Network Technologies

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Network Technologies

Client and Server

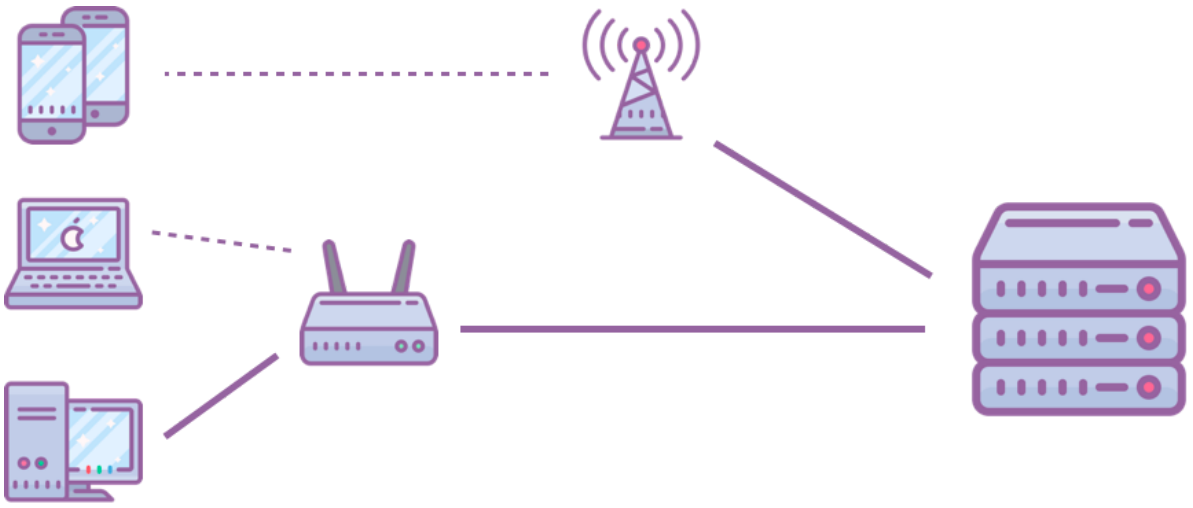
What happens if you type in a web address in your browser and press enter?

1. Your computer sends a request to the server.
   This is a signal for the server: "Give me this website!"
2. The server sends a response to your computer.
   The response is the website that you requested.

This is called ***Request*** (1) and ***Response*** (2).

In this scenario, your computer is the ***client***, and the web server that hosts the website that you requested is the ***server***.

Devices



Client devices

- Laptops
- Smartphones
- Computer station
- ...

Network Devices

- Mobile towers
- WiFi Router
- ...

Servers

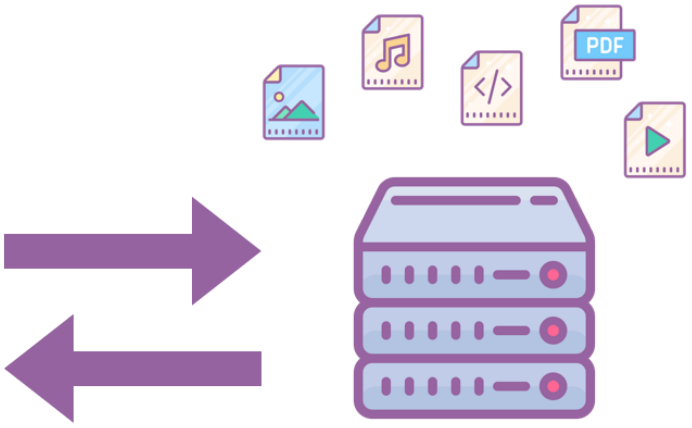
- Spotify
- Google
- Facebook
- ...

Connections

- Cable
- WiFi
- Mobile network

Servers

What does a server do?

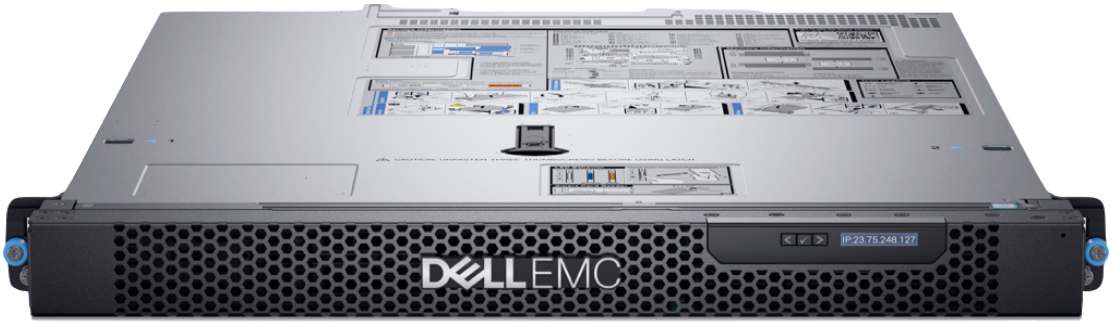


A web server stores files:

- Music files: e.g. MP3
- Image files: e.g. PNG, JPG
- Code files: e.g. HTML, CSS files
- Misc. files: e.g. PDF files
- Video files: e.g. MPG files

If a client requests a file, the server delivers it.

This is what a server looks like:



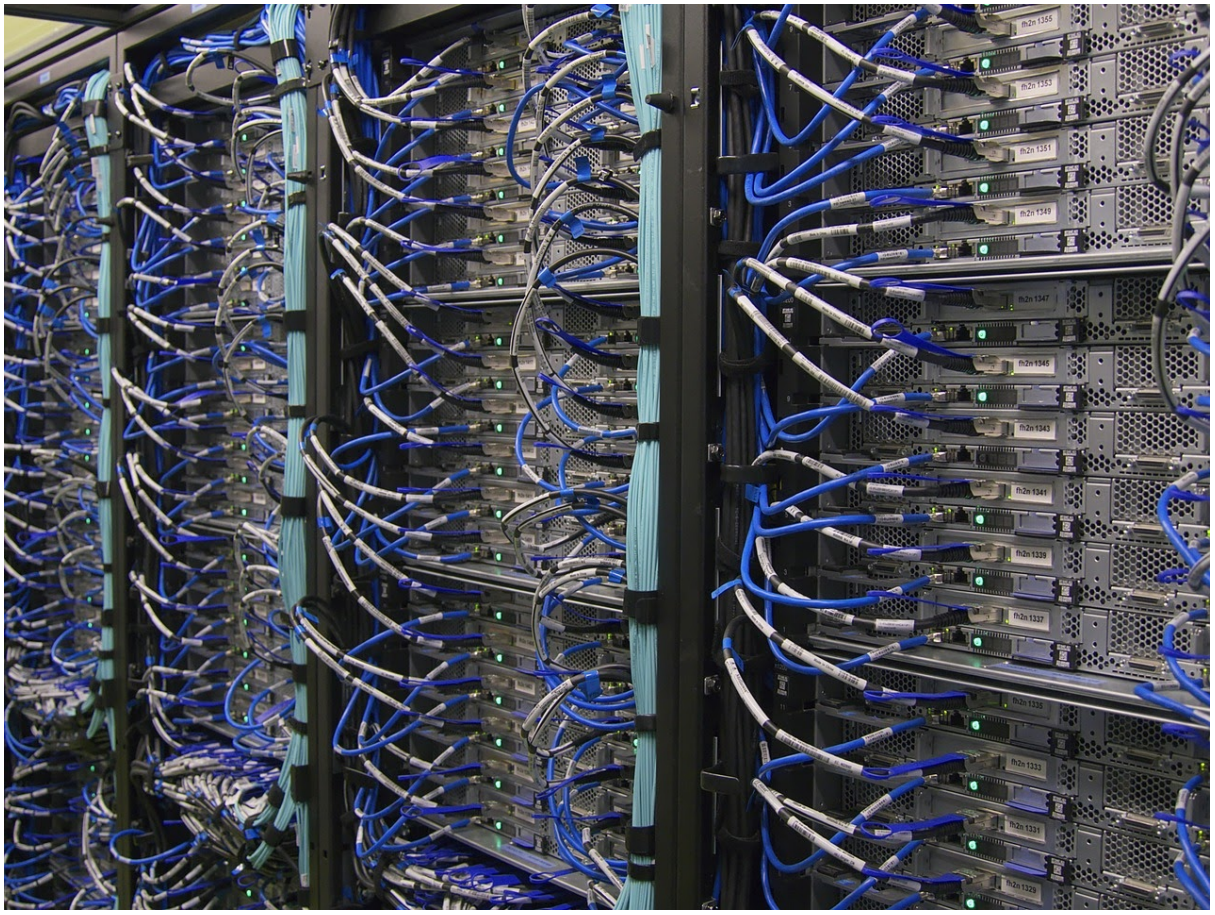
Ports on the back side:

- 2 power plugs: if one fails, the second takes over
- 3 network connections: 2 for fail-save connections, 1 for admin

Data Centers

Data centers are places where a lot of servers are stored and rented for companies to run their web servers on them. They usually have a large number of server machines, which are stacked on top of each other in large racks.

The amount of computers creates a lot of heat. Because of this, the server rooms are usually built enclosed like greenhouses, so that they can be cooled down. The racks are all ventilated and the room is cooled with ACs. This is usually very loud.

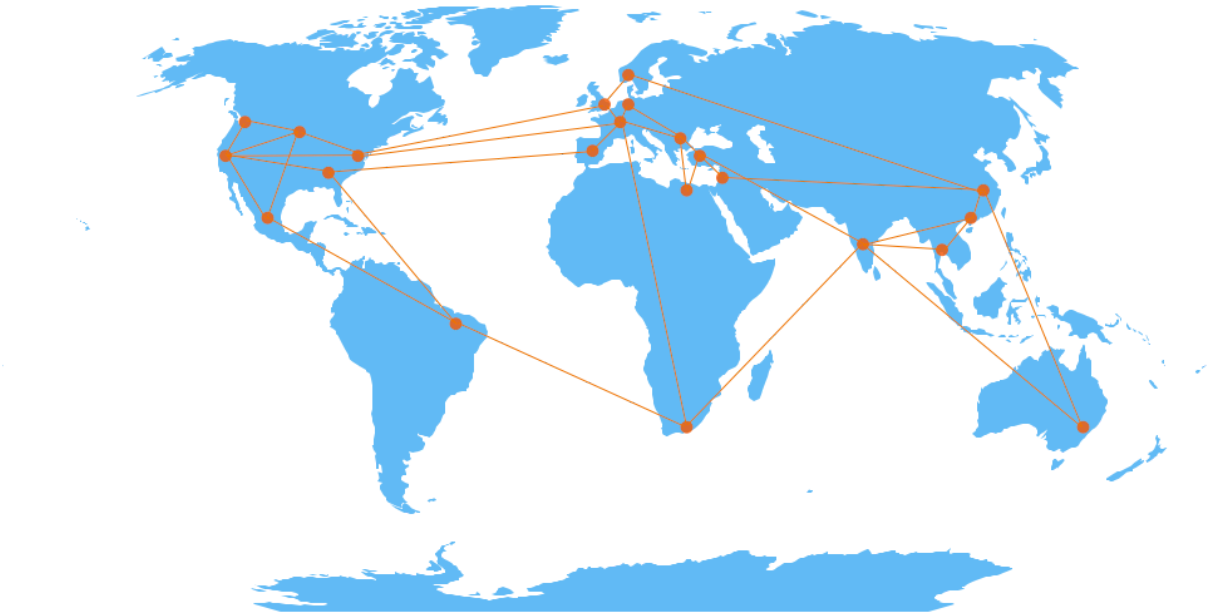


On the back side you can see that the servers are all connected by multiple cables, including various network and power cables.

Networks

What is a network?

- A network is multiple devices (servers) connected to each other.
- In a network, each device is a ***network node***.
- On the internet, these network nodes are distributed over the globe.

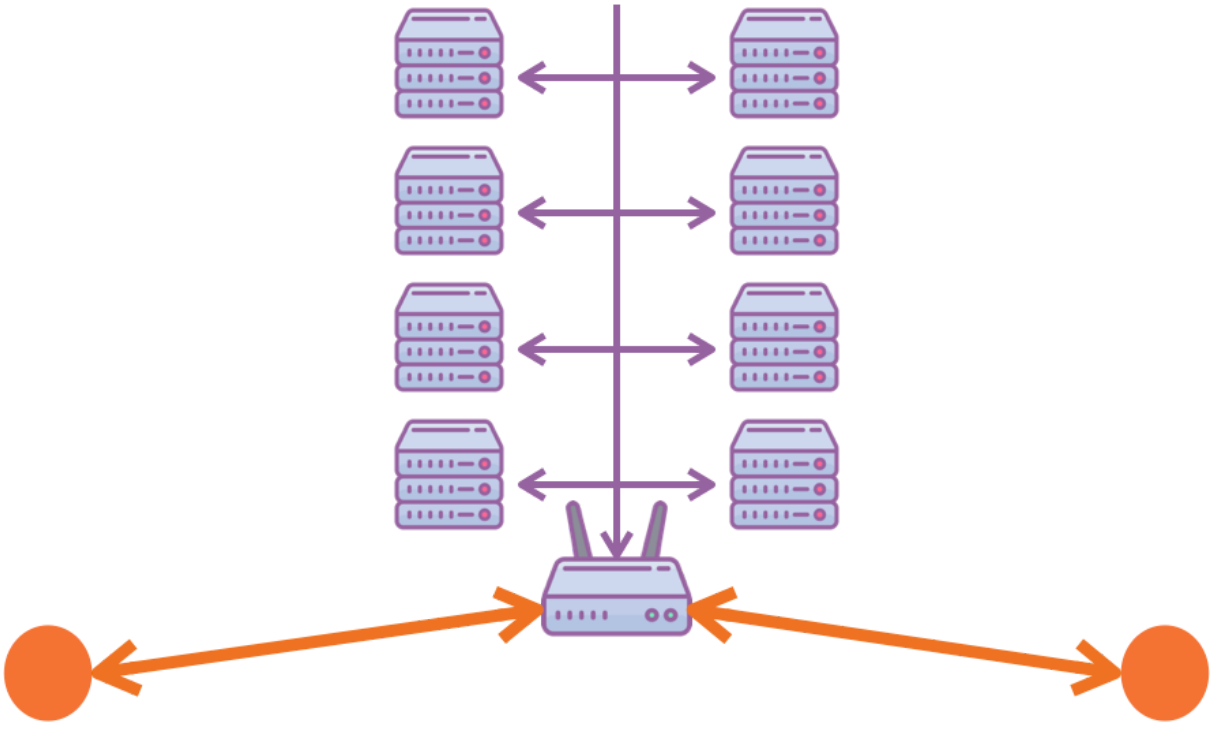


The internet is the network which connects the data centers which are distributed all over the world together. Hence the name “inter” - “network”.

Routers

To connect data centers with each other, we need ***routers***.

Routers are devices that connect a local network with the internet, i.e. with other networks or data centers.



At home, routers look something like this:

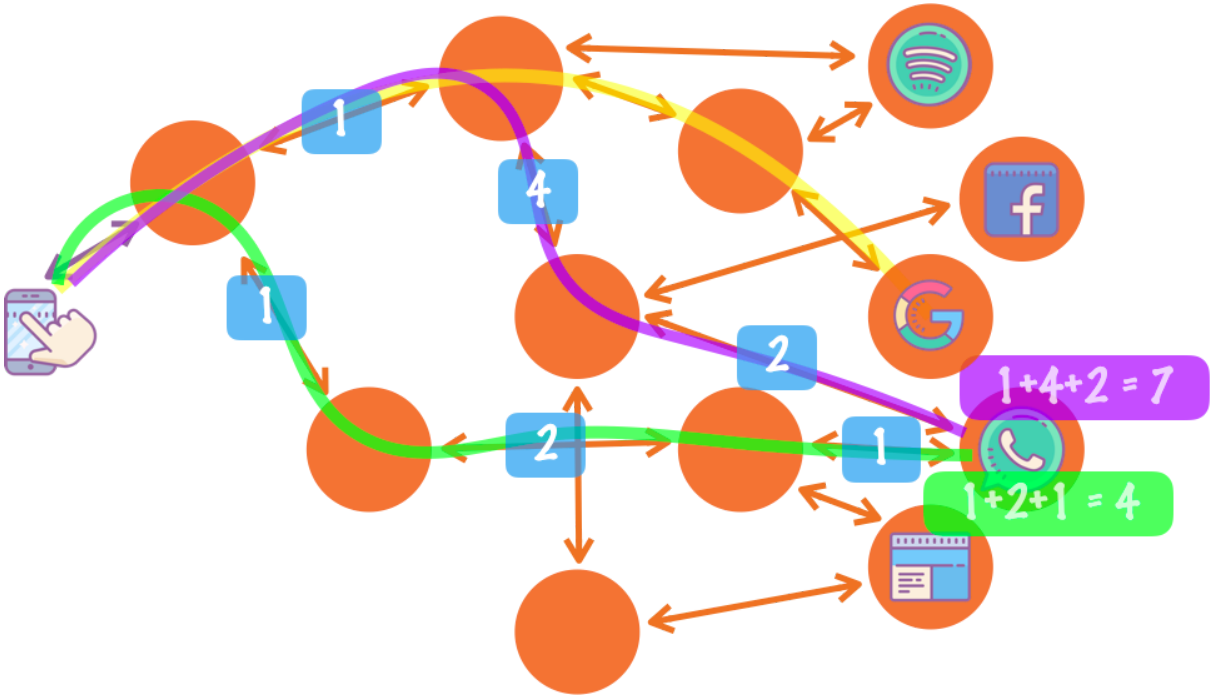
Data centers use more powerful routers. They look like this:

Routing

The task of a router is to decide where data should be sent. They receive and send data from and to other networks or keep the data in the local network if this was intended. This is called ***routing***.

How can your router at home send data from Hamburg to Google in the USA?

- We lay a new cable (we don't want to do that)
- We use existing connections between networks
- Client side: our device + WiFi router
- Server side: Google, Facebook, spotify, WhatsApp etc.
- We need to find a route from our client network to the target network
- There are usually multiple routes
- This is good, because if one fails, we can use the other



How do we decide which route to take?

- All routes are evaluated (traffic, workload, length, speed, data loss etc.).
- The one with the best evaluation (lowest workload, shortest, fastest etc.) is chosen.
- Each network has the responsibility to decide which next path is the shortest one.
- The path might change even while you are on e.g. a video call or are streaming music without you noticing it

IXPs - The Backbone of the Internet

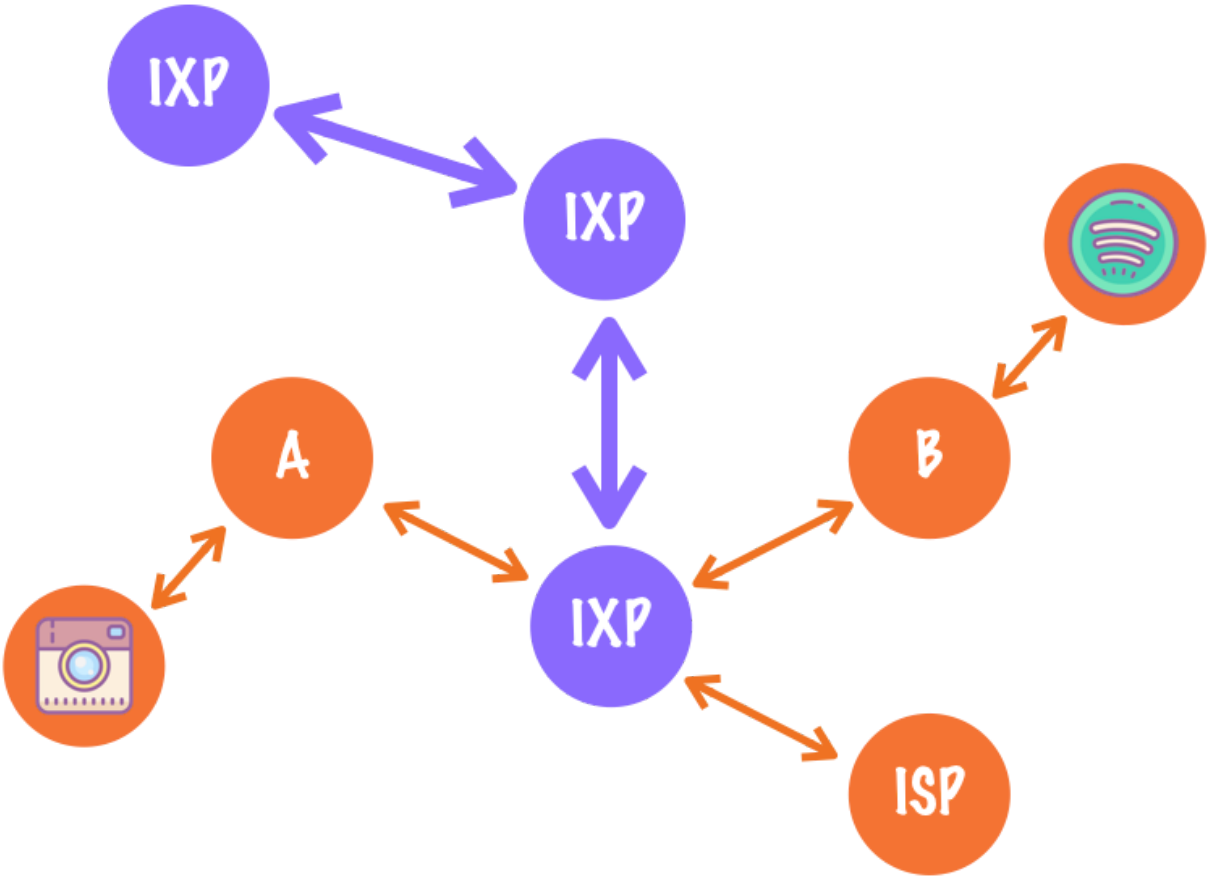
ISP - Internet Service Provider

- An ISP is your network provider (e.g. Telekom).
- The data centers get their money from the service provider.
- The service provider gets their money from you.

The workload of a network can often change. If there's a new popular service (e.g. a new app like Spotify), the old paths may be too inefficient, so new paths need to be established occasionally.

IXP - Internet Exchange Point

It is very rare that new cables are laid between the networks. Instead, they use IXPs (Internet Exchange Points). They have strong connections with each other, and if the need arises, they can agree on new paths between each other.



IXPs are organizations that create the "backbone" of the internet: large data centers with strong and fast connections by cable.

IXPs connect networks, ISPs and other IXPs with each other.

IXPs use very large routers. They usually rent space in large data centers.

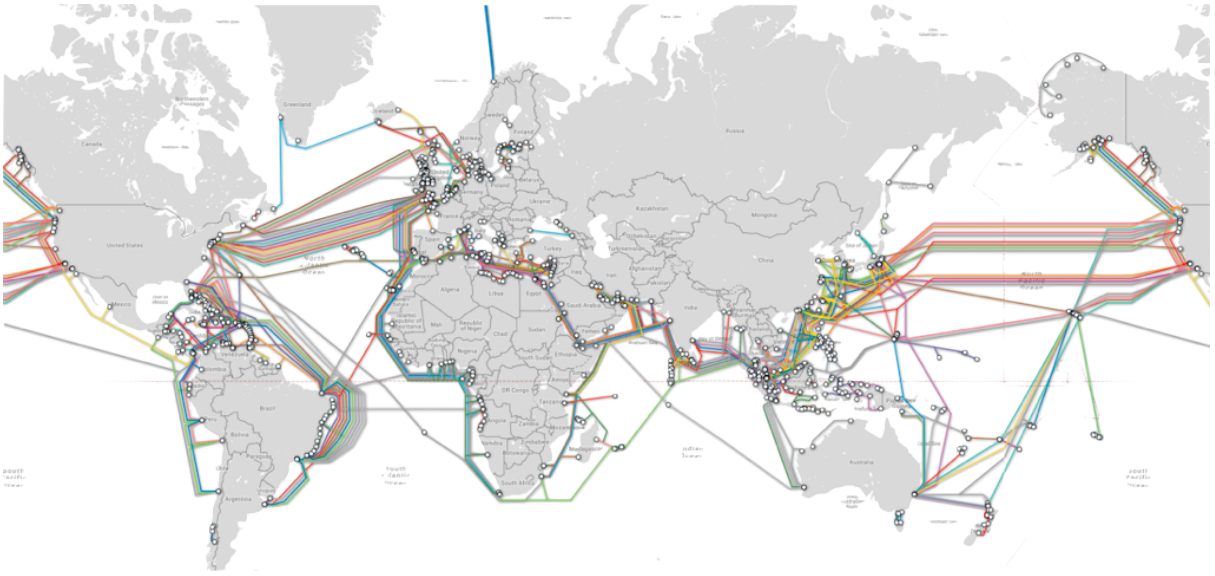
They have publicly accessible lists of which services are directly connected.

DE-CIX in Hamburg:
https://www.de-cix.net/en/locations/germany/hamburg/connected-networks

The Internet

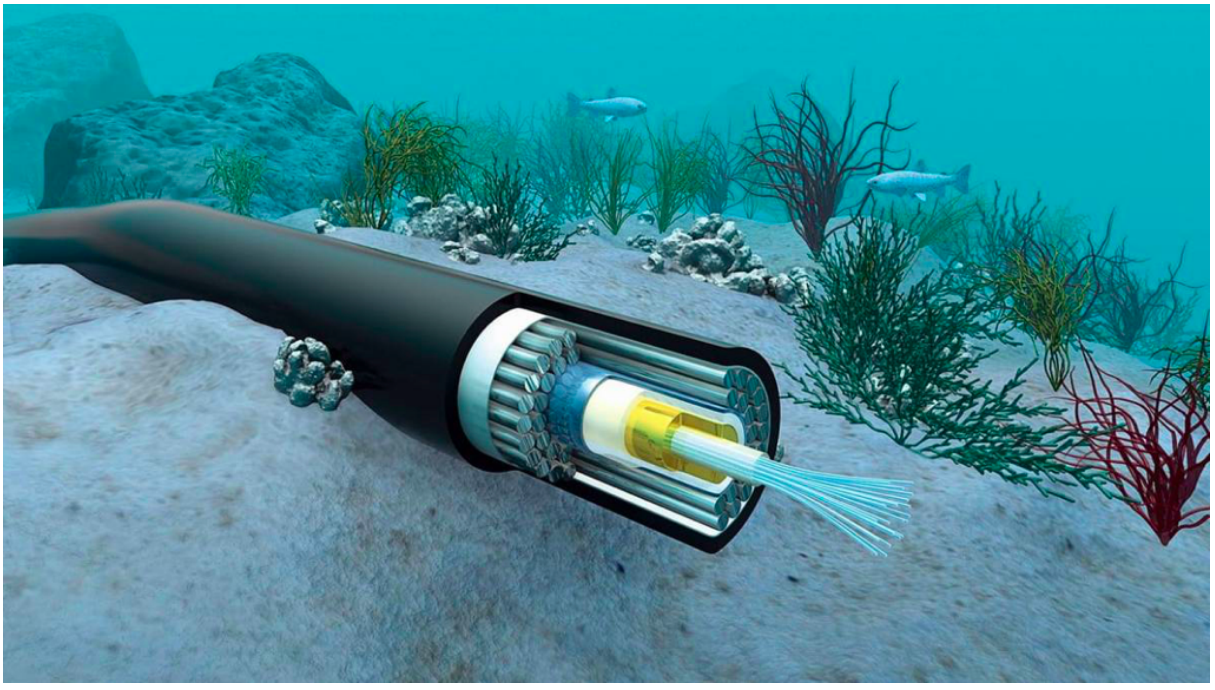
The internet is a network that spans the whole globe.

This map shows important publicly known connections through the sea. Not all connections are known, because they are often proprietary, and companies want to protect their cables from vandalism and hacking.



Deep Sea Cables

To create connections between continents, there are deep sea cables installed.



For deep sea cables, sharks are a problem. They like to bite the cable, because they react to the electromagnetic field.

Land Cables

Through land, cables are laid either as phone cables (for DSL) or as optic fiber cables.

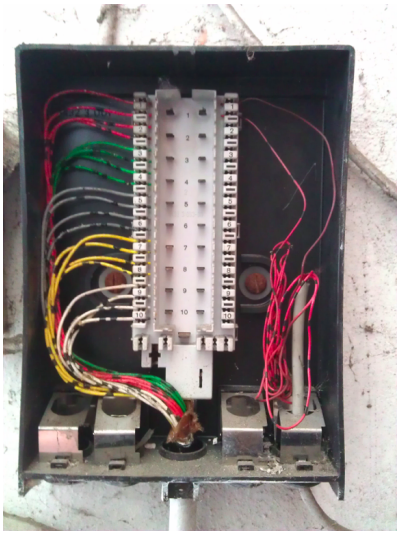
Phone cables.

Optic fiber cables.

Distribution Boxes

On the street, distribution boxes distribute the large bundle of cables to the buildings.

In the building, you then have distribution boxes (usually in the basement) that distribute the connections to all apartments.



Protocols

Client and server need a standard that defines how they communicate with each other, and how to send and receive data. This is done with protocols.

HTTP - HyperText Transfer Protocol

TCP - Transmission Control Protocol

IP - internet protocol

DNS - Domain Name System

These are the protocols that we use on a daily basis

HyperText Transfer Protocol

The HTTP protocol is the protocol that makes the ***world-wide web*** possible.

The world-wide web:

- The web is not the internet
- Internet = medium, network
- Web = websites, web applications
- HTTP = a set of rules to request and receive files from a server
- HTTPS is the encrypted, secure version of HTTP

History of the Web

- Creator: Tim Berners-Lee in 1989

- Academic background: we have papers that quote different papers
- Can we make a system so that we have links where we can get from one paper to the other?
- Paper = web page
- Reference = hyperlink

📚 Read more: https://webfoundation.org/about/vision/history-of-the-web/

HTTP Methods

HTTP has different methods for requesting, updating, uploading or deleting data.

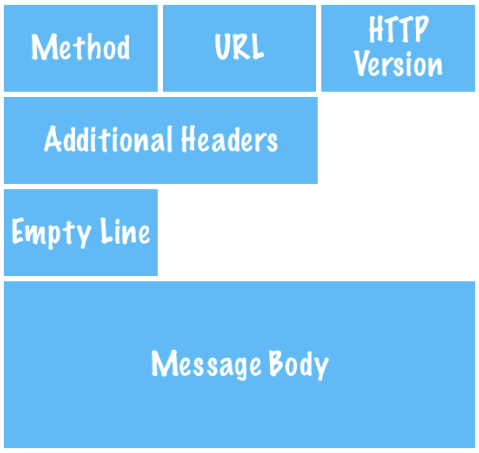
GET	= get a document from the server
POST	= post / send something to the server
PUT, PATCH	= update some existing document / data
DELETE	= delete a document / data

GET Request

- Response: HTML that the browser receives and renders the website from it
- In the HTML there are other files referenced, e.g. images
- For every image, the browser makes another GET request to get the image file
- Response of that: the picture file
- The browser then puts it into the website

Example: spiegel.de needs about 350 requests for all the content on the home page.

What does a request look like?

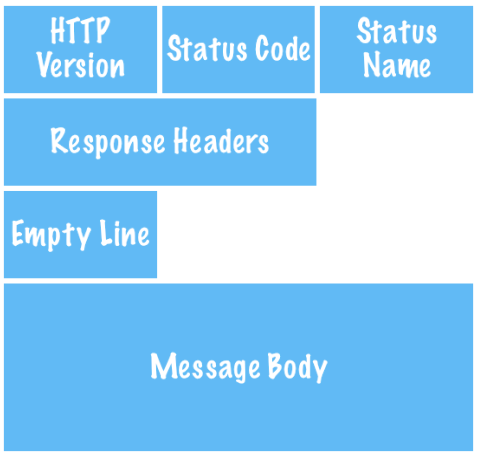


1. Method: GET, POST, PUT, PATCH, UPDATE, or DELETE
2. URL: spiegel.de
3. HTTP Version: 1.1
4. Additional Headers (e.g. language, browser, ...)
5. Empty line
6. Message body (for the POST, PUT, PATCH requests, data goes here)

Example request:

```
GET / HTTP/1.1
    Host: www.spiegel.de
    Connection: keep-alive
    Purpose: prefetch
    Upgrade-Insecure-Requests: 1
    User-Agent: Mozilla/5.0 (Macintosh; Intel Mac OS X 10_14_0)
    AppleWebKit/537.36 (KHTML…
    Accept:
    text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,image/apng,
    */
    Accept-Encoding: gzip, deflate
    Accept-Language: de
    Cookie:
    __gads=ID=b983721bda83d7ae:T=1487252257:S=ALNI_MYlth5Tx71QzpXnN3I0AoPWAu4Uog
    ;…
```

What does a response look like?



1. HTTP version

2. Status code
3. Status name
4. Response Headers: server time, file format, size ...
5. Empty line
6. Message body (contains binary file or HTML code)

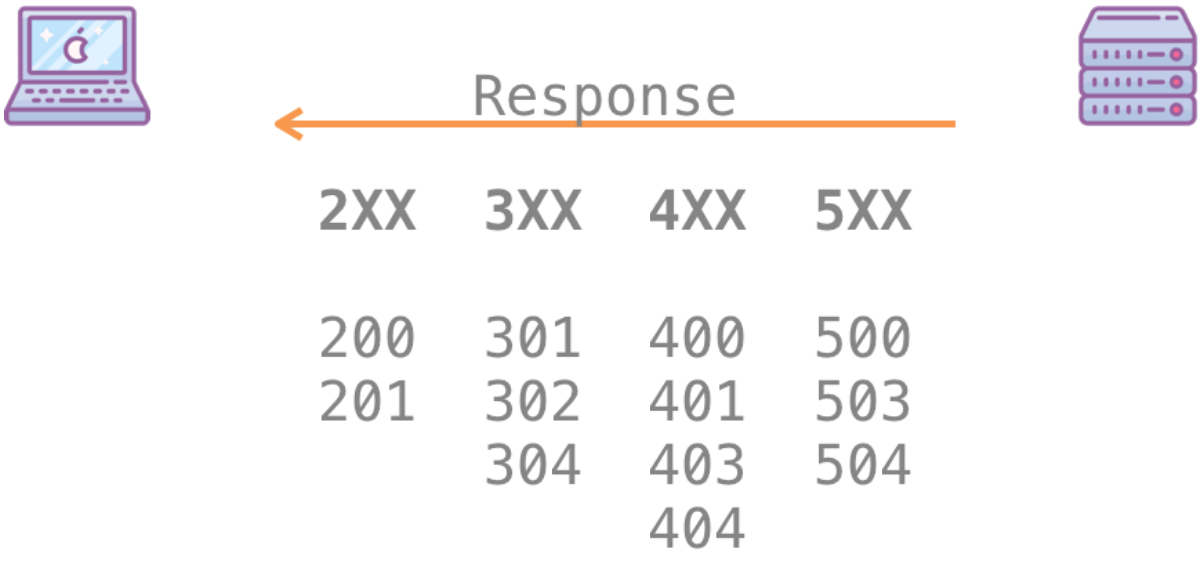
Example response:

```
HTTP/1.1 200 OK
Date: Thu, 25 Oct 2018 08:54:53 GMT
Cache-Control: no-transform
Expires: Thu, 25 Oct 2018 08:55:38 GMT
X-SP-TE: 5001893
X-Robots-Tag: index, follow, noarchive, noodp
Content-Type: text/html;charset=UTF-8
Content-Encoding: gzip
X-SP-AP: 5001887
Vary: Accept-Encoding, isssl
Age: 17
X-SP-PR: 5001887
Accept-Ranges: bytes
Content-Length: 68939
Connection: keep-alive

<!DOCTYPE HTML PUBLIC "-//W3C//DTD HTML 4.01 Transitional//EN"
"http://www.w3.org/TR/html4/loose.dtd"><html lang="de">
<head>
<title>SPIEGEL ONLINE - Aktuelle Nachrichten</title>
<meta http-equiv="X-UA-Compatible“ content="IE=edge“ />
…
```

Response Status Codes

In HTTP, the response always includes a status code. This indicates whether the request was successful or not, and if not, why that is.



2XX = all good
- 200 = OK
- 201 = Created (for POST and PUT/PATCH)

3XX = valid, but not here anymore
- 301 = redirect
- 304 = didn't change, just show your cache

4XX = not ok, client did a mistake
- 400 = bad request (you sent something that's not valid)
- 401 = unauthorized - you need to login
- 404 = not found

5XX = not ok, server did a mistake
- 500 = server error

📚 List of all status codes:
https://developer.mozilla.org/en-US/docs/Web/HTTP/Status

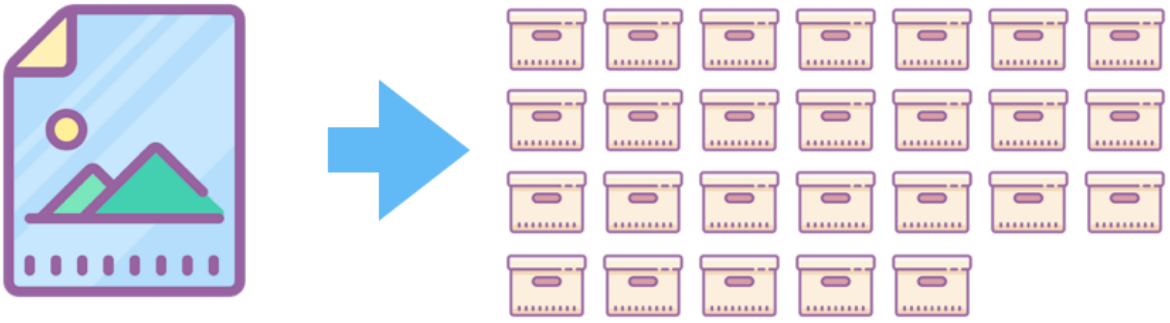
HTTPS

HTTPS is just like HTTP, just that the data is encrypted. This means that the network nodes in between cannot read the content, only sender and receiver can read it.

This is based on certificates with a public and a private part. The private part is used for encryption. The public part of the certificate verifies the origin of the website.

Network Packets

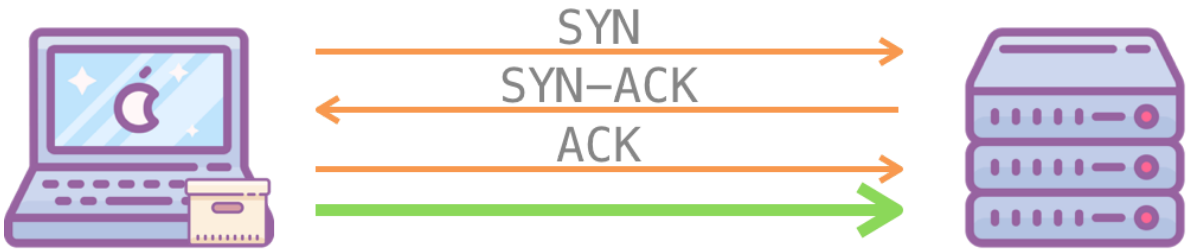
If data is sent with HTTP, it is not sent as-is, but the data is split into smaller packets.



This is done by the ***Transmission Control Protocol (TCP).*** It splits the data into small packets and labels them.

These packets may not take the same route all the time. It is possible that different packets of the same file are sent through other routes. TCP labels the packets so that it can reassemble the file, even if packets arrived in the wrong sequence.

TCP also makes sure that the connection is stable before it sends a packet. Each packet sending needs a so-called 3-way-handshake before it can be sent over the network. This is done with sending quick SYN (synchronize) - ACK (acknowledge) - SYN-ACK messages.



If a packet gets lost on the way (this happens all the time), TCP takes care of re-sending the packet until all packets have arrived.

MTU - Maximum Transfer Unit

The MTU is a setting in the router that determines the size of a package. The size changes, it is a dynamic value that the router adjusts depending on connection and data to balance between the size of each packet and the amount of 3-way-handshakes that need to be done..

Ports

HTTP is not the only protocol. There are various other protocols, e.g. SMTP for email or FTP for file transfer. One server can receive requests for different protocols. To be able to distinguish between them, the server uses ***ports***.

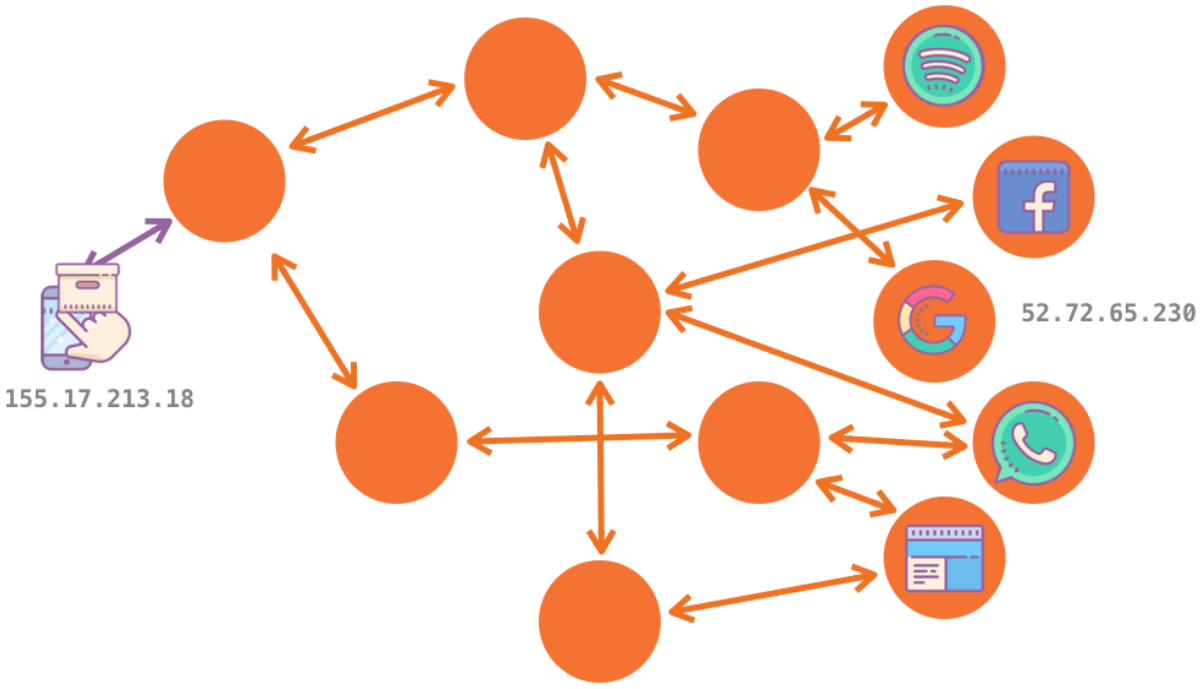
Ports are like tunnels on the server, that filter out data. Each protocol has its own port.

A port is a number. These numbers are standardized. Examples are **80** or **8080** for web servers (HTTP), or **25** for email.

The TCP protocol takes care that packets meant for a certain server on a machine are actually arriving there. It uses port numbers for that.

The Internet Protocol

The Internet Protocol (IP) takes care of routing. It makes sure that a packet arrives where it is supposed to go.



IP Addresses

To address a server, the IP protocol uses IP addresses.

An IP address looks like this: `77.247.84.239`

This is an IP version 4 (IPv4) address. It consists of 4 blocks of numbers between 0 and 255.

Because this address space is running out at some point, version 6 of the IP protocol (IPv6) was created.

IPv6 addresses look like this: `2a04:4540:6b03:3200:f832:5995:c43b:8844`

Every device has an IP address, sometimes both an IPv4 and an IPv6 address.

The address is known in the network, so routers can determine where to send packets to by the IP address.

IP Routing

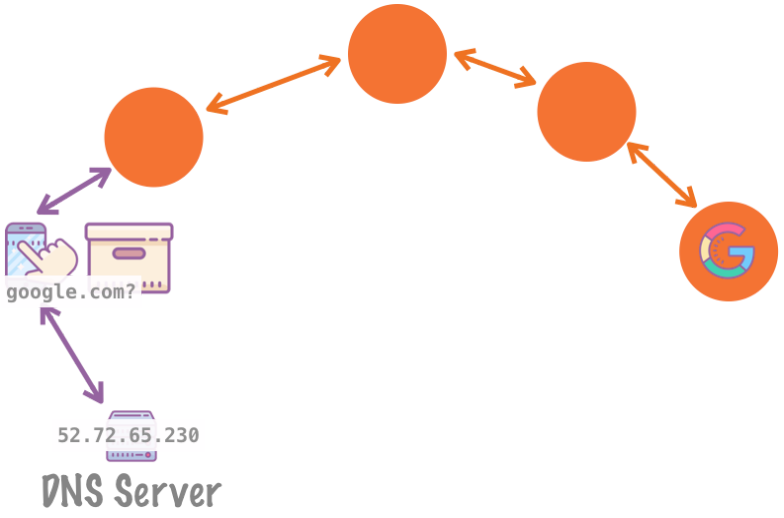
How does the router know where to send the packet to just by the IP address?

- Each network node has its own routing tables
- Routing tables list IP addresses ranges of connected networks
- Each network knows from this table which next network to send the package to

Domain Name System

The ***Domain Name System (DNS)*** takes care of translating domain names (e.g. www.google.com) to IP addresses. It is like an internet phonebook. It maps domain names to IP addresses.

This is looked up from so-called ***DNS servers***. A DNS server's purpose is to keep a register of domain name mappings.



Glossary

Client	A device (laptop, mobile phone, computer) that requests a website from a server.
Server	A computer that saves files (websites, images, music, video files etc.) and delivers them on request from a client device.
Request	The client sends out a request to the server e.g. for a website or a different kind of file.
Response	The server reacts with a response that contains the requested file.
Data center	A center with a large collection of servers.
Network	A network is multiple devices connected with each other.
Network node	In the network, a device is also called a network node.
Internet	The internet is a large network that spans across the globe.
Router	The router is a device that connects networks with each other.
Routing	Routing is the action of sending data over the network by creating a route that leads to the destination device. Routing is the task of routers.
ISP	Internet Service Provider A network provider, e.g. Telekom.
IXP	Internet eXchange Point Organizations that maintain strong connections between networks, the “backbone” of the internet.
HTTP	HyperText Transfer Protocol The protocol of the world wide web (used for websites).
HTTPS	Secure HTTP. The content that is sent via HTTPS is encrypted and unreadable by anyone tapping into the network.
TCP	Transmission Control Protocol Takes care of splitting the data sent over the internet into small packets.
IP	Internet Protocol The protocol responsible for routing.
DNS	Domain Name Service Mapping from domain names (e.g. www.google.de) to IP addresses. The “phone book” of the internet.

DNS Server	A server that exists only to maintain an updated table that maps domain names to IP addresses.
World Wide Web	The part of the internet used for websites.
HTTP methods	When a client makes a request to a server, it can use one of a selection of methods: GET, POST, PUT, PATCH or DELETE.
Status code	The response that a server sends back to the client will have a response code: a code that indicates whether or not the response is successful, and if not, why that is.
Network packet	Data is not sent over the network as-is, but is split into small packets, which are sent over the network independent from each other, and then reassembled at the receiver.
MTU	Maximum Transfer Unit A setting in the router that defines how big a packet is. It is a variable setting and changes according to the network connection and the data.
Port	A port is a number that is used to address certain servers that run on the same machine. Web usually uses port 80 or 8080, email uses 25.
SMTP	Simple Mail Transfer Protocol The protocol that is used for email.
IPv4	IP address version 4. Looks like this: 77.247.84.239
IPv6	IP address version 6. Looks like this: 2a04:4540:6b03:3200:f832:5995:c43b:8844

Useful Links

Connected Networks of DE-CIX Hamburg:
https://www.de-cix.net/en/locations/germany/hamburg/connected-networks

List of all status codes: https://developer.mozilla.org/en-US/docs/Web/HTTP/Status

Test your IPv6 address: http://test-ipv6.com/

The history of the web: https://webfoundation.org/about/vision/history-of-the-web/