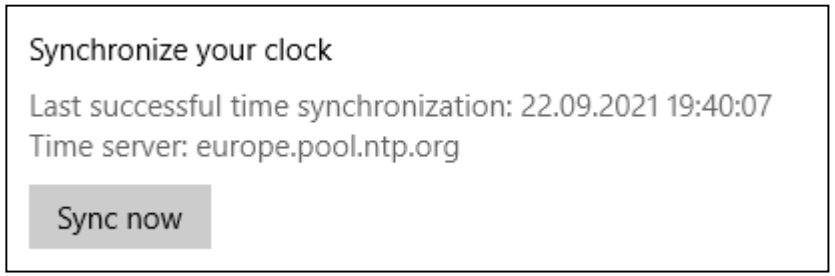
Domain Name System

- Typically, the client queries a *DNS resolver* on port 53
  - Well-known public resolvers:
    `1.1.1.1` (Cloudflare), `8.8.8.8` (Google), `9.9.9.9` (Quad9)
- The DNS resolver performs the actual recursive lookup if needed
  - This allows centralized caching of responses!

- DNS resolver address can also be determined via DHCP
  - Recall: **D**ynamic **H**ost **C**onfiguration **P**rotocol
    - It does IP address auto-configuration, we talked about it 😉

Network Time Protocol

- UDP port 123
- Time synchronization over the internet
- Synchronized clocks are required for many operations
  - Time-based 2FA tokens, expiry of SSL certificates, Kerberos tokens, …



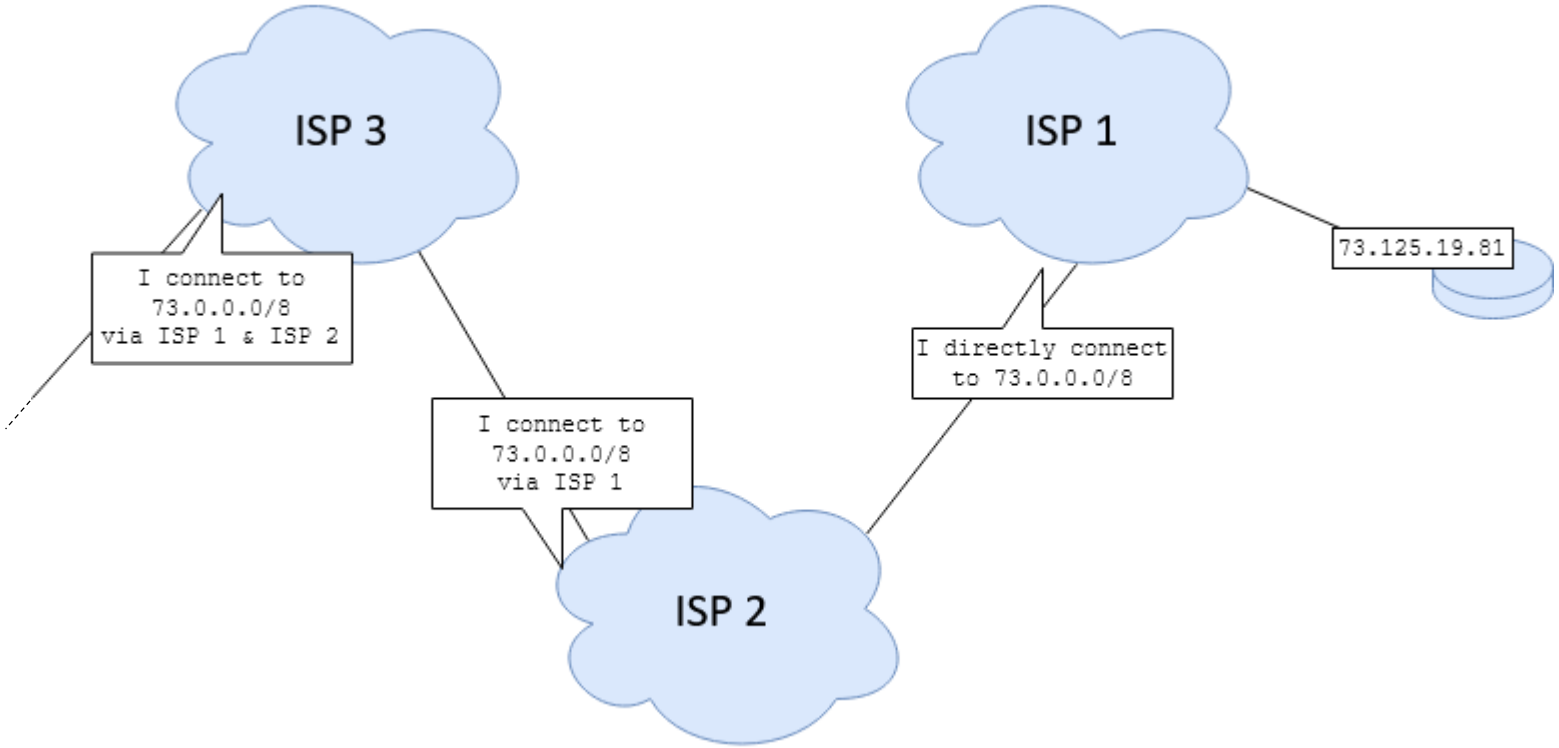

```
gallantron@ipn009:~$ ntpdate -d pool.ntp.org
23 Sep 14:11:04 ntpdate[159]: ntpdate 4.2.8p12@1.3728-o (1)
Looking for host pool.ntp.org and service ntp
91.206.8.34 reversed to svn.mediainvent.at
host found : svn.mediainvent.at

server 91.206.8.34, port 123
stratum 2, precision -21, leap 00, trust 000
refid [161.143.24.141], root delay 0.000610, root dispersion 0.029587
transmitted 4, in filter 4
reference time:    e4f6e9b1.246b51c0  Thu, Sep 23 2021 13:55:29.142
originate timestamp: e4f6ed5e.e6ff1685  Thu, Sep 23 2021 14:11:10.902
transmit timestamp:  e4f6ed5e.e602ffcb  Thu, Sep 23 2021 14:11:10.898
filter delay:  0.04388  0.03754  0.03914  0.03960
        0.00000  0.00000  0.00000  0.00000
filter offset: -0.00477 -0.00492 -0.00568 -0.00318
        0.000000 0.000000 0.000000 0.000000
delay 0.03754, dispersion 0.00082
offset -0.004928
```

Secure SHell

- TCP port 22
- Secure remote administration
  - Unless you have an insecure password…
- Using SSH as a building block in other applications is popular
  - SSH provides authentication + encryption
  - Example: **`git`**

Border Gateway Protocol

- TCP port 179
- Responsible for maintaining the global IP routing table
  - Essentially a distributed shortest-path graph algorithm



HyperText Transfer Protocol

- TCP port 80 (HTTP), TCP port 443 (**HTTP** over **S**SL)
  - SSL adds authentication & encryption – more on this next year!
- Every web page you view uses it

- Simple concept: ask the server for a document
  - The meaning of “document” has evolved greatly over the years
  - Originally: actual *document*, a static piece of content
  - Today: anything you can possibly imagine, often dynamically generated
    - Many applications communicate via HTTP due to its ubiquitous support

HTTP request

Method

Requested resource

```
GET /document.html HTTP/1.1\r\n
Accept: text/html\r\n
Host: webserver.net\r\n
User-Agent: SimpleWebBrowser\r\n
Connection: keep-alive\r\n
\r\n
```

Request line

Headers

Blank line – end of headers

HTTP response

Status code

```
HTTP/1.1 200 OK\r\n
Content-Type: text/html; charset=UTF-8\r\n
Content-Length: 47\r\n
Server: MyWebServer\r\n
Connection: close\r\n
\r\n
<html><head><title>Hello!</title></head></html>
```

Status line

Headers

Blank line – end of headers

HTTP methods

- **GET** – retrieve resource
- **HEAD** – retrieve only headers of resource
  - Example: check if a cached file has changed
- **POST** – modify resource
  PUT
  DELETE
  PATCH

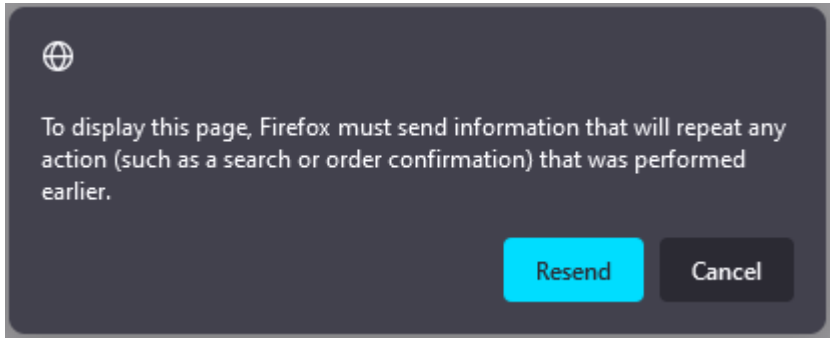
Read-only

Modify resource

HTTP methods

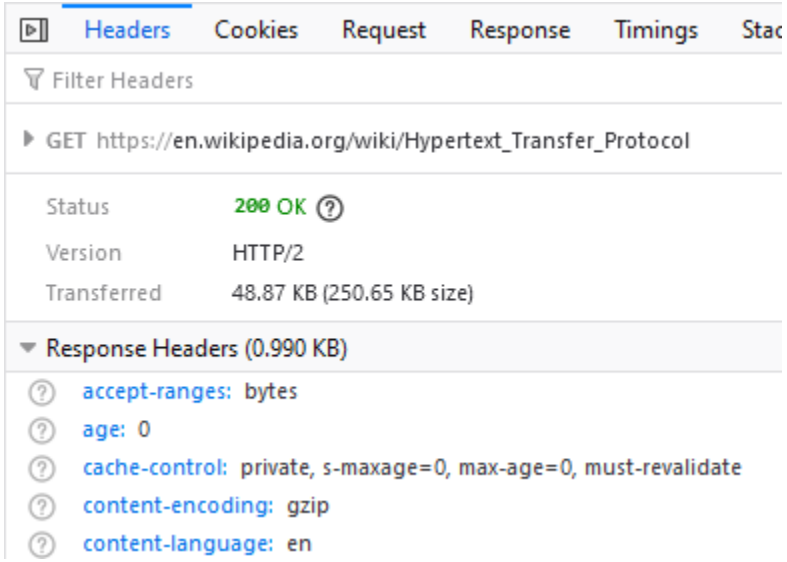
- Method functionality is purely by convention
  - There's nothing stopping you from deleting a file when a **`GET`** request is made
  - Just because you *can*, doesn't mean you *should*…

- Clients will offer different degrees of safeguards for different methods
  - Example: Reloading the result of a **`POST`** request triggers a dialog box



HTTP – you can try this at home!

- Open a new browser tab
- Open the developer tools (F12 in Firefox and Chrome)
- Switch to the “Network” tab
- Open your favorite website
- Each line is one HTTP request being made
  - Click on them to see what’s happening!

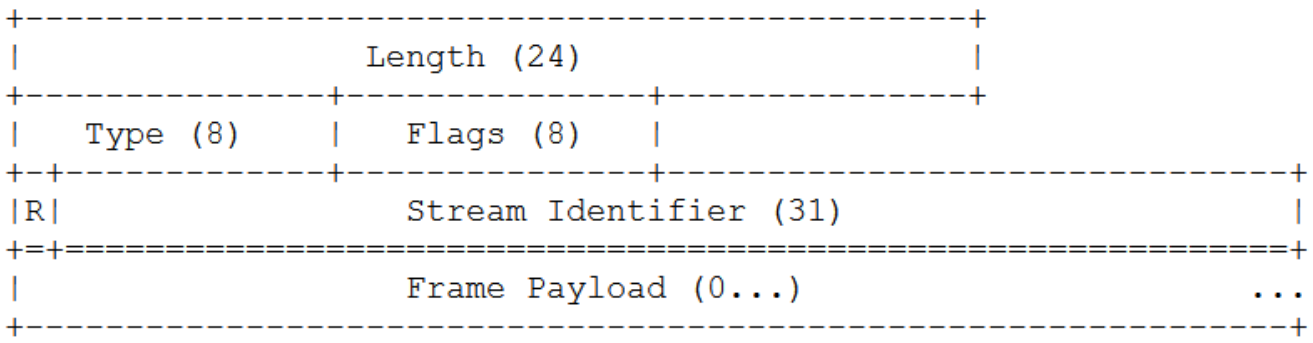


HTTP/1.1 – Problems

- Multiple requests can be sent over a single connection!
  - But: the responses still need to come in order…
    - **`search.php?search=bismuth`** ← Slow database query
    - **`search.css`** ← Fast file request — Needs to wait
  - Even though we know we need the file, we can't retrieve it…

HTTP/2

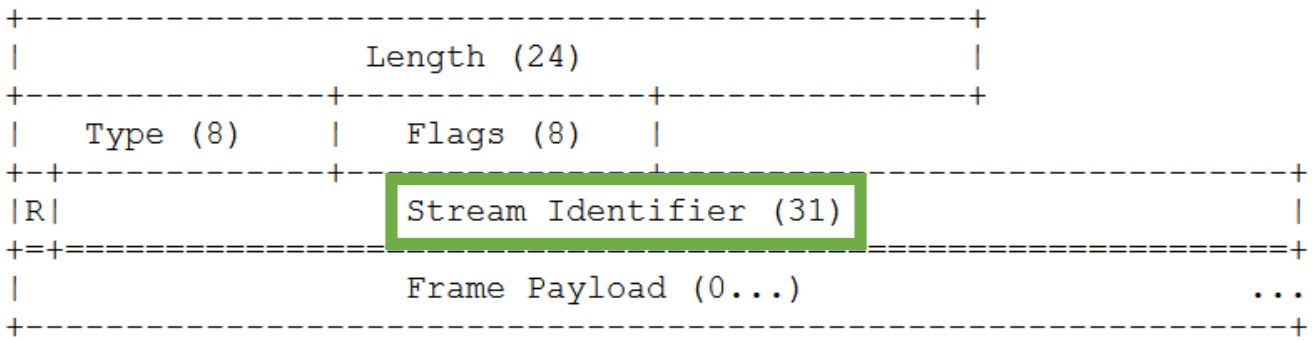
- No longer human readable
  - Binary representation is more compact



- Same request/response semantics, header fields, etc…

HTTP/2

- No longer human readable
  - Binary representation is more compact



- Same request/response semantics, header fields, etc…
- **Stream Identifier** allows multiple responses to be sent in parallel

HTTP/2

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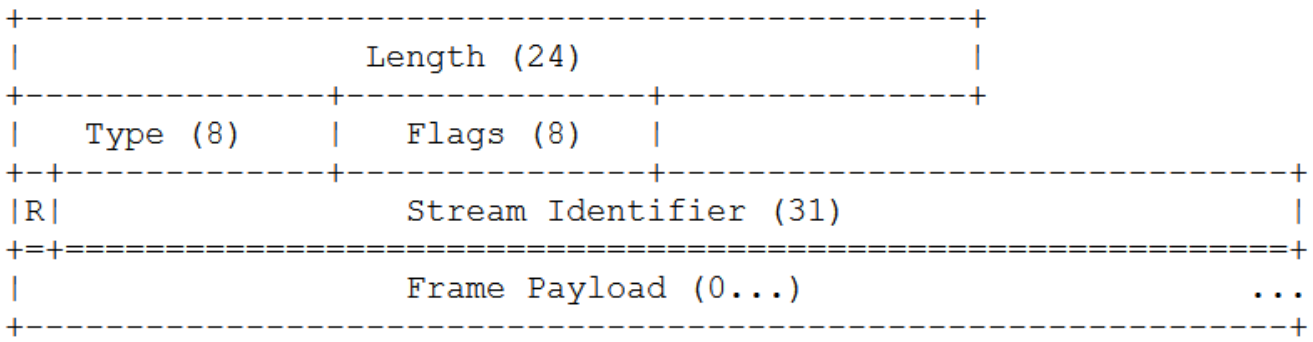


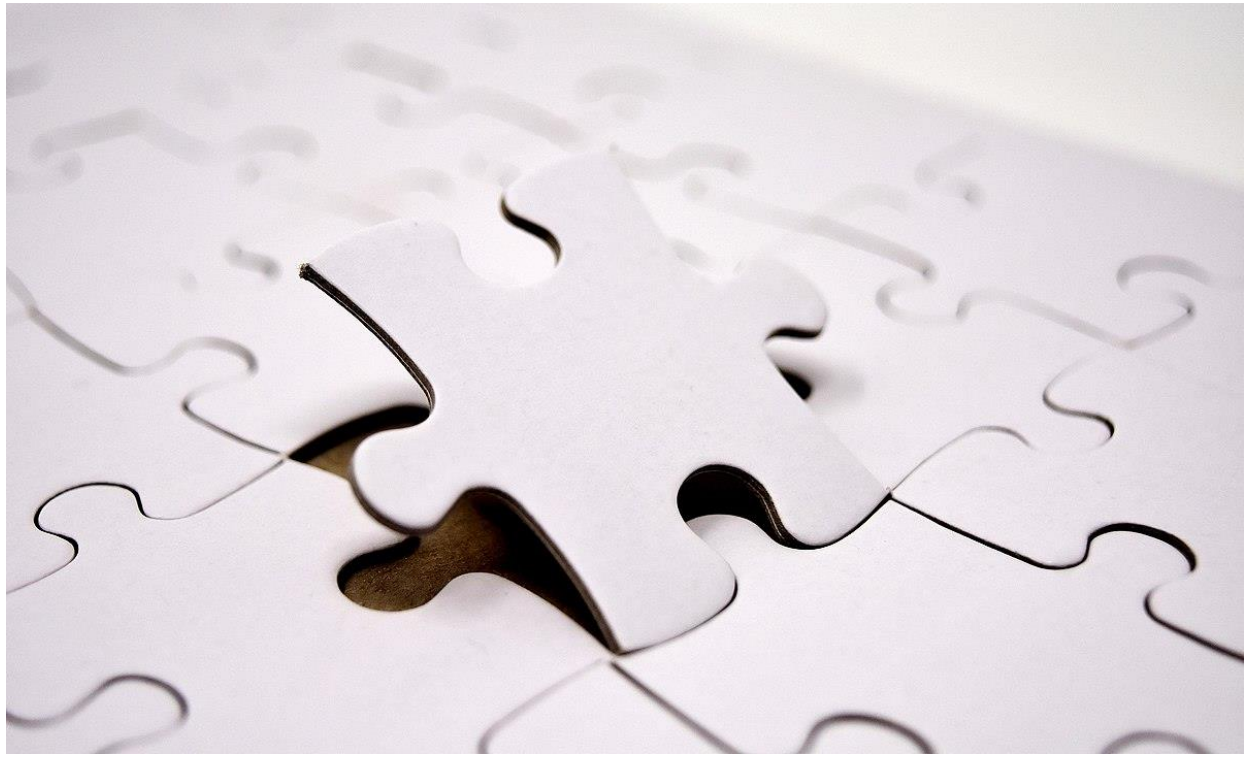
- Same request/response semantics, header fields, etc…
- Stream Identifier allows multiple responses to be sent in parallel
- Still runs over a TCP connection…
  - Packet loss on any stream “pauses” all streams’ data

HTTP/3

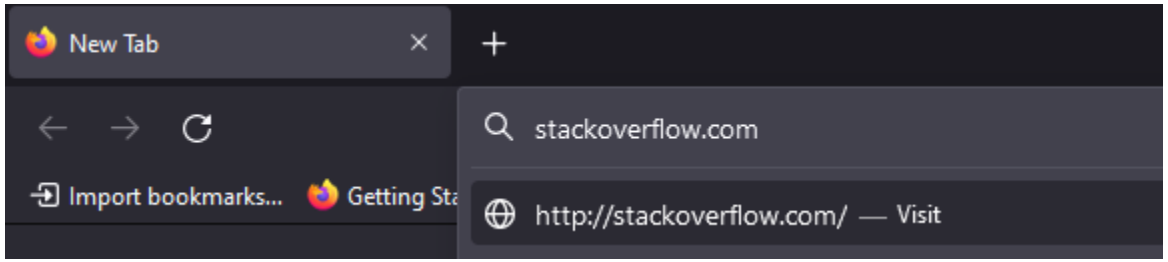
- QUIC to replace TCP
  - **Q**uick **U**DP **I**nternet **C**onnection
    - Originally developed by Google, since standardized by IETF
  - UDP at the transport layer for minimal overhead
  - Provides byte stream facilities similar to TCP
    - Aware of multiple data streams within a single connection
- Otherwise identical to HTTP/2

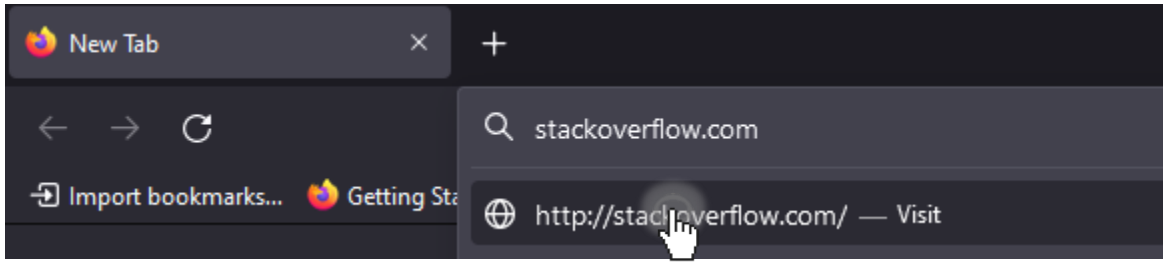
… and many, many, many, many more …

- Any program with network features is part of “the application layer”
  - Try running **`netstat`** while logged into your favorite game!

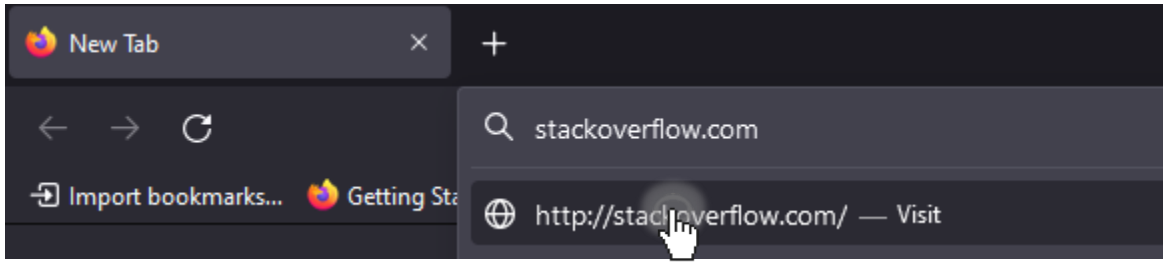


Putting it all together

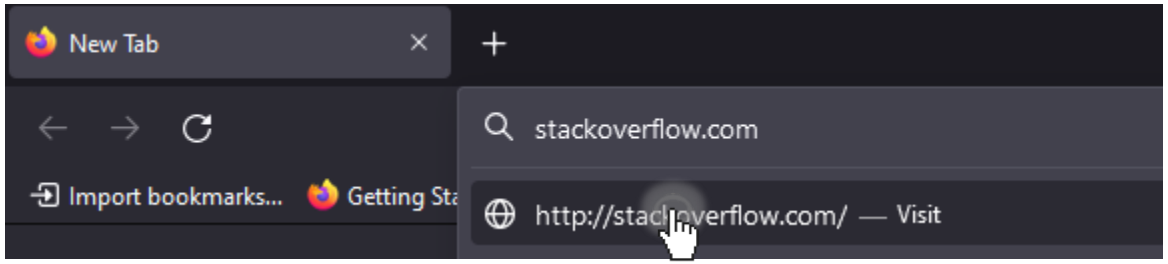

New Tab
stackoverflow.com
Import bookmarks...
Getting Sta
http://stackoverflow.com/ — Visit



- OK, what happens?



- Step 1: We need to figure out where **`stackoverflow.com`** is!
  - Let's ask our favorite DNS resolver!
  - DNS resolvers listen on UDP port 53
  - UDP is stateless, so we can just send our DNS request



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Hi, transport layer. Please send the following data to 8.8.4.4 on UDP port 53:

```
b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f l o w 03 c o m 00 00 ff 00 01
```

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```

Pick an unused UDP port… 49640

Attach a UDP header… done.

Network layer, please send the following data to 8.8.4.4:

```
c1 e8 00 35 00 23 00 00
b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f l o w 03 c o m 00 00 ff 00 01
```

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`b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f l o w 03 c o m 00 00 ff 00 01`

UDP datagram header

Offsets	Octet	0								1								2								3							
Octet	Bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	0	Source port																Destination port															
4	32	Length																Checksum															

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c1 e8 00 35 00 23 00 00
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Our IP address… it's 192.168.42.18.
What's the next hop towards 8.8.4.4? The default gateway, 192.168.42.254.
What's the MAC address for that… ah, it's f2:d3:09:9d:53:1a.
Link Layer, please send the following data to f2:d3:09:9d:53:1a via port eth0:
45 00 00 3f 1a 8a 00 00 ff 11 aa 5d c0 a8 2a 12 08 08 04 04 c1 e8 00 35 00 23 00 00
b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f l o w 03 c o m 00 00 ff 00 01

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```

Offsets	Octet	0								1								2								3							
Octet	Bit	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
0	0	Version				Header Length				DSCP						ECN		Total Length															
4	32	Identification																Flags				Fragment Offset											
8	64	Time To Live								Protocol								Header Checksum															
12	96	Source IP Address																															
16	128	Destination IP Address																															

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```
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b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f l o w 03 c o m 00 00 ff 00 01
```

Our MAC address is `a8:5e:de:32:19:27`.
Hi, other side. Here's frame data modulated into the electrical current flowing over the wire:

```
a8 5e de 32 19 27 f2 d3 09 9d 53 1a 08 00 45 00 00 3f 1a 8a 00 00 ff 11 aa 5d c0 a8 2a 12 08
08 04 04 c1 e8 00 35 00 23 00 00 b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f
l o w 03 c o m 00 00 ff 00 01 93 a0 13 f7
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```
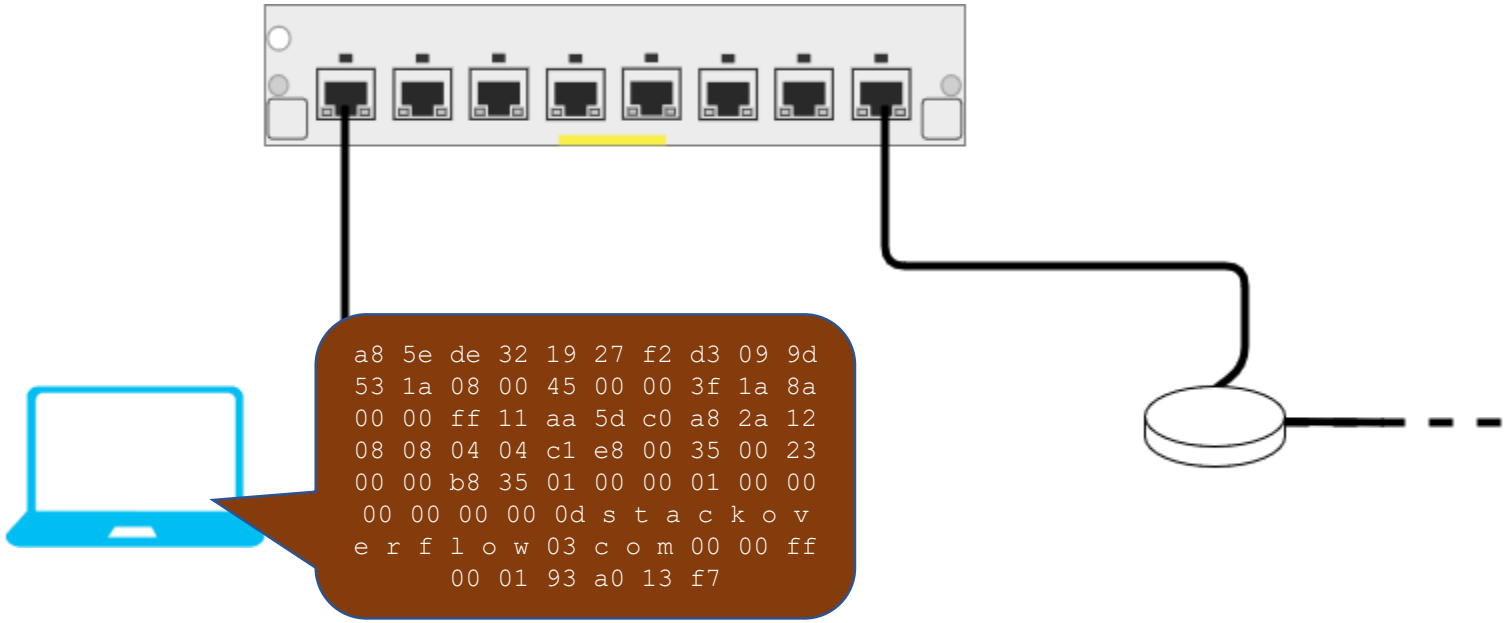
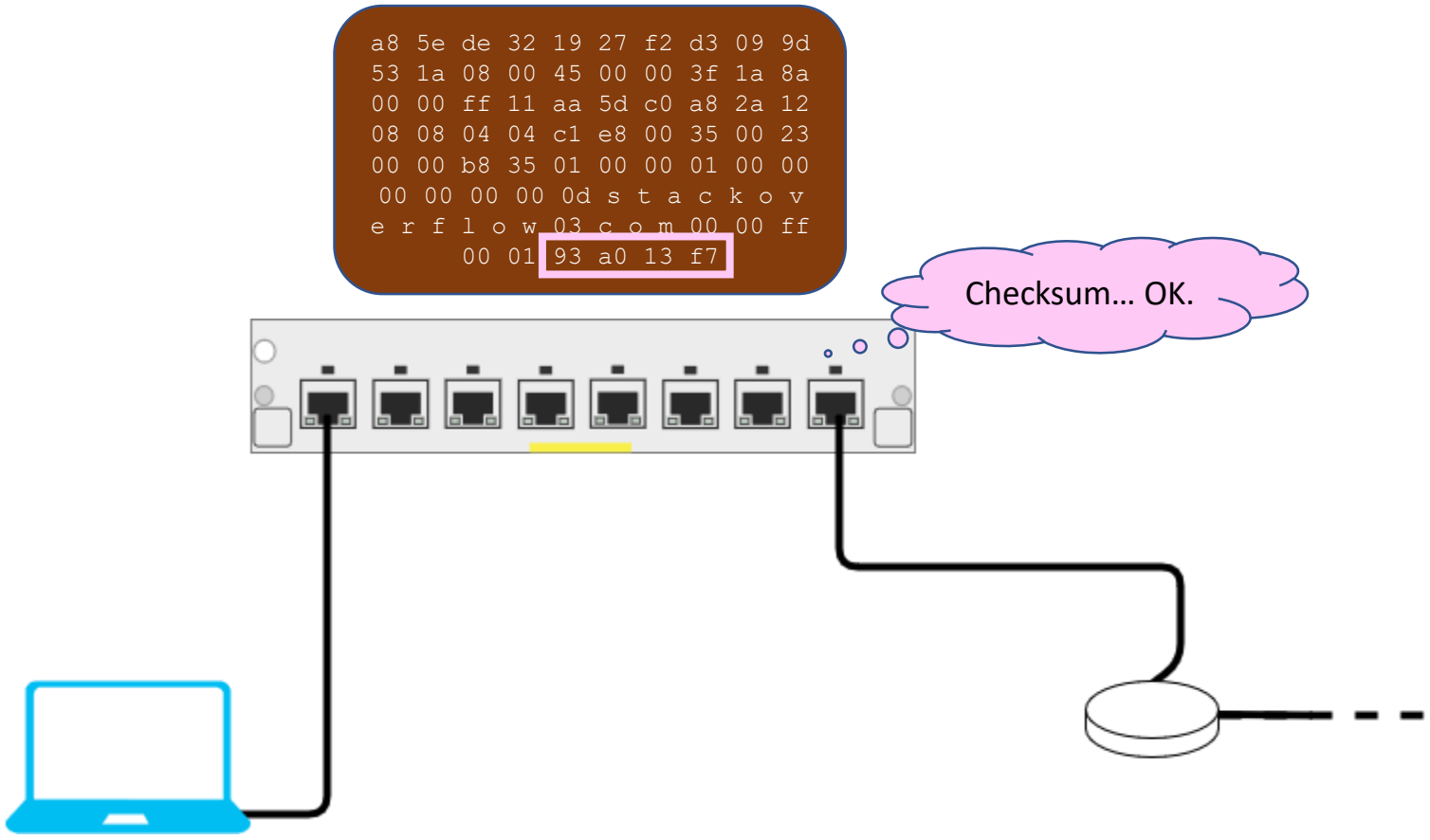
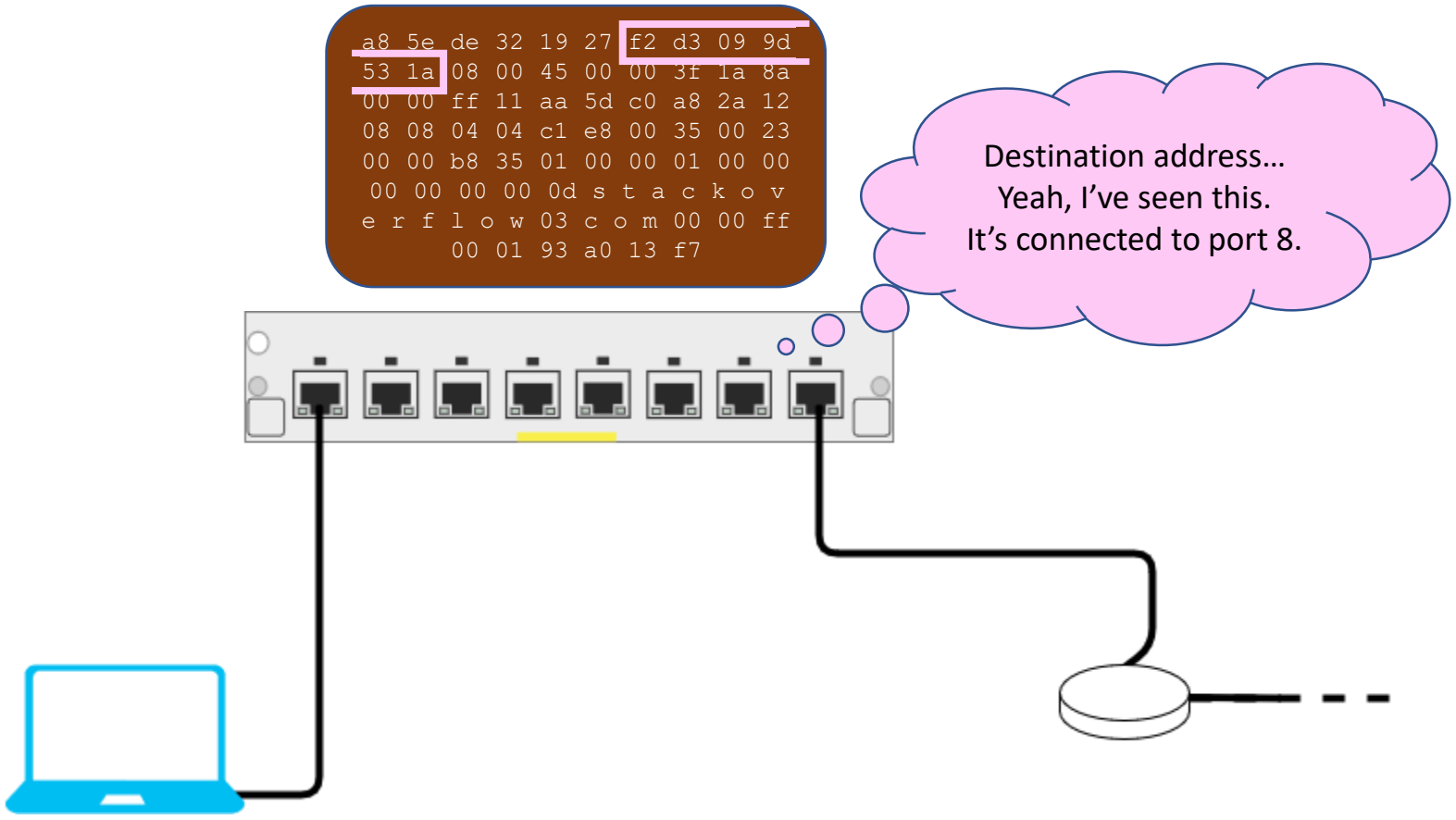
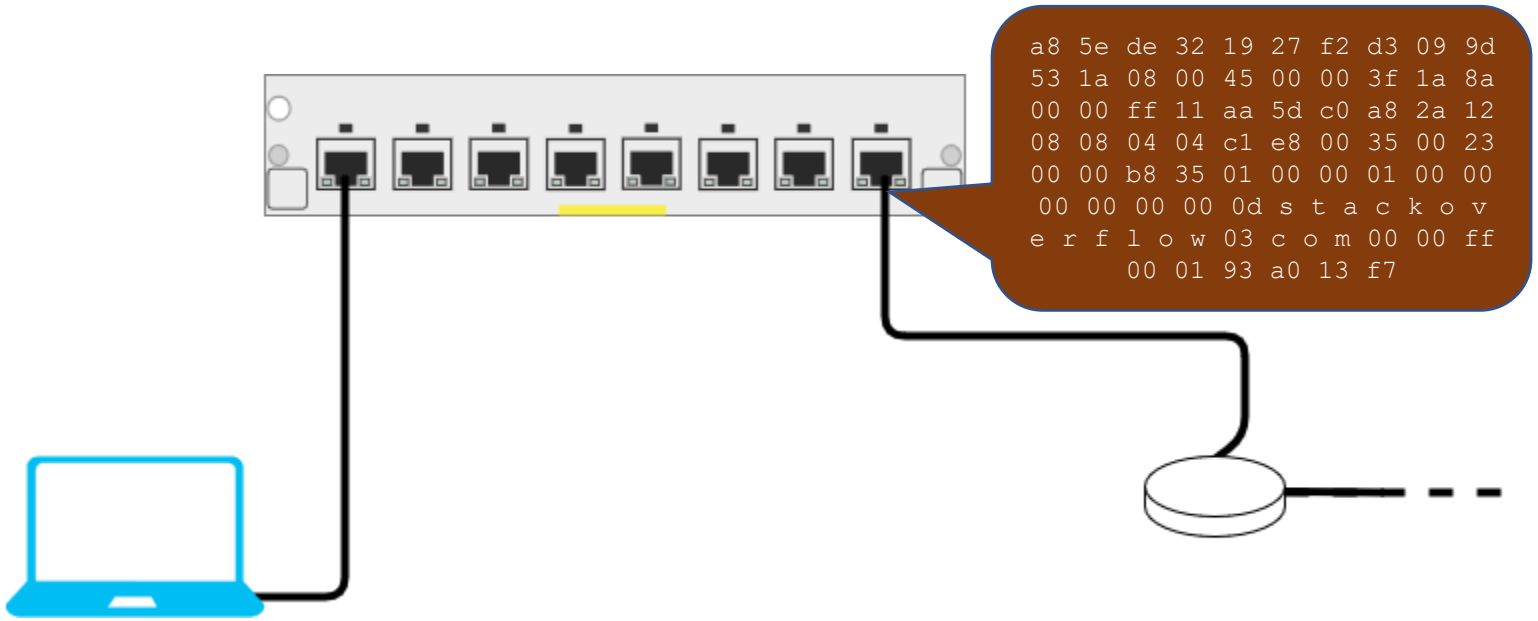


a8 5e de 32 19 27 f2 d3 09 9d
53 1a 08 00 45 00 00 3f 1a 8a
00 00 ff 11 aa 5d c0 a8 2a 12
08 08 04 04 c1 e8 00 35 00 23
00 00 b8 35 01 00 00 01 00 00
00 00 00 00 0d s t a c k o v
e r f l o w 03 c o m 00 00 ff
00 01 93 a0 13 f7


a8 5e de 32 19 27 f2 d3 09 9d
53 1a 08 00 45 00 00 3f 1a 8a
00 00 ff 11 aa 5d c0 a8 2a 12
08 08 04 04 c1 e8 00 35 00 23
00 00 b8 35 01 00 00 01 00 00
00 00 00 00 0d s t a c k o v
e r f l o w 03 c o m 00 00 ff
00 01 93 a0 13 f7
Checksum… OK.


a8 5e de 32 19 27 f2 d3 09 9d
53 1a 08 00 45 00 00 3f 1a 8a
00 00 ff 11 aa 5d c0 a8 2a 12
08 08 04 04 c1 e8 00 35 00 23
00 00 b8 35 01 00 00 01 00 00
00 00 00 00 0d s t a c k o v
e r f l o w 03 c o m 00 00 ff
00 01 93 a0 13 f7
Destination address…
Yeah, I've seen this.
It's connected to port 8.


a8 5e de 32 19 27 f2 d3 09 9d
53 1a 08 00 45 00 00 3f 1a 8a
00 00 ff 11 aa 5d c0 a8 2a 12
08 08 04 04 c1 e8 00 35 00 23
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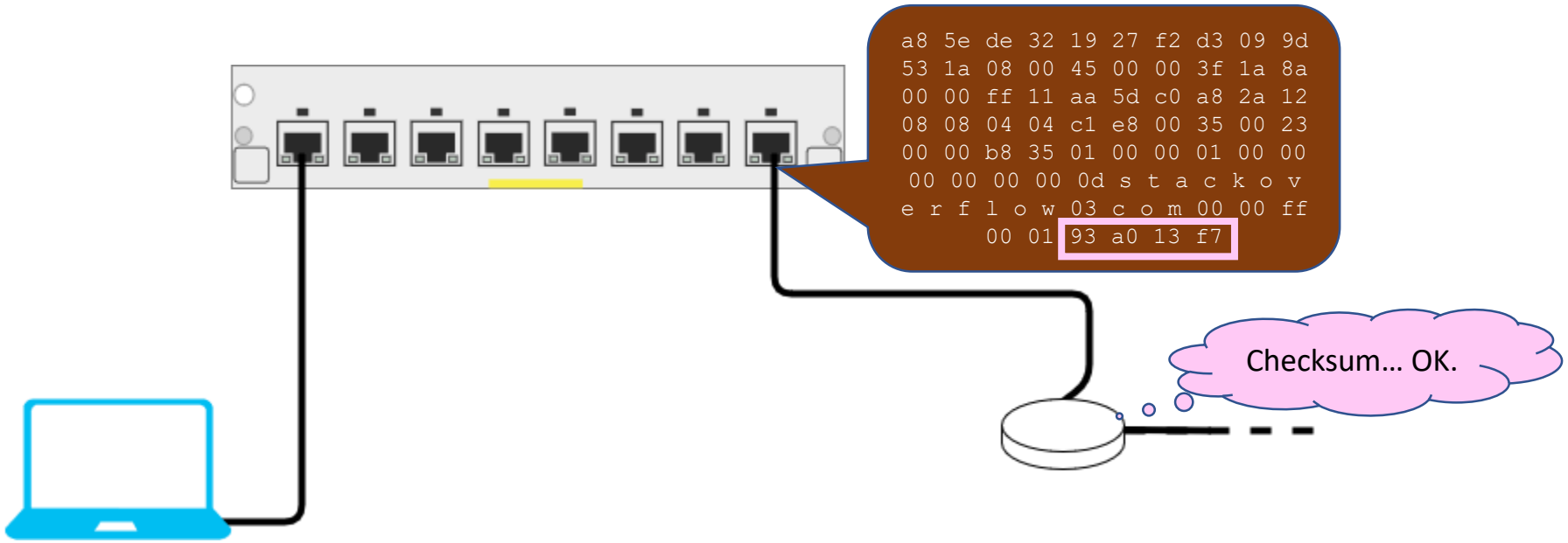
a8 5e de 32 19 27 f2 d3 09 9d
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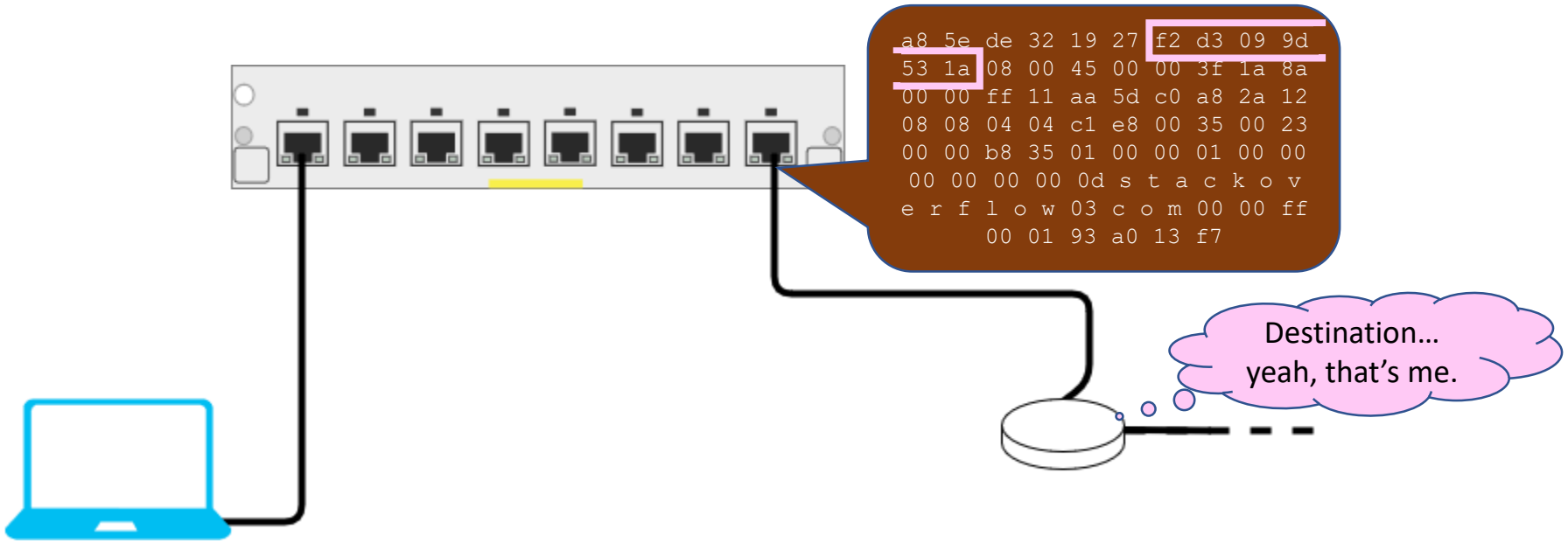
00 01 93 a0 13 f7
Checksum… OK.


a8 5e de 32 19 27 f2 d3 09 9d
53 1a 08 00 45 00 00 3f 1a 8a
00 00 ff 11 aa 5d c0 a8 2a 12
08 08 04 04 c1 e8 00 35 00 23
00 00 b8 35 01 00 00 01 00 00
00 00 00 00 0d s t a c k o v
e r f l o w 03 c o m 00 00 ff
00 01 93 a0 13 f7
Destination…
yeah, that's me.

Hey, Network Layer, data arrived for you:

```
45 00 00 3f 1a 8a 00 00 ff 11 aa 5d c0 a8 2a 12 08 08 04 04 c1 e8 00 35 00 23 00 00
b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f l o w 03 c o m 00 00 ff 00 01
```

Hey, Network Layer, data arrived for you:

```
45 00 00 3f 1a 8a 00 00 ff 11 aa 5d c0 a8 2a 12 08 08 04 04 c1 e8 00 35 00 23 00 00
b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f l o w 03 c o m 00 00 ff 00 01
```

Let's see… destination address 8.8.4.4? That's not me, I need to pass this on…
First, decrease the TTL field, and recalculate the checksum… then…
Next hop in that direction is… 192.168.255.254…
I have its MAC address cached… `a7:a2:23:95:d6:a6`.
Link Layer, please send this data to `a7:a2:23:95:d6:a6` via port `eth1`:

```
45 00 00 3f 1a 8a 00 00 fe 11 ab 5d c0 a8 2a 12 08 08 04 04 c1 e8 00 35 00 23 00 00
b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f l o w 03 c o m 00 00 ff 00 01
```

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```
45 00 00 3f 1a 8a 00 00 ff 11 aa 5d c0 a8 2a 12 08 08 04 04 c1 e8 00 35 00 23 00 00
b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f l o w 03 c o m 00 00 ff 00 01
```

Let's see… destination address 8.8.4.4? That's not me, I need to pass this on…
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```
45 00 00 3f 1a 8a 00 00 fe 11 ab 5d c0 a8 2a 12 08 08 04 04 c1 e8 00 35 00 23 00 00
b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f l o w 03 c o m 00 00 ff 00 01
```

Let's see… destination address 8.8.4.4? That's not me, I need to pass this on…
First, decrease the TTL field, and recalculate the checksum… then…
Next hop in that direction is… 192.168.255.254…
I have its MAC address cached… a7:a2:23:95:d6:a6.
Link Layer, please send this data to a7:a2:23:95:d6:a6 via port eth1:

```
45 00 00 3f 1a 8a 00 00 fe 11 ab 5d c0 a8 2a 12 08 08 04 04 c1 e8 00 35 00 23 00 00
b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f l o w 03 c o m 00 00 ff 00 01
```

Our MAC address on that interface… 58:42:30:35:8a:08.
Hi, other side, here's data:

```
58 42 30 35 8a 08 a7 a2 23 95 d6 a6 08 00 45 00 00 3f 1a 8a 00 00 ff 11 aa 5d c0 a8 2a 12 08
08 04 04 c1 e8 00 35 00 23 00 00 b8 35 01 00 00 01 00 00 00 00 00 00 0d s t a c k o v e r f
l o w 03 c o m 00 00 ff 00 01 d9 96 19 f0
```

…

Looking Forward…

Let’s Get Dangerous

- So far, everyone has played nice…
  - Real life is difficult, and people are people
- INP.33404UF Information Security
  - Suddenly, everyone is evil – and so are you
  - See you next year!