



OST

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Distributed Systems (DSy)

Introduction - Location

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Learning Goals

- Distributed systems add complexity. Avoid complexity!
- Why do we need distributed systems?
 - 1) Scaling (if one machine is not enough)
 - 2) Location (to move closer to the user)
 - 3) Fault-tolerance (HW will fail eventually)

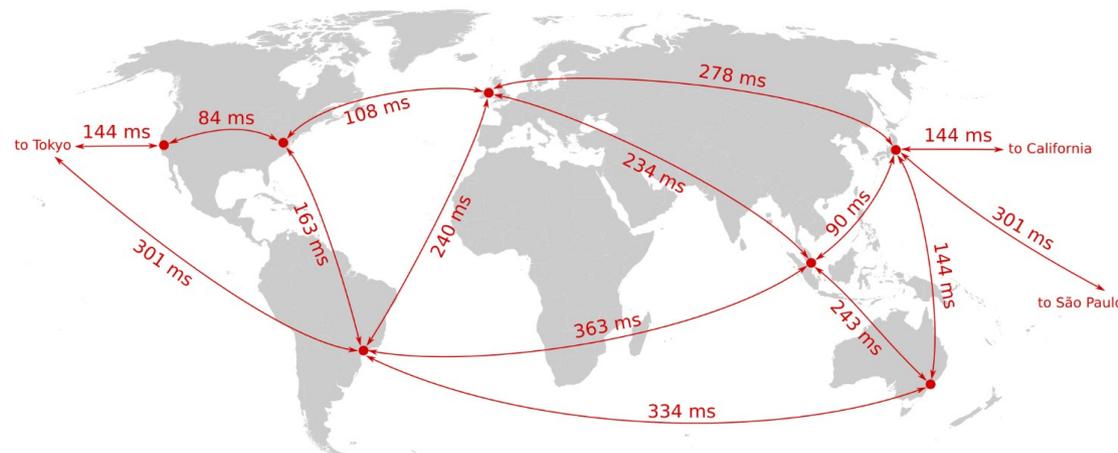
Distributed Systems Motivation

- Why Distributed Systems

- Location

- CPU, bandwidth, SSD, ... gets faster, latency stays
 - Einstein: nothing in nature is faster than the speed of light → you will always have latency

- Speed of light (c) in vacuum is ~300'000 km/s → Physical limit
- Latency: time for signal to travel from source to destination and back (round-trip time)
 - Perfect vacuum light tube to Sydney: RTT
 - $(16540 \div 300000) \times 1000 \times 2 = \sim 110\text{ms}$
 - In practice: ~298ms [link] (ping au-In.metercdn.net) – processing takes time



16,540 km

Distance from Rapperswil-Jona to Sydney



Distributed Systems Motivation

- **Traceroute**: visualize the hops
 - Ping shows only total RTT, traceroute shows the path
 - traceroute au-ln.metercdn.net
 - Sends packets with increasing TTL (Time to Live), starting at 1
- Each router decrements TTL by 1, sends back ICMP "Time Exceeded" when TTL=0
 - Some routers do not send timeout packets, or lower prio
 - Hetzner / Amsterdam 11ms – Sydney 401ms – underseecable – not suer if ost / west route

```
traceroute to au-ln.metercdn.net (172.105.163.170), 20 hops max, 60 byte packets
 1  _gateway (172.31.1.1)  2.238 ms  2.795 ms
 2  static.206.180.243.136.clients.your-server.de (136.243.180.206)  0.756 ms  0.754 ms
 3  * *
 4  * *
 5  core-spine-rdev2.cloud2.fsn1.hetzner.com (213.239.239.41)  1.027 ms  1.025 ms
 6  core24.fsn1.hetzner.com (213.239.227.222)  1.215 ms  1.213 ms
 7  core5.fra.hetzner.com (213.239.224.94)  5.777 ms  5.816 ms
 8  core51.ams.hetzner.com (213.239.203.53)  11.190 ms  11.188 ms
 9  core10.ams.hetzner.com (213.239.224.121)  11.246 ms  11.244 ms
10  * *
11  i-48.sydo-core04.telstraglobal.net (202.84.247.38)  401.907 ms  401.891 ms
12  bundle-ether4.oxf-gw30.sydney.telstra.net (203.50.13.93)  394.383 ms  394.359 ms
13  bundle-ether1.oxf-gw31.sydney.telstra.net (203.50.6.101)  394.840 ms  394.818 ms
14  bundle-ether6.stl-core30.sydney.telstra.net (203.50.6.109)  393.429 ms  392.497 ms
15  ae0.alx-edge421.sydney.telstra.net (203.50.12.133)  391.238 ms  391.214 ms
16  aka3962919.lnk.telstra.net (120.151.79.162)  398.437 ms  398.403 ms
17  ae22.gw2.syd1.netarch.akamai.com (104.70.113.23)  397.822 ms  397.869 ms
18  * *
19  * *
20  * *
```

- Space? Starlink altitude: LEO ~550km [[link](#)]
 - Perfect condition, optimal location, no processing delay, no handoffs between satellites: theoretical latency: 7.3ms,
- In practice: latency 20-60ms [[link](#)]

Speed of Light

- Practice vs. theoretical limit -
~300ms vs 110ms / 20-60ms vs 7.3ms
- No direct path (fiber)
 - Land route in Europe (Switzerland to Mediterranean coast): ~1'000 km
 - Maybe [SeaMeWe-5?](#) ~16'000km
 - Singapore to Sydney (undersea cable): ~7,000 km
 - Total estimate: ~24,000 km
- $(24000 \div 300000) \times 1000 \times 2 = 160\text{ms}$
 - Still not 298ms
- Signal travels only speed of light in vacuum
 - Fiber = signal travels in glass [\[link\]](#) ~200'000 km/s

- [Single mode](#) fibers provide lower latency than multimode fibers, [refractive index](#), wavelength of the light
- Hollow core fiber e.g. [\[link\]](#) with less latency
- Copper propagates faster [\[link\]](#), but not much

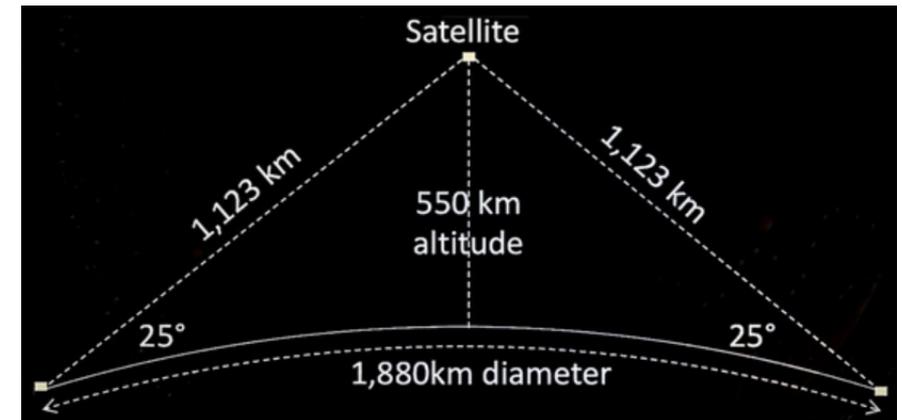
Minimum velocity factors allowed for network cable standards

VF (%)	Cable type	Ethernet physical layer
74~79%	Cat-7 twisted pair	
77%	RG-8/U	Minimum for 10BASE5 ^[4]
67%	Optical fiber (silica glass)	Minimum for 10BASE-FL, ^[5] 100BASE-FX, ...
67%	Plastic optical fiber	1000BASE-RHx PMMA
63%	Plastic optical fiber	polystyrene
65%	RG-58A/U	Minimum for 10BASE2 ^[6]
65%	Cat-6A twisted pair	10GBASE-T
64%	Cat-5e twisted pair	100BASE-TX, 1000BASE-T
58.5%	Cat-3 twisted pair	Minimum for 10BASE-T ^[7]

Speed of Light

- $(24000 \div 200000) \times 1000 \times 2 = 240\text{ms}$
 - Non-optimal routing, queuing delays, routing delays and traffic inspection, signal repeating, protocol overhead
 - ~50-60ms - plausible
- Satellites have direct connection, light/radio travels through air/space almost at $\sim 300'000\text{km/s}$
- Wifi with lowest latency? No
 - CSMA/CA, wait times before transmission, acknowledgment packets, retransmissions, signal processing at transmitter, processing at receiver, MAC layer processing, protocol stack traversal, DCF (Distributed Coordination Function) backoff, channel busy waiting
 - Typical case: +5ms latency

- Starlink in theory with lower latency than fiber?
- Yes, latency to cover distance may be smaller using satellites [\[link\]](#)



- Latency satellite (vacuum):
 - $((2 \times 1123) \div 300'000) \times 1000 \times 2 = 15\text{ms}$
- Latency fiber (glass)
 - $(1880 \div 200'000) \times 1000 \times 2 = 18.8\text{ms}$

Speed of Light

- Bandwidth much higher with fiber ~23Pb/s
 - Laser: NASA ~200Gb/s, Starlink ~200Gb/s
- Weather conditions affecting signal strength (ground – satellite), geomagnetic storms
- Protocol overhead, network processing, signal encoding/decoding, queuing
- Geostationary satellite: 477ms latency
- Inter-satellite communication [[youtube](#)]



Distributed Systems Motivation

- Importance of latency
 - Amazon: +100ms latency → 1% sales loss [link]
 - Google: +500ms latency → 20% drop in traffic [link]
 - Bing: +500ms latency → revenue down 1.2% [link]
- Gaming
 - Gaming / e.g., [Esports](#) LoL, price ~\$5m:
 - Human reaction time [200ms](#)
 - Total [from keypress to display](#):
 - Thinkpad 13 ChromeOS: 70ms
 - Lenovo X1 carbon 2016: 150ms
 - TV output lag ~8ms ([random TV](#))
 - Competitive gaming: use special hardware!
 - 120 or 240hz, low latency mouse/keyboard

Sensitivity to latency in online gaming
>300 ms – game unplayable
>150 ms – player performance degraded
>100 ms – player performance affected
50 ms – target performance
13 ms – lower limit of detectability

Source: PubNub



Distributed Systems Motivation

- [Keyboard](#) 15-60ms (2017)
 - Key travel time!
 - PS/2 vs USB keyboard
 - USB polling ~8ms, PS/2 interrupt based, direct path to CPU, USB gaming keyboard with 1ms polling
- [Measuring Input Lag](#) [\[link\]](#) (2017)
 - Tablet pen, latency 20-80ms [\[link\]](#)
 - Jitter: variation in latency over time
 - Stable 50ms better than fluctuating 30-80ms
 - 100cm one way, with speed of light: $\sim 3.3\text{ns} = 0.0000033\text{ms}$
 - [Latency not the reason](#), seeing details



Distributed Systems Motivation

- Reducing latency
 - Assumption: perfect repeater, switch, router with no latency
 - Perfect mouse, keyboard, display
- RTT to Sydney still 110ms with perfect (unrealistic) conditions
 - nothing in nature is faster than the speed of light → you will always have latency
- Legal requirements for data location
 - GDPR: EU personal data must be stored/processed in EU
 - Location is not only performance, but also compliance
- Place services closer to user → distributed system
 - Reduced latency
 - Can increased bandwidth and throughput
 - Can improved reliability and availability
 - Drawback: coordination of data replication and caching
- e.g., [CDN](#): Content delivery network
 - Place your images, sites, scripts close to your users
 - Edge Computing (Generalization of CDN concept)
- New protocols can decrease nr. of RTT
 - Upcoming lecture