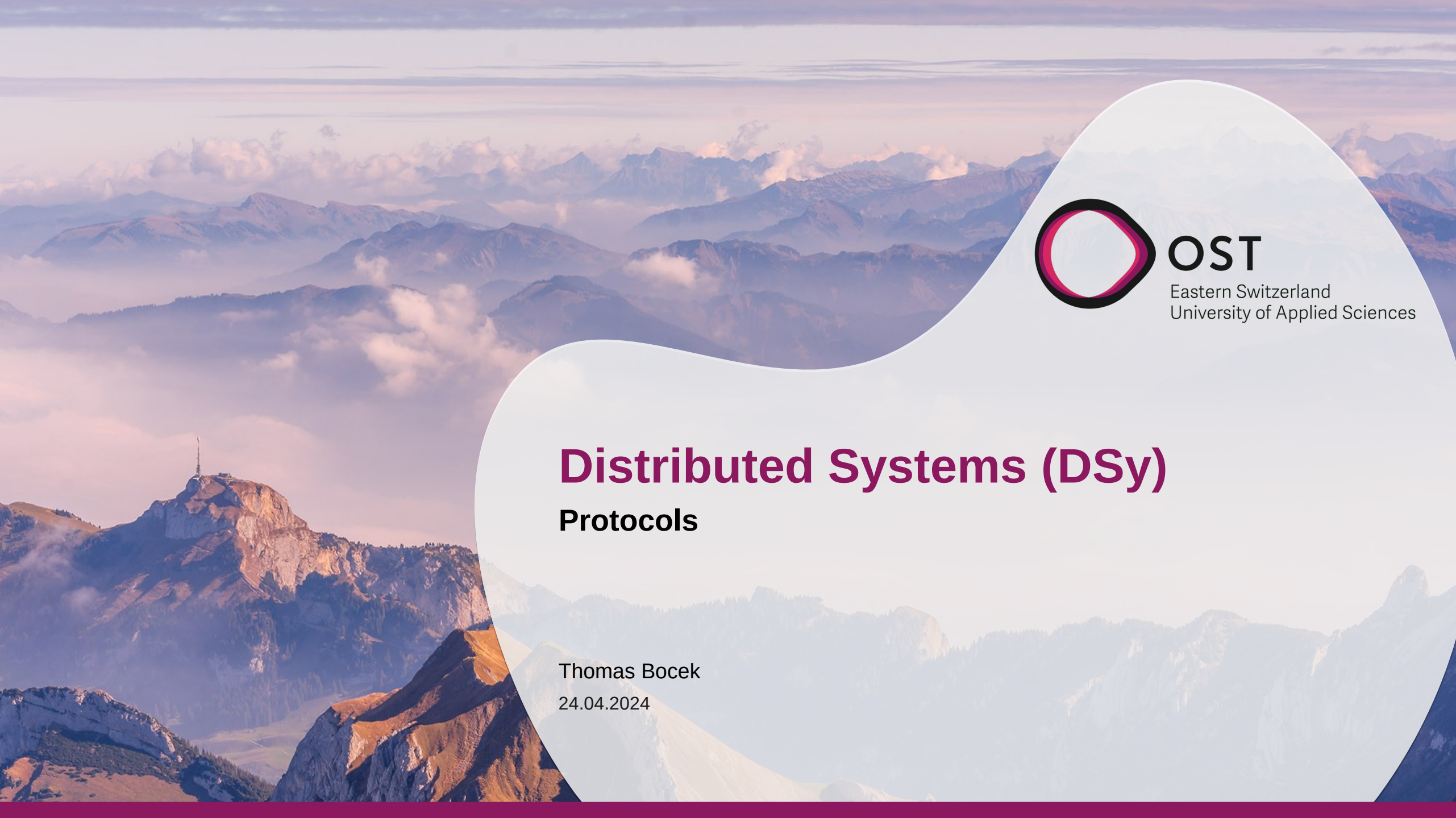

OST
Eastern Switzerland
University of Applied Sciences

Distributed Systems (DSy)

Protocols

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24.04.2024

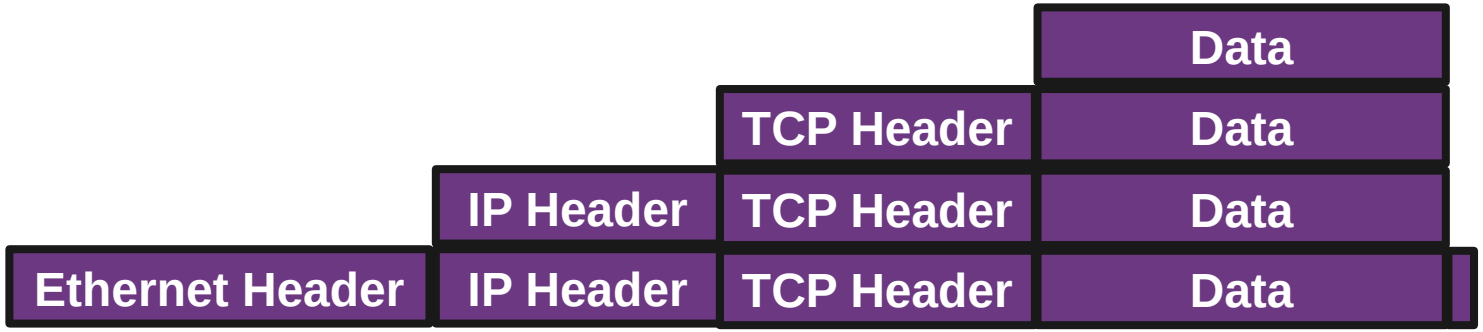
Learning Goals

- Lecture 8 (Protocols)
  - How do network layers work?
  - What are the TCP mechanisms?
  - What are the problems of TCP, and how other protocols (HTTP/3) can improve that

Networking: Layers

- Networking: Each vendor had its own proprietary solution - not compatible with another solution
  - IPX/SPX – 1983, AppleTalk 1985, DECnet 1975, XNS 1977
- Nowadays most vendors build compatible networks hardware/software from different vendors
  - Cisco, Dell, HP, Huawei, Juniper, Lenovo, Linksys, Netgear, MicroTik, Siemens, Ubiquiti, etc.
- Goal of layers: interoperability
  - 1984: ISO 7498 - The Basic Reference Model for Open Systems Interconnection

OSI model	"Internet model"
Application	Application
Presentation	
Session	
Transport	Transport
Network	Internet
Data link	Link
Pysical	



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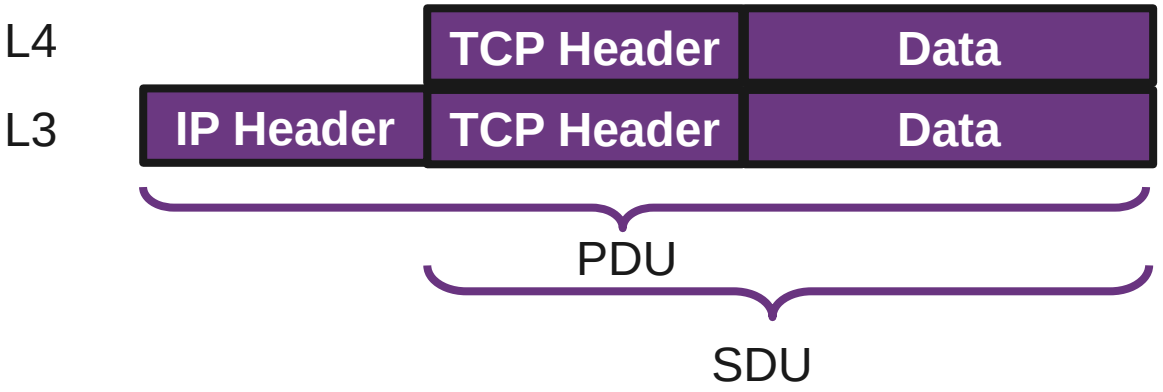
Networking: Definitions

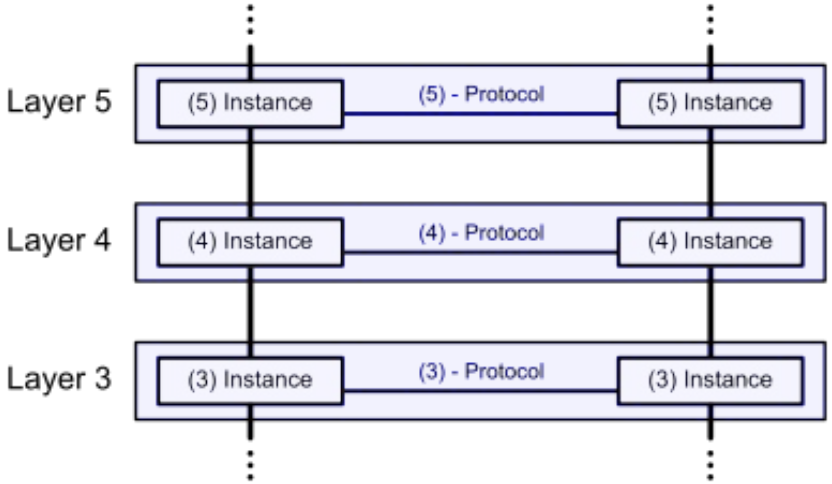
RFC 1122, Internet STD 3 (1989)	OSI model
Four layers	Seven layers
"Internet model"	OSI model
Application	Application
	Presentation
	Session
Transport	Transport
Internet	Network
Link	Data link
	Physical

source: https://en.wikipedia.org/wiki/Internet_protocol_suite

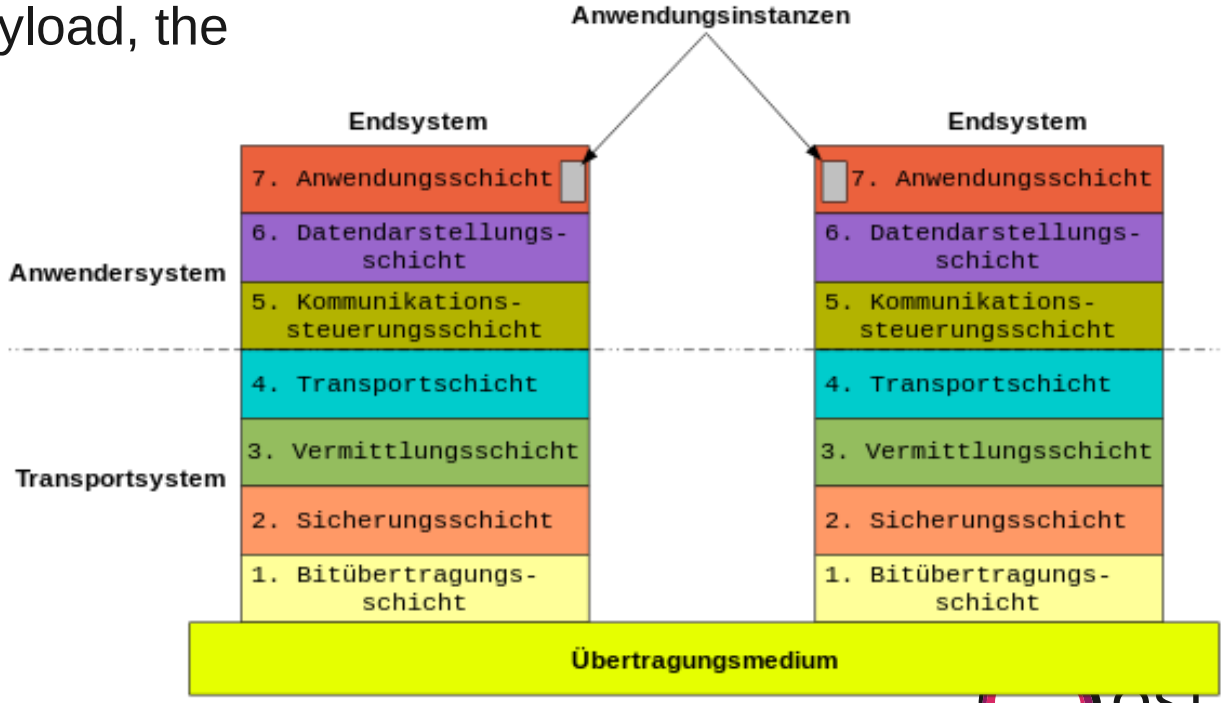
Layer Abstraction

- Protocols enable an entity/instance to interact with an entity/instance at the same layer in another host
- Service definitions: provide functionality to an (N)-layer by an (N-1) layer
- Each PDU contains a protocol header and payload, the service data unit (SDU). E.g. PDU of L3:





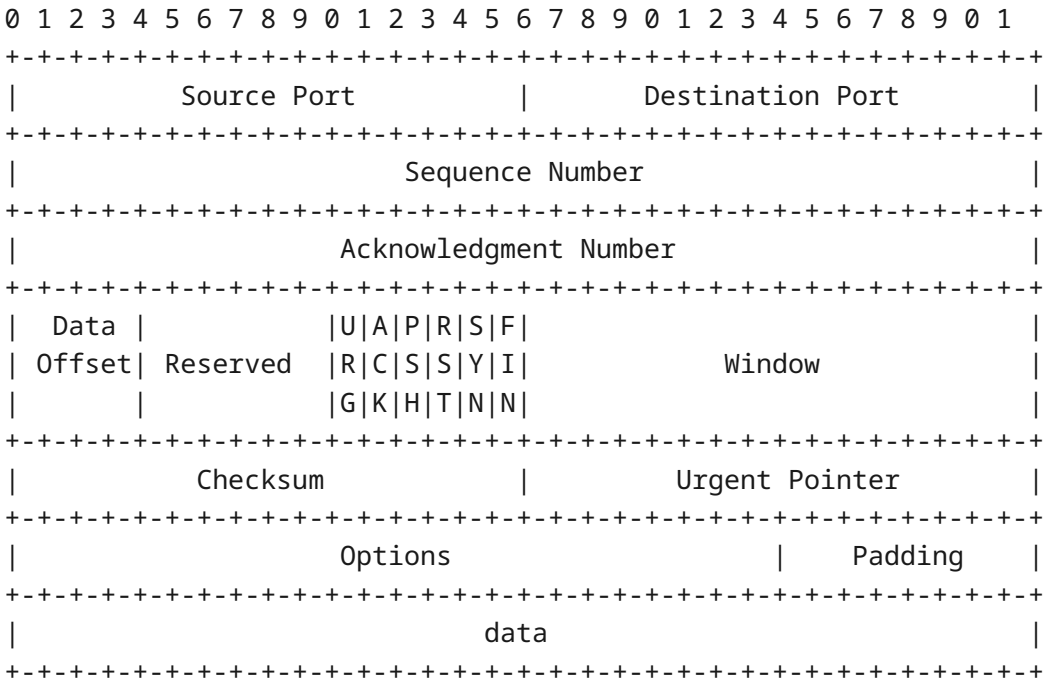
source: https://en.wikipedia.org/wiki/OSI_model



source: https://de.wikipedia.org/wiki/OSI-Modell

Layer 4 - Transport

- TCP (Transmission Control Protocol)
  - Reliable (retransmission)
  - Ordered
  - Window – capacity of receiver
  - Checksum – 16bit (crc16)
  - TCP overhead: 20bytes
    - IP overhead: 20bytes
    - Ethernet frame: 18bytes (crc32)
- TCP tries to correct errors; you don’t need to worry…
  - Sometimes, you need to worry…



source: http://freesoft.org/CIE/Course/Section4/8.htm

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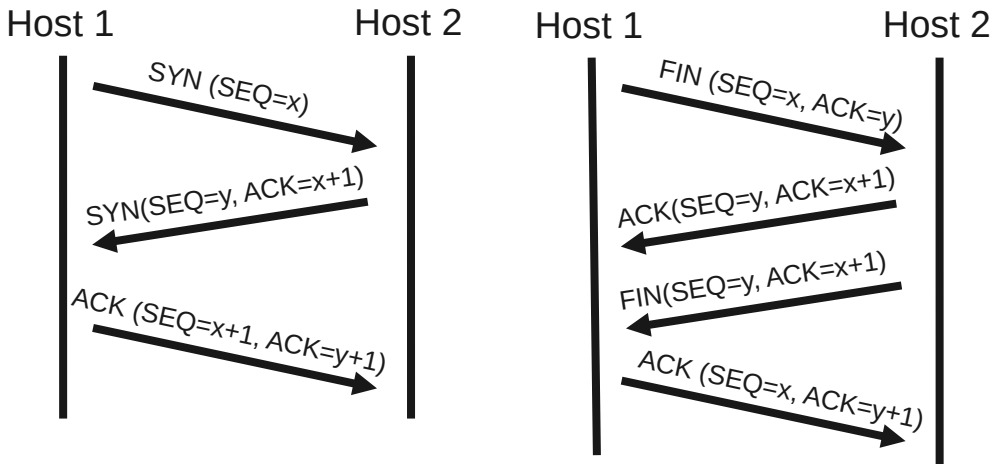
Layer 4 - TCP

- Connection establishment
  - SYN, SYN-ACK, ACK (three way)
  - Initiates TCP session: initial sequence number is ~ random
- Connection termination
  - FIN, ACK + FIN, ACK (three/four way)
  - 3-way handshake, when host 1 sends a FIN and host 2 replies with a FIN & ACK
- Sequences and ACKs
  - Identification each byte of data
  - Order of the bytes → reconstruction
  - Detecting lost data: RTO, DupACK:



- Retransmission timeout
  - If no ACK is received aftert timout (e.g. 2xRTT), resend.
- Duplicate cumulative acknowledgements, selective ACK [link]
  - ACKs for last consecutive packets
  - 3 times same ACK → retransmit missing packets (fast retransmit)

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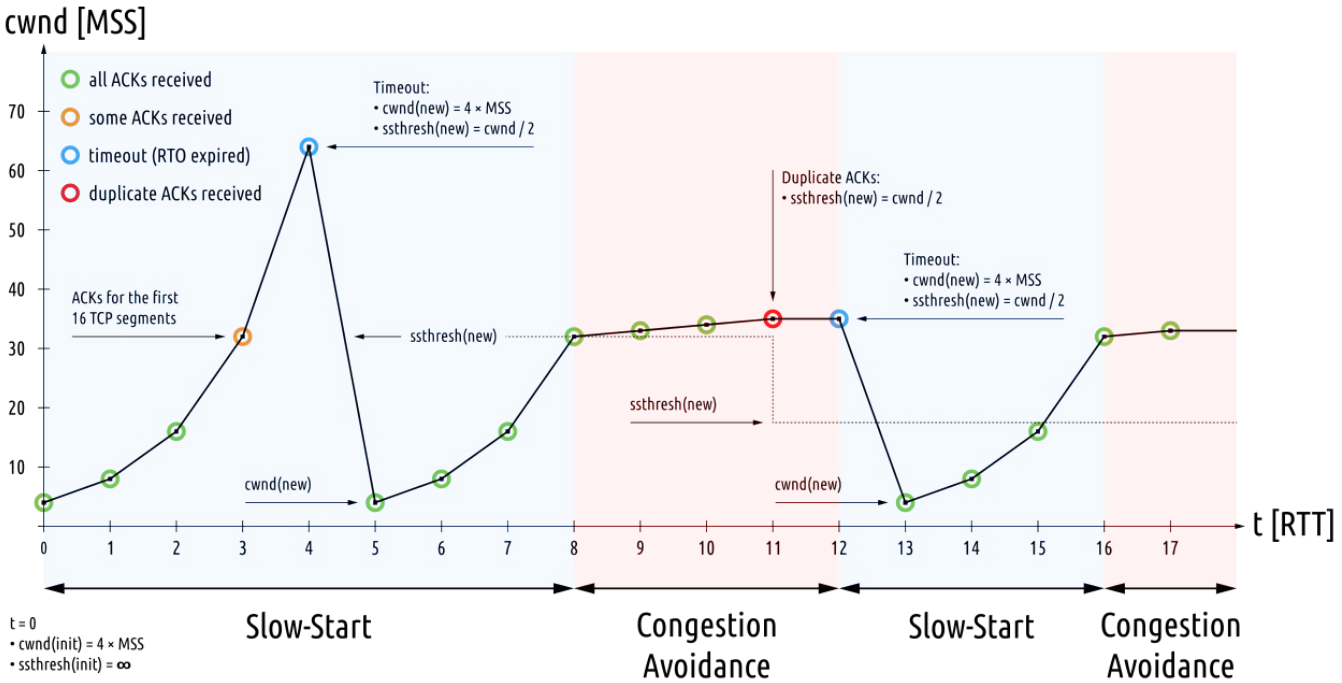
Layer 4 - TCP

- Flow control
  - Sender is not overwhelming a receiver
  - Back pressure
  - Sliding window:
    - Receiver specifies the amount of additionally received data in bytes that can be buffered
    - Sender up to that amount of data before ACK
- Congestion control
  - slow-start
  - congestion avoidance
- Difference flow/congestion control



source:
https://upload.wikimedia.org/wikipedia/commons/thumb/2/24/TCP_Slow-Start_and_Congestion_Avoidance.svg/1280px-TCP_Slow-Start_and_Congestion_Avoidance.svg.png

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TCP/IP from an Application Developer View

- Server in golang (repo)
  - git clone https://github.com/tbocek/DSy
  - Download GoLand, or others
  - go run server.go → server
- Listening on TCP port 8081
  - Return string in uppercase
- Node.js version
  - Download WebStorm, or other
- Client:
  - nc localhost 8081

```
const net = require('net');
const server = new net.Server();
server.listen(8081, function() {
   console.log('Launching server...');
});

server.on('connection', function(socket) {
   socket.on('data', function(chunk) {
      console.log(`Data received from client: $
{chunk.toString()}`);

socket.write(chunk.toString().toUpperCase() +
"\n");
   });
});
```

```
package main
import ("bufio"
    "fmt"
    "net"
    "strings")
func main() {
    fmt.Println("Launching server...")
    ln, _ := net.Listen("tcp", ":8081") // listen
on all interfaces
    for {
        conn, _ := ln.Accept() // accept
connection on port
        message, _ :=
bufio.NewReader(conn).ReadString('\n') //read line
        fmt.Print("Message Received:",
string(message))
        newMessage := strings.ToUpper(message)
//change to upper
        conn.Write([]byte(newMessage + "\n"))
//send upper string back
    }
}
```


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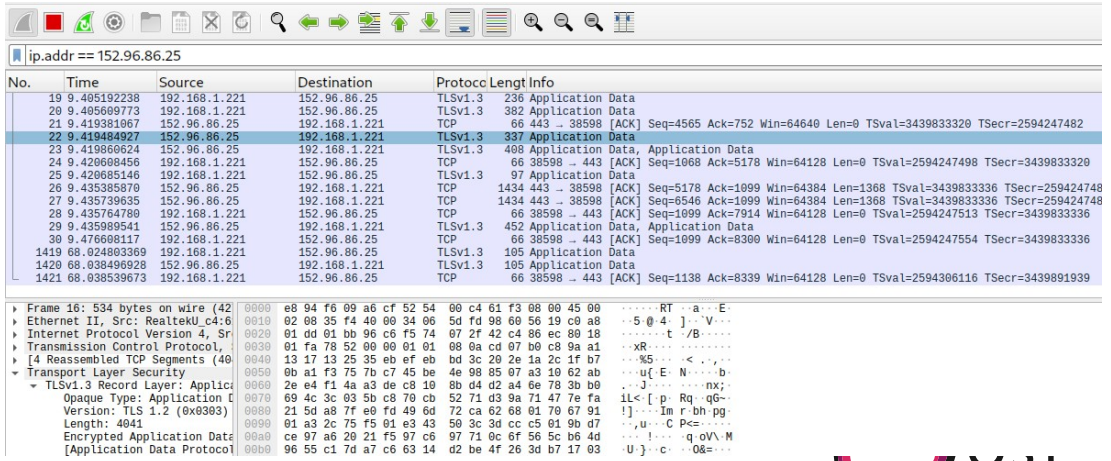
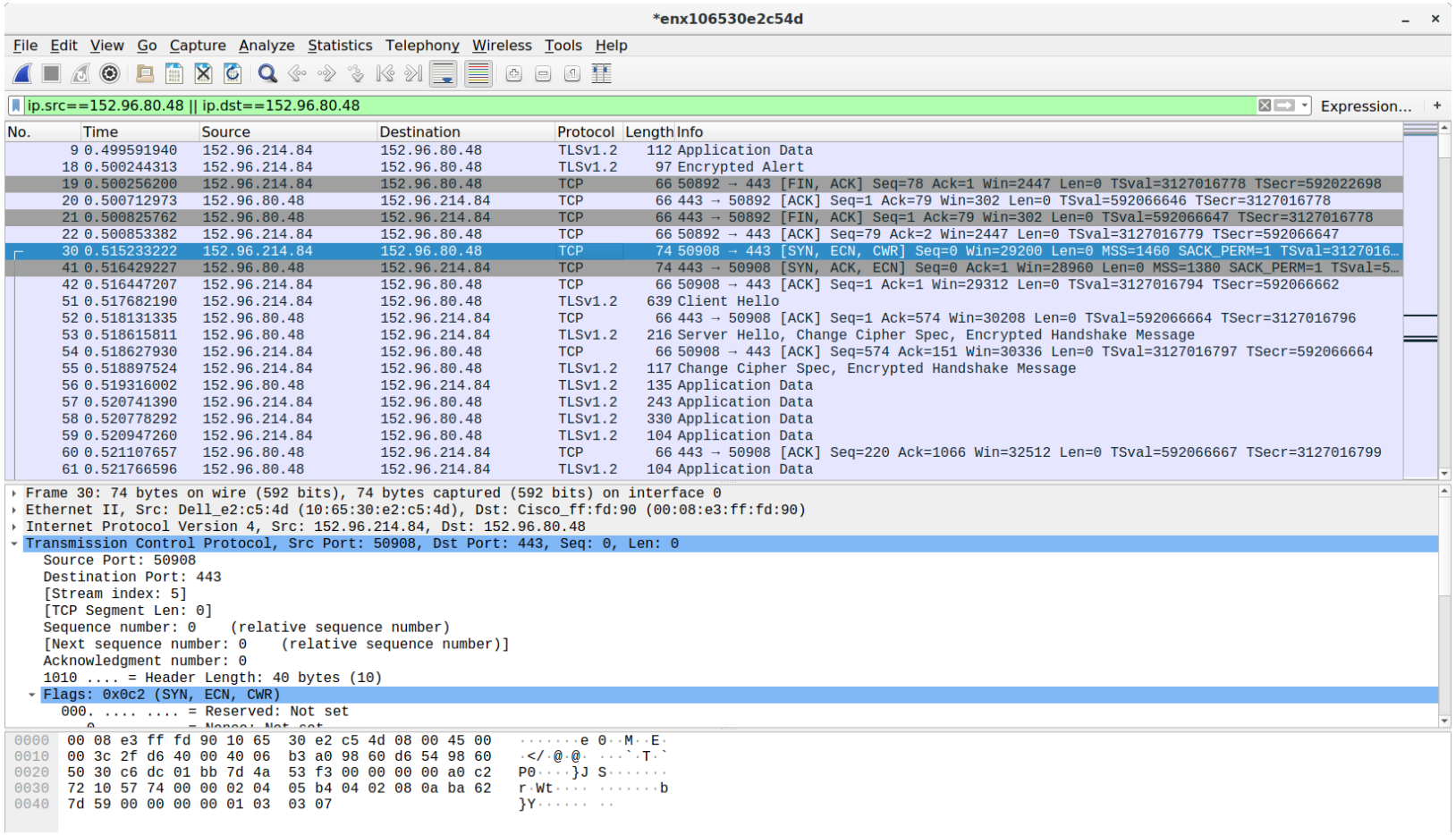
TCP Considerations

- Fallacy 2: Latency is zero
  - Nürnberg data center: 15ms, Australia: 300ms
  - Ping ftp.au.debian.org , Starklink + 50ms
- Problem: TCP handshake is not flexible
  - You need a handshake (1RT)
    1) If you want to make sure the other side accepts packets (and not drop it) - ensure both sides are ready to transmit and receive data
    2) If you want to exchange public / private keys
  - TCP supports 1) but not 2)
    - Use another security layer for 2), but a security layer needs at least 1 RT
    - TCP + Security = at least 2 RT
      - Nürnberg + Starlink:2 x (15 + 50ms) = 130ms
      - Australian: (2 x 300ms) = 600ms
- TCP + Security at least 2 RT
  - DNS query may be required too: 3 RT
  - Old security protocols add RT: 4RT
- Starklink, Kuiper, OneWeb in lower orbit
  - Viasat is 631 ms (higher orbit)
- Worst case: Starlink/Australia/DNS/TCP/old sec: 1.4s before data can be sent → new protocols on the way (HTTP/3)
- Wireshark



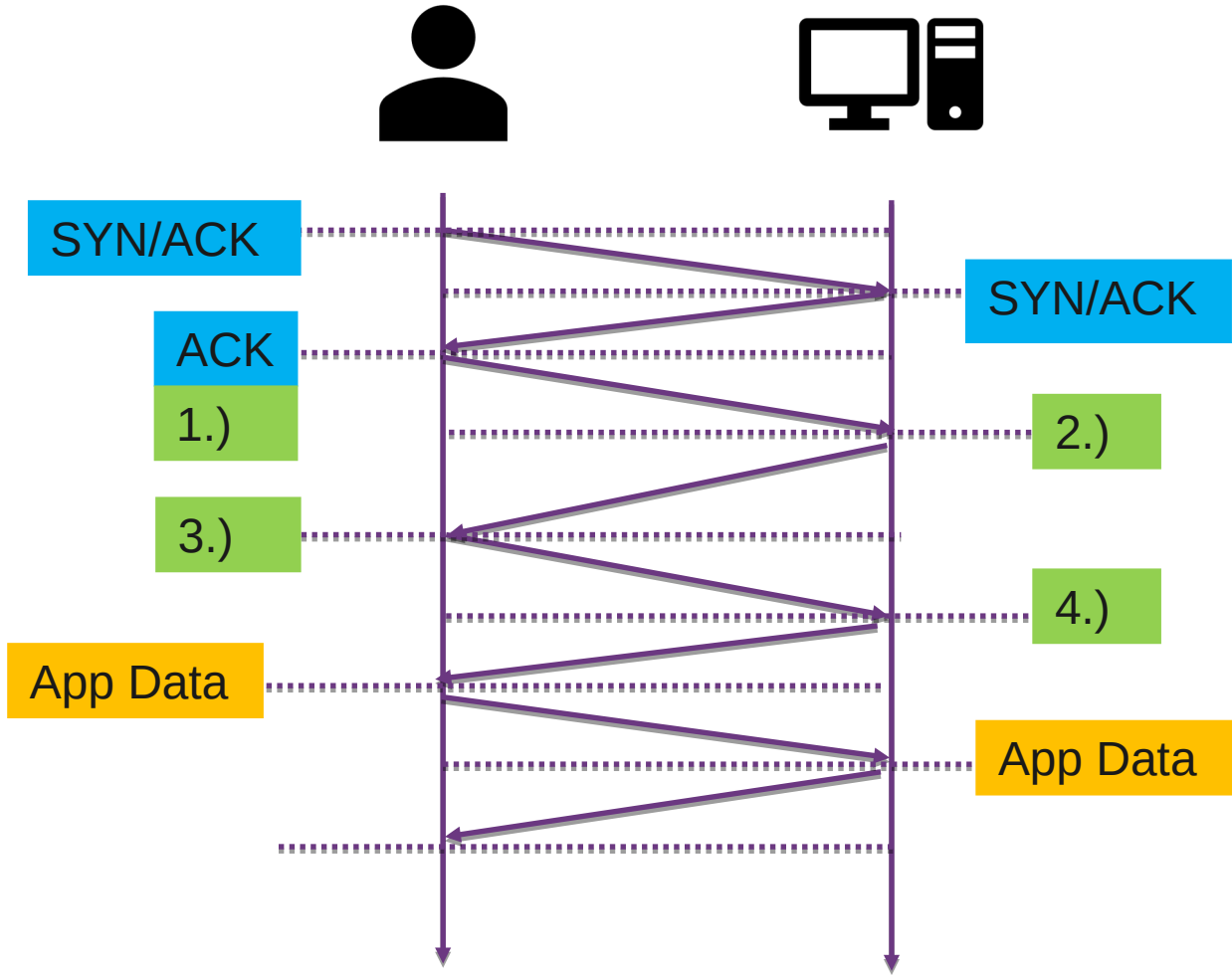
Wireshark – sometimes needed when designing protocols

- Decrypt TLS
  - `export SSLKEYLOGFILE=/tmp/keylogfile.txt`



Layer 4 – TCP + TLS

- Security: Transport Layer Security (TLS)
  1. "client hello" lists cryptographic information, TLS version, ciphers/keys
  2. "server hello" chosen cipher, the session ID, random bytes, digital certificate (checked by client), optional: "client certificate request"
  3. Key exchange using random bytes, now server and client can calc secret key
  4. "finished" message, encrypted with the secret key
  - 3 RTT to send first byte, 4RTT to receive first byte



https://www.ibm.com/support/knowledgecenter/en/SSFKSJ_8.0.0/com.ibm.mq.sec.doc/q009930_.htm

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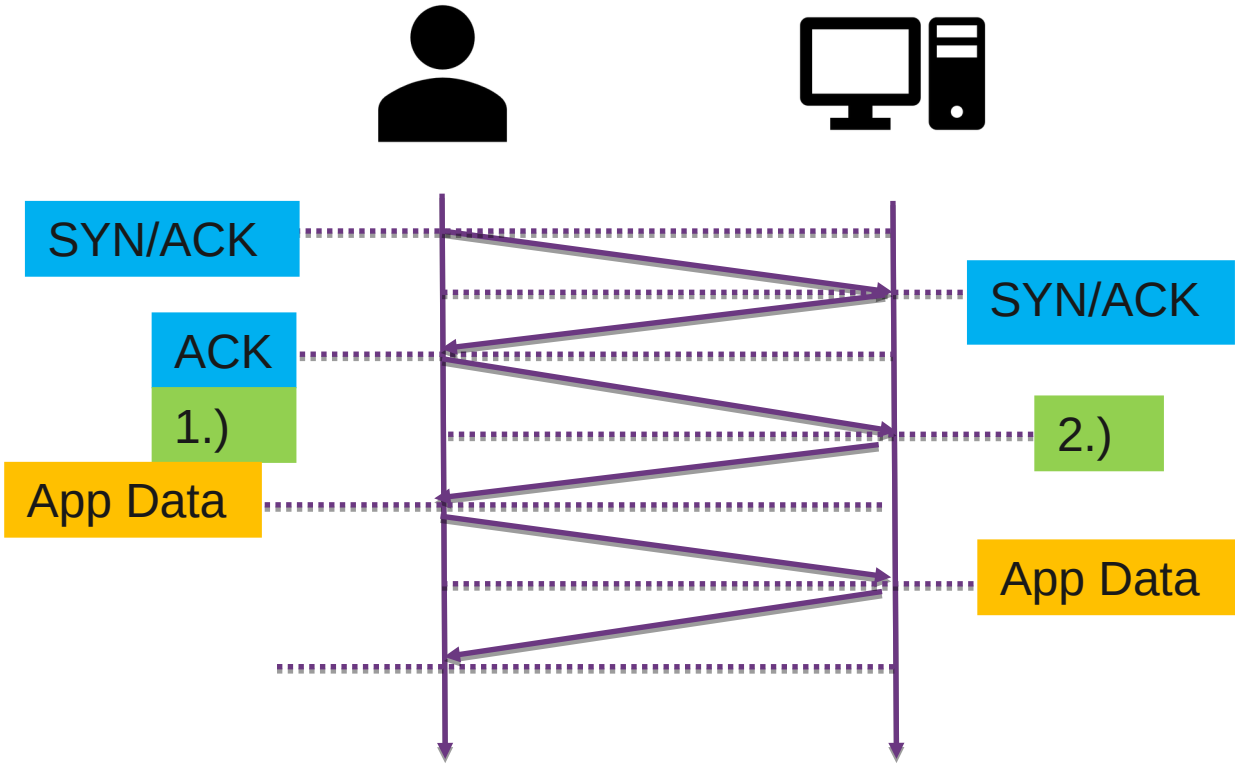
```
PING sydney.edu.au (129.78.5.8) 56(84) bytes of data.
64 bytes from scilearn.sydney.edu.au (129.78.5.8): icmp_seq=1 ttl=233 time=307 ms
64 bytes from scilearn.sydney.edu.au (129.78.5.8): icmp_seq=2 ttl=233 time=305 ms
64 bytes from scilearn.sydney.edu.au (129.78.5.8): icmp_seq=3 ttl=233 time=305 ms
```

Layer 4 – TCP + TLS

- TCP + TLS handshake:
  - 1RTT - Ping to Australia: 329ms
  - 3RTT = 987ms! No data sent yet
- TLS 1.3, finished Aug 2018
  - 1 RTT instead of 2
    - 1.) Client Hello, Key Share
    - 2.) Server Hello, key Share, Verify Certificate, Finished
  - 0 RTT possible, for previous connections, loosing perfect forward secrecy
  - 95% of browsers used already support it



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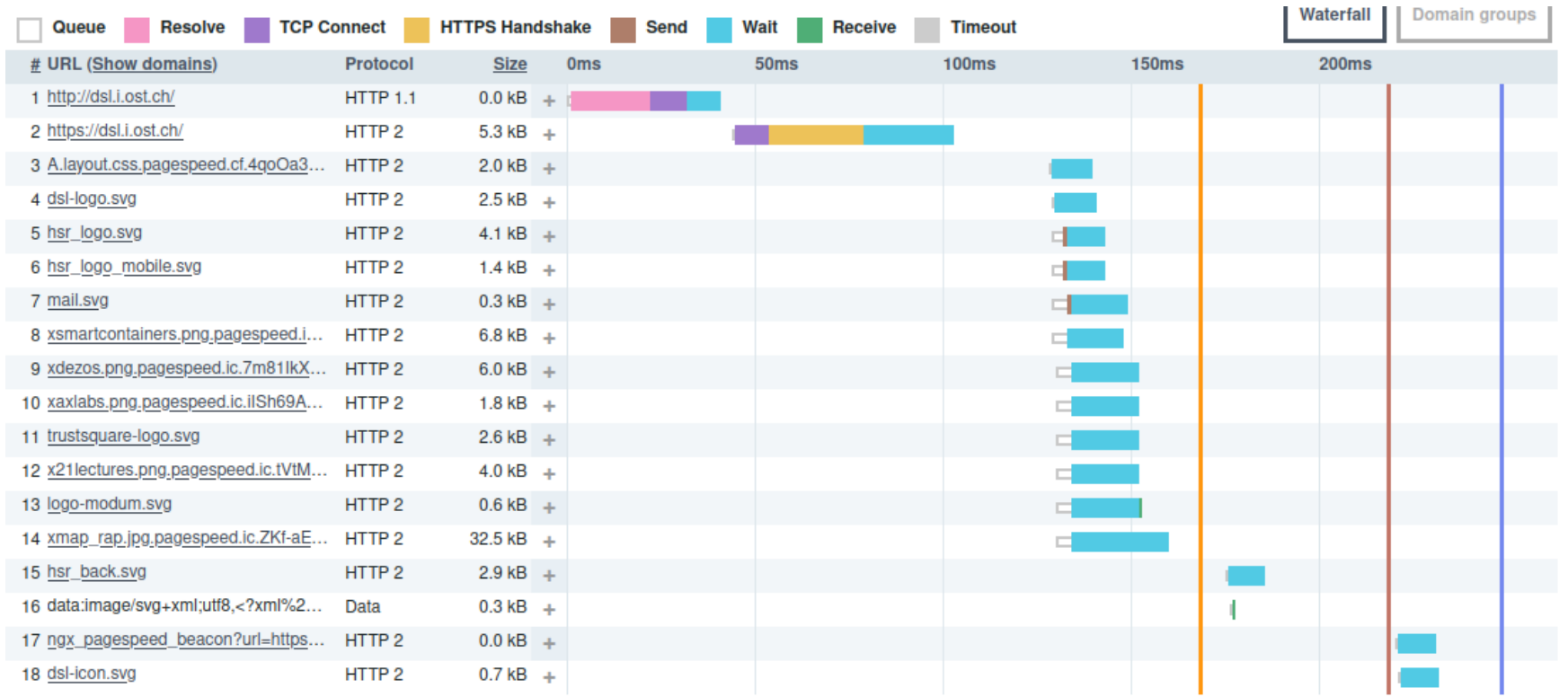
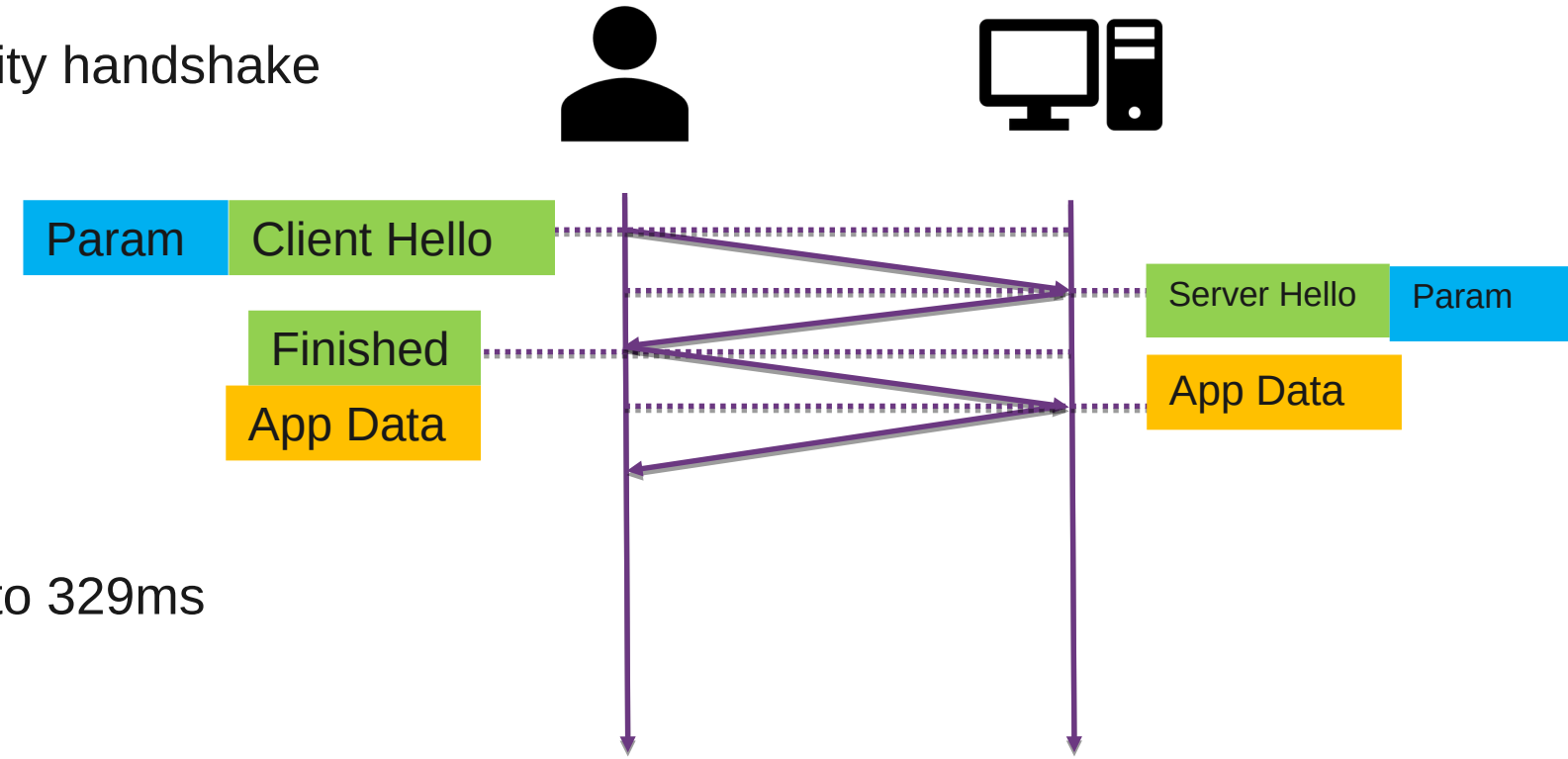
Layer 4 – TCP + TLS

- Website Speed Test [link]
  - Resolve → DNS, TCP Connect → TCP Handshake, HTTPS Handshake → TLS/SSL



QUIC / HTTP3

- QUIC: 1RTT connection + security handshake
  - For known connections: 0RTT
  - Built in security
  - Reports
    - Facebook
    - state of HTTP
- Example Australia: from 987ms to 329ms



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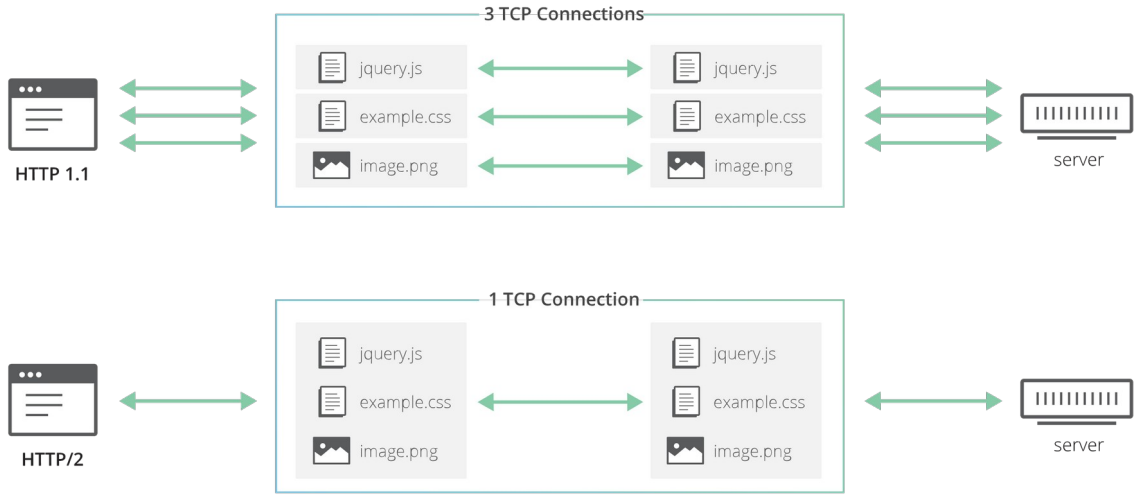
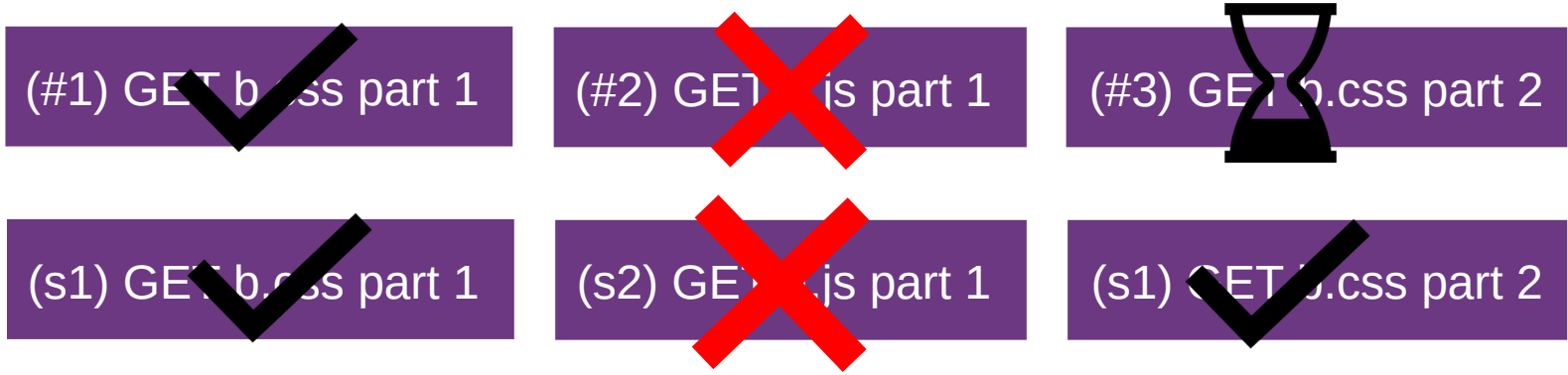
QUIC / HTTP3

- Multiplexing in HTTP/2
  - HTTP/1 → HTTP/2
- HTTP/2: Head-of-line blocking
  - One packet loss, TCP needs to be ordered
  - QUIC can multiplex requests: one stream does not affect others
- HTTP/3 is great, but…
  - NAT → SYN, ACK, FIN, conntrack knows when connection ends, not with QUIC, timeouts, new entries, many entries
  - HTTP header compression, referencing previous headers
  - Many TCP optimizations

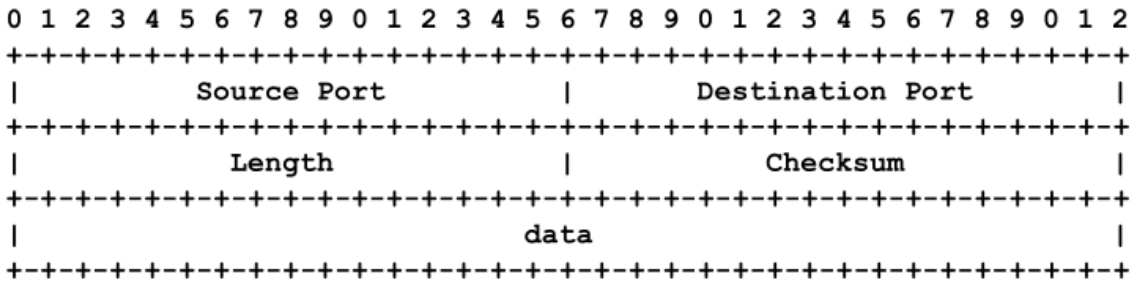


source: https://blog.cloudflare.com/the-road-to-quic/



Layer 4 - Transport

- User Datagram Protocol (UDP)
  - UDP is used for DNS, streaming audio and video
  - Simple connectionless communication model
  - No guarantee
    - Delivery
    - Ordering
    - Duplicate protection



- SCTP (Stream Control Transmission Protocol)
  - Message-based
  - Allows data to be divided into multiple streams
  - Syn cookies - SCTP uses a four-way handshake with a signed cookie.
  - Multi-homing multiple IP addresses of endpoints
  - Not widely used: “ We have been deploying SCTP in several applications now, and encountered significant problem with SCTP support in various home routers. ”
    - E.g., OpenWRT – not enabled by default
    - E.g., UFW - Uncomplicated Firewall – not supported
  - SCTP used by WebRTC, but tunneled over UDP

UDP example

- UDP Server (Java)

```
import java.net.*;

class Server
{
    public static void main(String args[]) throws
Exception
    {
        DatagramSocket serverSocket = new
DatagramSocket(8081);
        byte[] receiveData = new byte[1024];
        while(true)
        {
            DatagramPacket receivePacket = new
DatagramPacket(receiveData, receiveData.length);
            serverSocket.receive(receivePacket);
            String s = new
String( receivePacket.getData());
            System.out.println("Message Received: " +
s);
        }
    }
}
```

- UDP Client (golang)

```
package main

import (
     "net"
)

func main() {
     srv, _ :=
net.ResolveUDPAddr("udp","127.0.0.1:8081")
     local, _ := net.ResolveUDPAddr("udp",
"127.0.0.1:0")
     conn, _ := net.DialUDP("udp", local, srv)
     defer conn.Close()
     conn.Write([]byte("5Anybody there?"))
}
```

- nc –u localhost 8081

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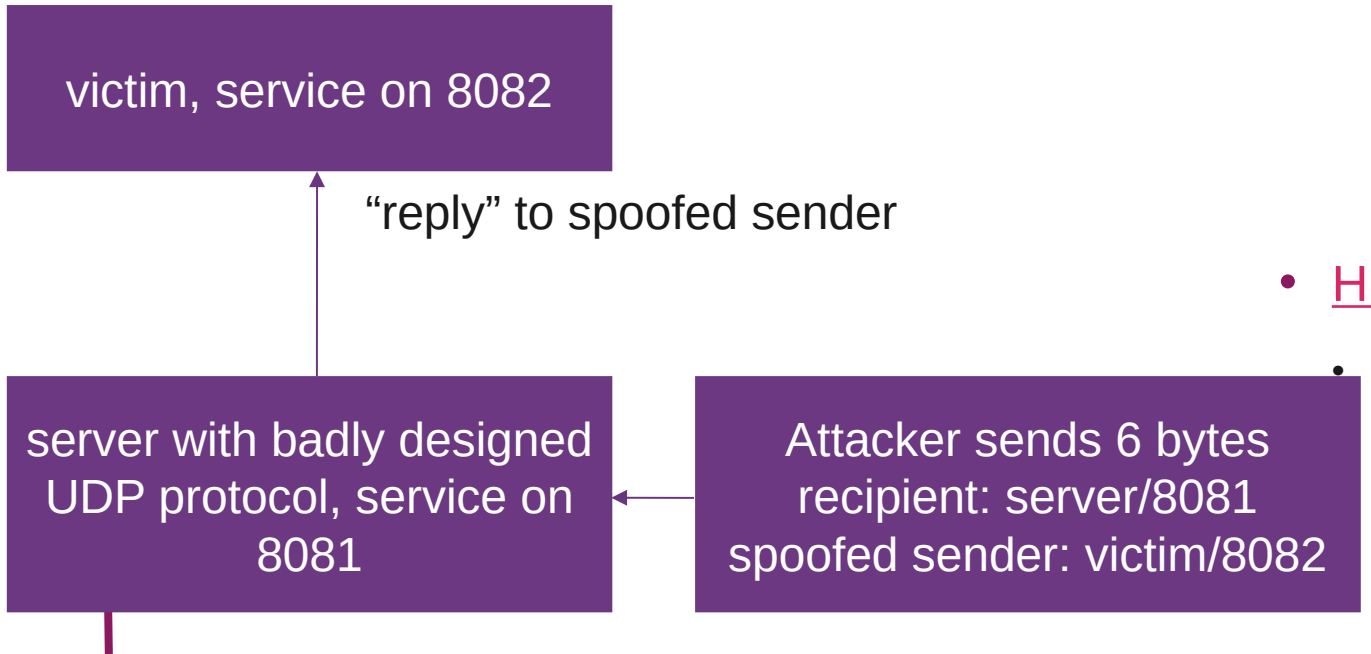
Layer 4 - Transport

- DDoS Amplification Attacks
  - Request 10 bytes, reply 100 bytes → factor 10
- Local demo with server-ra/victim, and hping3
  - hping3 --udp IP -p 8081 -E test.tmp -d 6 -s 8082 -c 1



- Attacker in go/Java/node/c#
  - You need to spoof UDP packets, typically not supported in those languages
  - Go: `func DialUDP(network string, laddr, raddr *UDPAddr) (*UDPConn, error)`
    - laddr: we need to set here the victims IP/port
    - But go tries to bind to that
    - Not yours: “bind: cannot assign requested address”
- Hping3: Pen test tool
  - hping3 is a command-line oriented IP, TCP, UDP, ICMP and RAW-IP packet assembler

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Comparison – Transport Layer

TCP *

- Transport layer
- Connection oriented
- Reliable transfer
- Streams
- Guaranteed order
- Widely used – HTTP/1, HTTP/2
- Flow and congestion control
- Heavyweight
- Error checking and recovery

UDP *

- Transport layer
- Connection less
- Unreliable transfer
- Messages
- Unordered
- Widely used – DNS, HTTP/3
- No flow, congestion
- Lightweight
- Error checking, no recovery

SCTP *

- Transport layer
- Connection oriented
- Reliable transfer
- Messages
- User can choose
- WebRTC
- Flow and congestion control
- Heavyweight
- Error checking and recovery

(QUIC) *

- Transport layer*
- Connection oriented
- Reliable transfer
- Multistream
- Guaranteed order
- HTTP/3
- Flow and congestion
- Heavyweight*
- Integrity check