ETH

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Communication Networks

Solution: Exercises week 1 and 2 – Introduction

Traceroute

Decipher a Packet Route

The `traceroute` (or `tracert` on Windows) command[a] 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*).

[a] 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  swizh1-100ge-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.newy32aoa.net.internet2.edu      (198.71.45.236)    85.752 ms   82.767 ms   82.455 ms
11  nyc-9208-i2-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-ptp-extgwa.net.nyu.edu                      (128.122.254.65)   83.006 ms   83.225 ms   83.279 ms
14  nyugwa-ptp-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  * * *
```

Formated traceroute output from ETHZ towards *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). 13-15 NeuStar (AS19905). Packets leave ETHZ at hop 5 (still an ETH IP).

Compare hop 9 and 10. Can you explain the huge 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?

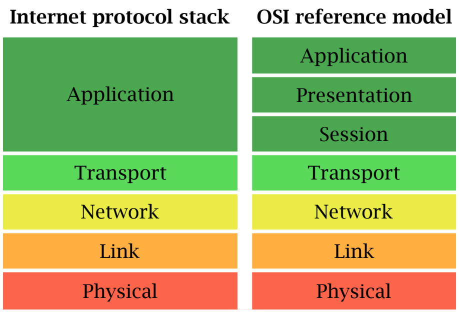
Solution: You will most likely observe a different route. Especially the first hops of the path can be completely different based on your Internet provider. Routing in the Internet is a dynamic process based on the currently available links/routers, AS configurations and preferences, congestion, ...

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.

Internet Structure

Layer Model



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

a) Bit-to-bit transmission over a link.

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.

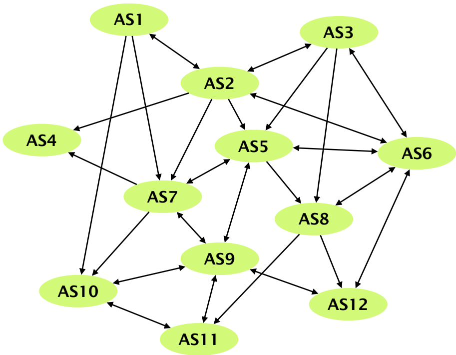
f) A router in a network.

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 Organization



A network of multiple autonomous systems (AS).

The network on the left consists of multiple autonomous systems (AS). Single-headed arrows point from providers to their customers. Double-headed arrows represent peer connections.

a) For each AS, identify if it is a Tier-1, Tier-2 or Tier-3 ISP network or an IXP.

Solution: Tier-1 ISPs: AS1, AS2, AS3. Tier-2 ISPs: AS5, AS7, AS8. Tier-3 ISPs: AS4, AS10, AS11, AS12. IXPs: AS6, AS9.

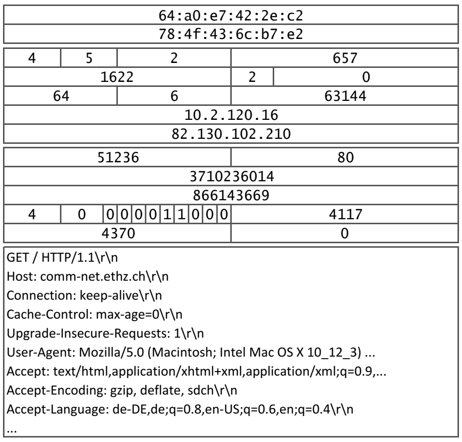
b) AS7 has two different providers (AS1 and AS2). How is this type of interconnection called? What are the advantages of multiple different providers for AS7? Can you see any disadvantages?

Solution: Multihoming.

Advantages: Still connected if one of the provider fails. For destinations (IP prefixes) which can be reached over both providers, AS7 can choose the better one based on cost, trust, ...

Disadvantages: network configuration is slightly more difficult. The total cost could be higher compared to an ISP with only one provider.

Internet Communication



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

The figure on the left shows a (simplified version of a) packet that was recorded at your machine's network interface using `Wireshark`[a].

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 lowermost 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*[b].

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[c])
- Application layer: HTTP (HTTP-Request in plain text)

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`.

[a] `https://www.wireshark.org/`
[b] `https://en.wikipedia.org/wiki/Internet_protocol_suite`
[c] `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.

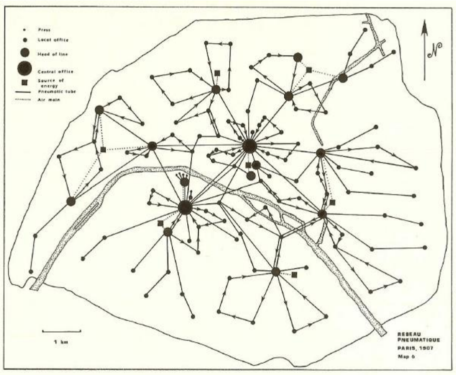
Solution: General formulas:

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

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

a) Pigeon post: Pigeons can be used as messengers. They are trained to transport messages of up to 75 g from one location to another. Assuming you want to send a USB flash drive with 16 GB[a] from Zürich to a friend in Paris (500 km). Calculate the bandwidth and the delay for a pigeon travelling 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: $bw = \frac{1.28\times10^{11}\,\text{bits}}{2.25\times10^{4}\,\text{s}} \approx 5.7\,\text{Mbps}$



The pneumatic tube network of Paris in 1907.

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 a external hard drive with 2 TB[b] 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: $bw = \frac{1.6\times10^{13}\,\text{bits}}{50\,\text{s}} \approx 320\,\text{Gbps}$

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[c] of data.[d] 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: $d = \frac{4700\,\text{km}}{100\,\text{km/h}} = 47\,h = 169'200\,\text{s}$
Bandwidth: $bw = \frac{8\times10^{17}\,\text{bits}}{1.692\times10^{5}\,\text{s}} \approx 4.7\,\text{Tbps}$

[a] 1 GB = 10^9 bytes
[b] 1 TB = 10^{12} bytes
[c] 1 PB = 10^{15} bytes
[d] 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 (3×10^8 m/s)?

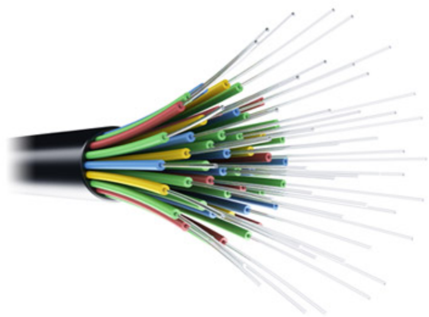
Solution: $t = \frac{\text{distance}}{\text{speed}} = \frac{2\times 1.66\times 10^7\ \text{m}}{3\times 10^8\ \text{m/s}} \approx 110.7\ \text{ms}$

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[a]. If you don't have a computer available you can use our measurement:
`PING sydney.edu.au (129.78.5.8):`
`time=328.942 ms`
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:

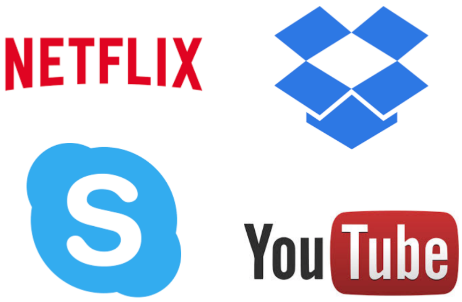
- As we have seen in the lecture, there is not only the propagation, but also the transmission, processing and queuing delay.
- The cables usually don't follow the straight-line between the two locations. Hence, the real distance is longer.
- The speed of light in fiber cables is reduced by about 30%.

[a] https://linux.die.net/man/8/ping



Optical fiber cable.

Application Requirements



Different Internet applications.

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.

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.