

## Communication Networks

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**Solution:** Exercises week 1 and 2 - Introduction

### Traceroute

#### Decipher a Packet Route

The `traceroute` (or `tracert` on Windows) command<sup>a</sup> is a useful tool to observe the route of packets towards a network host. You will learn the underlying functionality of `traceroute` in a later lecture. Below, you find a `traceroute` output from ETHZ towards the New York University ([www.nyu.edu](http://www.nyu.edu)).

<sup>a</sup><https://linux.die.net/man/8/traceroute>

```
> traceroute www.nyu.edu
traceroute to web.gslb.nyu.edu (128.122.119.202), 64 hops max, 52 byte packets
 1 82.130.102.1 (82.130.102.1) 0.849 ms 0.616 ms 0.820 ms
 2 rou-ref-rz-bb-ref-rz-etx (10.10.0.41) 0.741 ms 0.671 ms 0.643 ms
 3 rou-fw-rz-ee-tik (10.1.11.129) 0.892 ms 0.836 ms 5.057 ms
 4 rou-fw-rz-gw-rz (192.33.92.170) 1.040 ms 0.852 ms 0.892 ms
 5 swiez2 (192.33.92.11) 0.982 ms 1.032 ms 0.974 ms
 6 swizhi-100ge-0-1-0-0.switch.ch (130.59.38.110) 0.913 ms 0.884 ms 0.959 ms
 7 swice1-100ge-0-3-0-0.switch.ch (130.59.36.93) 5.796 ms 6.485 ms 4.591 ms
 8 switch.mx1.gen.ch.geant.net (62.40.124.21) 4.213 ms 4.173 ms 4.203 ms
 9 ae4.mx1.par.fr.geant.net (62.40.98.152) 11.508 ms 13.460 ms 11.560 ms
10 et-3-1-0.102.rtsw.newy32a0a.net.internet2.edu (198.71.45.236) 85.752 ms 82.767 ms 82.455 ms
11 nyc-9208-12-newy.nysernet.net (199.109.5.1) 82.457 ms 82.548 ms 82.434 ms
12 199.109.5.6 (199.109.5.6) 82.609 ms 82.624 ms 82.684 ms
13 dmzgwa-ntp-extgwa.net.nyu.edu (128.122.254.65) 83.006 ms 83.225 ms 83.279 ms
14 nyugwa-ntp-dmzgwa.net.nyu.edu (128.122.254.88) 82.815 ms 82.789 ms 82.701 ms
15 wsqdcgwa-vl902.net.nyu.edu (128.122.1.38) 83.156 ms 83.194 ms 82.933 ms
16 ***
```

Formatted `traceroute` output from ETHZ towards [www.nyu.edu](http://www.nyu.edu) (New York University). The columns from left to right are: network hop number, IP/domain name (if resolvable), actual IP address, three individual measurements for the round trip time.

Look at the route the packet takes. Can you identify different ASes? At which point does it leave ETHZ?

**Solution:** 1-7 SWITCH (AS559) (2,3 are internal ETH routers; private IP addresses). 8,9 GEANT (AS21320). 10 ABILENE Internet2 (AS11537), 11-12 Nysernet (AS3754), 13-15 New York University (AS12). Packets leave ETHZ at hop 5 (still an ETH IP).

Compare hop 9 and 10. Can you explain the time difference?

**Solution:** Packets “traverse” the Atlantic Ocean through underwater cables.

Execute the same traceroute command from your personal computer. Do you observe the same route? What did change? (Over the ETH WLAN you will see strange output due to NAT<sup>a</sup>.)

**Solution:** You will most likely observe a different route. Especially the first hops of the path can be completely different based on your Internet provider. Routing in the Internet is a dynamic process based on the currently available links/routers, AS configurations and preferences, congestion, ...

Assuming you could execute the reverse traceroute command from the New York University towards *www.tik.ethz.ch*, would you expect the same route just in reverse order?

**Solution:** Most likely not. The forward and reverse path between two nodes in the Internet do not have to be the same.

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<sup>a</sup><http://lostintransit.se/2013/05/29/nat-translation-what-happened-to-my-traceroute/>

# Internet Structure

## Layer Model

Communication over the Internet can be decomposed into independent layers. In the lecture, we have discussed the Internet protocol stack which contains 5 layers. Another often used model is the OSI (Open Systems Interconnection) model with 7 layers. Find the best matching layer for the following operations/devices. You can use the already known 5-layer model. **Hint:** Some of the operations could be implemented in different layers.

Internet protocol stack	OSI reference model
Application	Application
	Presentation
	Session
Transport	Transport
Network	Network
Link	Link
Physical	Physical

Internet communication layers: Internet protocol stack and the OSI reference model.

a) Bit-to-bit transmission between two devices.

**Solution:** Physical layer

b) Encryption of a message.

**Solution:** Application layer

c) A switch in a network.

**Solution:** Link layer

d) Routing path search.

**Solution:** Network layer

e) Adding a sequence number to each packet.

**Solution:** Transport layer (e.g. TCP protocol), but also the application layer could provide this functionality.

f) A router in a network.

**Solution:** Network layer

g) A middlebox in a network performing deep packet inspection (DPI) to find malware in Web traffic.

**Solution:** To analyze the payload of packets the middlebox is operating in the application layer. Most likely, it will also use information from other layers, e.g. IP addresses from the network layer.



## Internet Communication

The figure on the left shows a (simplified version of a) packet that was recorded at your machine's network interface using Wireshark<sup>a</sup>.

a) What kind of activity does this packet belong to?

**Solution:** Web browsing. The easiest way to see this is by looking at the payload of the application layer (the lower-most box in the figure). There, one can see that the packet contains a HTTP-GET request to `comm-net.ethz.ch`.

b) From the lecture, you know that a packet is composed of data in different layers. The fields in the left-hand figure are already grouped to four blocks representing the link, network, transport and application layer. Do you know which protocol is used in each of the four layers? *Hint: You may want to have a look at the list of protocols on Wikipedia<sup>b</sup>.*

**Solution:**

- Link layer: Ethernet (indicated by the address-format `00:00:00:00:00:00`)
- Network layer: IP version 4 (indicated by the address-format `000.000.000.000`)
- Transport layer: TCP (identifiable by comparing with the format of the TCP-header<sup>c</sup>)
- Application layer: HTTP (HTTP-Request in plain text)

64:a0:e7:42:2e:c2			
78:4f:43:6c:b7:e2			
4	5	2	657
1622		2	0
64	6	63144	
10.2.120.16			
82.130.102.210			
51236		80	
3710236014			
866143669			
4	0	0 0 0 0 1 1 0 0 0	4117
4370		0	
GET / HTTP/1.1\r\n			
Host: comm-net.ethz.ch\r\n			
Connection: keep-alive\r\n			
Cache-Control: max-age=0\r\n			
Upgrade-Insecure-Requests: 1\r\n			
User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_12_3) ...			
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,...			
Accept-Encoding: gzip, deflate, sdch\r\n			
Accept-Language: de-DE,de;q=0.8,en-US;q=0.6,en;q=0.4\r\n			
...			

Packet consisting of data in four layers (link, network, transport and application layer).

c) After being sent out at your machine's network interface, the packet will traverse a switch which will forward it based on the destination address. On which layer does the switch operate and which is the destination address it will look at?

**Solution:** Switches operate at the link layer. The destination address in this layer is `64:a0:e7:42:2e:c2`.

d) After leaving your local network, the packet will traverse a router. On which layer does the router operate and which is the destination address it will look at?

**Solution:** Routers operate at the network layer. The destination address in this layer is `82.130.102.210`.

<sup>a</sup><https://www.wireshark.org/>

<sup>b</sup>[https://en.wikipedia.org/wiki/Internet\\_protocol\\_suite](https://en.wikipedia.org/wiki/Internet_protocol_suite)

<sup>c</sup>[https://en.wikipedia.org/wiki/Transmission\\_Control\\_Protocol](https://en.wikipedia.org/wiki/Transmission_Control_Protocol)

# Bandwidth and Delay

## Network Characterization

Calculate and compare the bandwidth and the delay for different communication methods.

**Solution:** General formulas:

$$\text{delay} = \frac{\text{distance from A to B}}{\text{speed}}$$

$$\text{bandwidth} = \frac{\text{total amount of data in bits}}{\text{delay}}$$

- a) Pigeon post: Pigeons can be used as messengers. They are trained to transport messages from one location to another. Assuming you want to send a USB flash drive with 16 GB<sup>a</sup> from Zürich to a friend in Paris (500 km) (only in one direction). Calculate the bandwidth and the delay for one pigeon carrying the USB drive and traveling at an average speed of 80 km/h.

**Solution:** Delay:  $d = \frac{500 \text{ km}}{80 \text{ km/h}} = 6.25 \text{ h} = 22'500 \text{ s}$

Bandwidth:  $bw = \frac{1.28 \times 10^{11} \text{ bits}}{2.25 \times 10^4 \text{ s}} \approx 5.7 \text{ Mbps}$

- b) Pneumatic tube: These systems were introduced in the late 19th century to transport small, urgent items within buildings or even within cities. The capsules travel at an average speed of 8 meters per second. Assuming you send an external hard drive with 2 TB<sup>b</sup> of storage through a tube from ETZ to the main building (distance 400 m), calculate the bandwidth and delay.

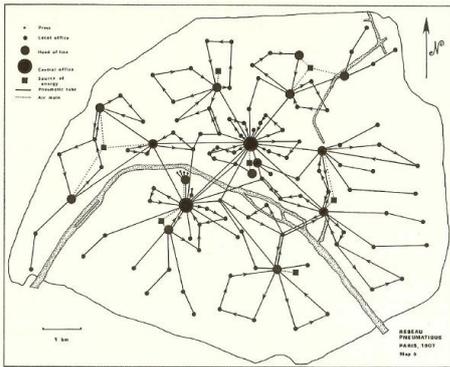
**Solution:** Delay:  $d = \frac{400 \text{ m}}{8 \text{ m/s}} = 50 \text{ s}$

Bandwidth:  $bw = \frac{1.6 \times 10^{13} \text{ bits}}{50 \text{ s}} \approx 320 \text{ Gbps}$

- c) AWS Snowmobile: Amazon uses a truck to move data from its customers to their data center. The truck houses a container which can store 100 PB<sup>c</sup> of data.<sup>d</sup> Assuming the truck is transporting data from New York to an AWS data center in San Francisco (distance 4700 km) at an average speed of 100 km per hour, calculate the bandwidth and the delay.

**Solution:** Delay:  $d = \frac{4700 \text{ km}}{100 \text{ km/h}} = 47 \text{ h} = 169'200 \text{ s}$

Bandwidth:  $bw = \frac{8 \times 10^{17} \text{ bits}}{1.692 \times 10^5 \text{ s}} \approx 4.7 \text{ Tbps}$



The pneumatic tube network of Paris in 1907.

<sup>a</sup>1 GB = 10<sup>9</sup> bytes

<sup>b</sup>1 TB = 10<sup>12</sup> bytes

<sup>c</sup>1 PB = 10<sup>15</sup> bytes

<sup>d</sup><https://techcrunch.com/2016/11/30/amazon-will-truck-your-massive-piles-of-data-to-the-cloud-with-an-18-wheeler/>

## Types of Delay

When accessing a website your data has to travel from your computer through different networks to the server on which the website resides and back.

- a) You want to access the website of the University of Sydney (www.sydney.edu.au). How long does it take for a data packet to travel to the server and back (straight-line distance Zürich-Sydney 16'600 km) assuming your data packet travels at the speed of light ( $3 \times 10^8$  m/s)?

**Solution:**  $t = \frac{\text{distance}}{\text{speed}} = \frac{2 \times 1.66 \times 10^7 \text{ m}}{3 \times 10^8 \text{ m/s}} \approx 110.7 \text{ ms}$

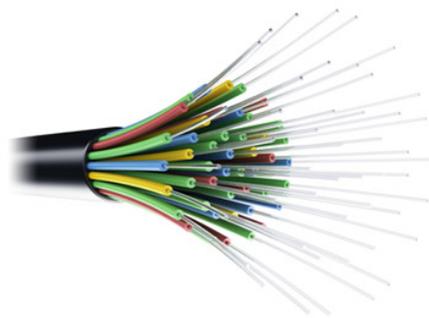
- b) Measure the time it actually takes for a packet to travel to the server and back by issuing a ping www.sydney.edu.au in a terminal<sup>a</sup>. If you don't have a computer available you can use our measurement:

```
PING sydney.edu.au (129.78.5.8):  
time=328.942ms
```

The calculated and measured times are not even close. Why do we observe such a difference?

**Solution:** The time calculated in the first task only accounts for the propagation delay (i.e., the time it takes to send the data at the speed of light) assuming a straight-line connection. In the following, we list some points which have been neglected:

- As we have seen in the lecture, there is not only the propagation, but also the transmission, processing and queuing delay.
- The cables usually don't follow the straight-line between the two locations. Hence, the real distance is longer.
- The speed of light in fiber cables is reduced by about 30%.



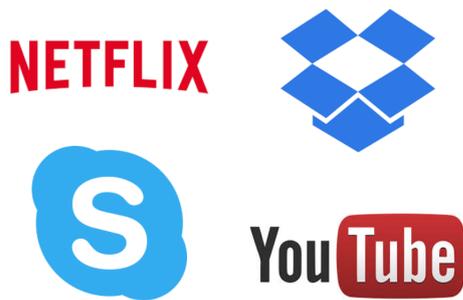
Optical fiber cable.

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<sup>a</sup><https://linux.die.net/man/8/ping>

## Application Requirements

Different applications pose different requirements to the network that need to be fulfilled for a good user experience. For each of the following applications, list their requirements in terms of bandwidth and delay (low, medium, high, not important) and explain your choices.



Different Internet applications.

a) Skype audio call

**Solution:** Low bandwidth, low delay: The audio calls require only up to 100 kbps. However, the delay needs to be low for having a natural conversation.

b) Skype HD video call

**Solution:** Medium bandwidth, low delay: The video streaming requires 5-10 Mbps. Again, the delay needs to be low for having a natural conversation.

c) Youtube video

**Solution:** Medium bandwidth, delay not important: The video stream requires around 10 Mbps. As the stream is not live, the delay is not important since it only affects the time until the stream starts.

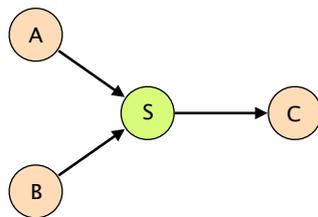
d) Data download from cloud storage

**Solution:** High bandwidth, delay not important: The higher the bandwidth, the faster the download. The delay is not important as it just affects the time until the first byte is received.

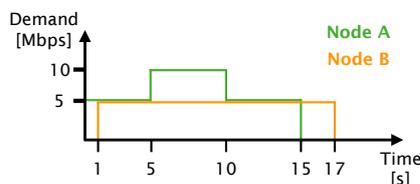
# Sharing

## Packet vs. Circuit Switching

Consider the network on the left. A and B are sending data towards C over a switch S and a shared link. All the links in the network have a bandwidth of 10 Mbps and you can assume that the propagation and switch processing time are negligible. For circuit switching, assume that circuit establishment and tear-down each take 50 ms. For packet switching, you can assume that switch S already knows how to reach C.



Network with a shared link.



Demand distributions for node A and B.

- a) How long does it take if node A is sending a 50 Mbit file to C using packet switching? B sends nothing.

**Solution:** 5 s

- b) How long does it take if node B is sending a 50 Mbit file to C using circuit switching? A sends nothing.

**Solution:** 5.1 s

Assume now that A and B are using packet switching and are each sending a 50 Mbit file to C at the same time.

- c) What will happen if the switch has no buffer?

**Solution:** Some of the packets are dropped.

- d) How large has the buffer to be (in Mbit) such that both senders can successfully transmit their files to C?

**Solution:** 50 Mbit

- e) For obvious reasons, switch buffers cannot be of unlimited size. How is it possible to successfully send data over the Internet even if some packets are dropped due to full buffers?

**Solution:** Dropped packets are retransmitted, e.g. using the reliable transport guarantees that the TCP protocol provides (transport layer).

Finally, assume that A and B have to send data with a demand according to the diagram on the left.

- f) How long does it take to send all data if A and B use circuit switching (reserving for the peak demand)?

**Solution:** First, node A reserves 10 Mbps bandwidth. During this time, node B cannot establish its circuit.  $0.05 + 15 + 0.05 + 0.05 + 16 + 0.05 = 31.2$  s

- g) How long does it take to send all data if A and B use packet switching (you can assume an unlimited buffer size on S)?

**Solution:** Both nodes start to send packets immediately. From 5 to 10 ms, packets are buffered. Assuming the switch always uses the full link bandwidth towards C:  $1 + 14 + 2 + 1.5 = 18.5$  s