Let's build a website together

We need three ingredients:
a host with an IP address, a domain name, a web server

Let's go somewhere far… What about Sydney?

Zurich ↔ Sydney: ~33 200 km
Theoretical round-trip time:

\[
\text{Speed of light in optical fiber} = \frac{299,792,458 \text{ m/s}}{1.468} = 204,218,296 \text{ m/s}
\]

\[
\text{Round-trip time} = \frac{33,200,000 \text{ m}}{204,218,296 \text{ m/s}} = 163 \text{ ms}
\]

Source: [fopnews](http://www.petergarritano.com/the-internet.html)

Somewhere in Manhattan...

http://www.petergarritano.com/the-internet.html

[Google crams more data into new Atlantic cable](https://www.wired.com/story/google-cramming-more-data-new-atlantic-cable)

[Source](http://marine.orange.com/en/Ships-and-submarine-vehicles/Cable-ships/Le-Rene-Descartes)

[Submarine cable map](https://www.submarinecablemap.com/)

We need three ingredients: a host with an IP address, a domain name, a web server.

Let's go for something fun!

The Internet
An exciting place

~30 billion
estimated* # of Internet connected devices in 2023

~13 exabytes
estimated* daily global IP traffic in 2022

1 Gigabyte = 1 Gbyte
The Internet

A tense place

Countries get disconnected for political reasons

volume(Great Wall of China) = 1 exabyte

~82% of all Internet traffic

estimated* percentage of video traffic in 2022

* Cisco Visual Networking Index

The Internet

A tense place

Belarus Has Shut Down the Internet Amid a Controversial Election

Myanmar coup: How the military disrupted the internet

Belarusians have complained of widespread outages in recent months, while the internet has been shut down in response to protests and political unrest.

Belarusian authorities have also been criticized for blocking access to international news websites and social media platforms, leading to a lack of information and communication.

Governments shut down the internet more than 50 times in 2016

Countries have displayed an increasing willingness to cut off their citizens from the outside world in order to silence opposition and control information.
Internet communications get congested for economical reasons.

Can ISPs selectively slow down traffic?

The U.S. Federal Communications Commission (FCC) set network neutrality rules in 2015, which it then repealed in 2017.

In Switzerland, network neutrality is enforced by the Swiss Telecommunications Act since January 2021.

Some Internet communications are interfered against or heavily congested.

A primer on the conflict between Netflix and Comcast.

Who should pay the other for Internet connectivity?
Due to congestion, throughput across Cogent to Comcast, Time Warner and Verizon were miserable

Situation massively improved after Netflix agreed to paid direct connection to the providers

Situation massively improved after Netflix agreed to paid direct connection to the providers

Internet infrastructures are regularly targeted by large-scale attacks

In June 2020, Amazon was targeted by a 2.30 Tbps DDoS attack

In August 2021, Microsoft was targeted by a 2.40 Tbps DDoS attack

In November 2021, Microsoft was targeted by a 3.47 Tbps DDoS attack

The Internet

A vital place during a pandemic
Following the lockdown in March 2020, (wired) networks saw traffic increasing by 15–20%

Unsurprisingly, we saw a strong increase in web conferencing, video, and gaming traffic

Despite being absolutely critical, the Internet infrastructure is inherently fragile

The Internet
A fragile place

Our engineering teams have learned that configuration changes on the backbone routers that coordinate network traffic between our data centers caused issues that interrupted this communication.

This disruption to network traffic had a cascading effect on the way our data centers communicate, bringing our services to a halt.
Someone in Google fat-thumbed a Border Gateway Protocol (BGP) advertisement and sent Japanese Internet traffic into a black hole.

[...] the result of which was traffic from Japanese giants like NTT and KDDI was sent to Google on the expectation it would be treated as transit.

The outage in Japan only lasted a couple of hours, but was so severe that [...] the country’s Internal Affairs and Communications ministries want carriers to report on what went wrong.

In February 2020, a planned maintenance work in Swisscom’s network shuts down emergency numbers

Internet, 4G, TV and telephone network affected as well

"Human factors are responsible for 50% to 80% of network outages"

Juniper Networks, What’s Behind Network Downtime?, 2008

Communication Networks
Course goals

Knowledge
Understand how the Internet works and why

Insights
Key concepts and problems in Networking

Naming  Layering  Routing  Reliability  Sharing

How do you address computers, services, protocols?
How do you manage complexity?

How do you find a path from A to B?

How do you communicate reliably using unreliable mediums?

How do you divide scarce resources among competing parties?

Skills
Build, operate and configure networks

Trinity using a port scanner (nmap) in Matrix Reloaded™

Insights
Learn about some of our current research

nsg.ee.ethz.ch

Your dream team for the semester

- Enrico and Max, both of whom followed the lecture in 2022
Our website: https://comm-net.ethz.ch
check it out regularly!

The course will be split in three parts
- Part 1: Overview
  ~1.5 lectures
- Part 2: Concepts
  ~1.5 lectures
- Part 3: Today’s Internet
  ~10 lectures

Your final grade
- Exam: 70%
  written, open book
- Projects: 30%
  continuous performance assessments

Your final grade
- Exam: 70%
  written, open book
- Projects: 30%
  continuous performance assessments

There will be two practical projects,
to be done in group of three students

1. Build and operate a real, working Internet (20%)
2. Implement an interoperable reliable protocol (10%)

Detailed instructions will follow
If you are a repeating student,
let us know if you want to keep your grades!

The course closely follows the textbook
Computer Networking: a Top-Down Approach
6th edition
using another edition is okay
but numbering might vary
see sections indicated on comm-net.ethz.ch

We’ll use ETH’s Matrix/Element Chat Room
to discuss about the course and assignments

Using the chat room is highly recommended
but facultative

Use it to
- ask questions
- chat with other students (e.g. your group)
- be informed about course announcements
  (also on our website)
Communication Networks

Part 1: Overview

#1 What is a network made of?
#2 How is it shared?
#3 How is it organized?
#4 How does communication happen?
#5 How do we characterize it?

Networks are composed of three basic components

- End-systems
  - Windows PC
  - Linux
  - server
  - MAC
  - laptop
  - car
  - navigator
  - heart
  - pacemaker
  - smartphone
  - iPad

End-systems come in a wide-variety

Switches & routers forward data to the destination

End-systems send & receive data
## Communication Networks
### Part 1: Overview

What is a network made of?

1. How is it shared?
2. How is it organized?
3. How does communication happen?
4. How do we characterize it?

### Communication Networks include:

- Home router
- Internet core router

### Routers/switches vary in size and usage:

- **Home router**
  - ≤10 cm
  - ≤0.5 kg
  - 1 Gbps

- **Internet core router**
  - >200 cm
  - >700 kg
  - >12 Tbps
  - (>920 Tbps in multi-chassis*)


### Links connect end-systems to switches and switches to each other

### Links, too, vary in size and usage

- Copper
  - ADSL, RJ-45,…
- Optical fibers
- Wireless link

### There exists a huge amount of access technologies

- **Ethernet**
  - most common, symmetric
- **DSL**
  - over phone lines, asymmetric
- **CATV**
  - via cable TV, shared
- **Cellular**
  - smart phones
- **Satellite**
  - remote areas
- **FTTH**
  - household
- **Fibers**
  - Internet backbone
- **Infiniband**
  - High performance computing

### A good network topology fulfills at least three requirements

- Tolerate failures
  - >1 path should exist between each node
- Allow sharing to be feasible & cost-effective
  - # links should not be too high
- Provide (ample) capacity
  - # links should not be too small

### Compare these three designs in terms of sharing, resiliency, and per-node capacity

<table>
<thead>
<tr>
<th>Design</th>
<th>Full-Mesh</th>
<th>Chain</th>
<th>Bus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disadvantages</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Switched networks provide reasonable and flexible compromise

<table>
<thead>
<tr>
<th>Design</th>
<th>Switched</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advantages</td>
<td>sharing and per-node capacity can be adapted to fit the network needs</td>
</tr>
<tr>
<td>Disadvantages</td>
<td>require smart devices to perform: forwarding, routing, resource allocation</td>
</tr>
</tbody>
</table>
Links and switches are shared between flows.

There exist two approaches to sharing: reservation and on-demand.

- **Reservation**
  - reserve the bandwidth you need in advance

- **On-demand**
  - send data when you need

**Between reservation and on-demand:**
Which one do you pick?

Assume the following peak demand and flow duration:

- **source 1**
  - peak rate: 10 Mbps
  - average rate: 11 Mbps
  - duration: 13 Mbps
- **source 2**
  - peak rate: 11 Mbps
  - average rate: 11 Mbps
  - duration: 11 Mbps
- **source 3**
  - peak rate: 13 Mbps
  - average rate: 13 Mbps
  - duration: 13 Mbps

What does each source get with reservation and on-demand?

- First-come first-served
- Equal (10 Mbps)

**Peak vs average rates**

- Each flow has peak rate P, average rate A
- Reservation must reserve P, but level of utilization is A/P
  - P=100 Mbps, A=10 Mbps, level of utilization=10%

- On-demand can usually achieve higher level of utilization
  - depends on degree of sharing and burstiness of flows

**Ultimately, it depends on the application**

- Reservation makes sense when P/A is small
  - voice traffic has a ratio of 3 or so

- Reservation wastes capacity when P/A is big
  - data applications are bursty, ratios >100 are common

That's why the phone network used reservations...
... and why the Internet does not!
The two approaches are implemented using circuit-switching or packet-switching, respectively.

Reservation  On-demand

Circuit switching relies on the Resource Reservation Protocol.

Let’s walk through example of data transfer using circuit switching.

The efficiency of the transfer depends on how utilized the circuit is once established.

This is an example of poor efficiency. The circuit is mostly idle due to traffic bursts.

This is another example of poor efficiency. The circuit is used for a short amount of time.

(1) src sends a reservation request for 10Mbps to dst
(2) switches “establish a circuit”
(3) src starts sending data
(4) src sends a “teardown circuit” message
Another problem of circuit switching is that it doesn’t route around trouble.

Pros and cons of circuit switching

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predictable performance</td>
<td>Inefficient if traffic is bursty or short</td>
</tr>
<tr>
<td>Simple &amp; fast switching</td>
<td>Complex circuit setup/teardown</td>
</tr>
<tr>
<td>Once circuit established</td>
<td>Which adds delays to transfer</td>
</tr>
<tr>
<td></td>
<td>Requires new circuit upon failure</td>
</tr>
</tbody>
</table>

What about packet switching?

In packet switching, data transfer is done using independent packets.

Since packets are sent without global coordination, they can “clash” with each other.

To absorb transient overload, packet switching relies on buffers.

Packet switching routes around trouble.

Pros and cons of packet switching

**Advantages**
- Efficient use of resources
- Simpler to implement
- Route around trouble

**Disadvantages**
- Requires buffer management and congestion control
- Unpredictable performance

Packet switching beats circuit switching with respect to resiliency and efficiency

The Internet is a network of networks

The Internet has a hierarchical structure

<table>
<thead>
<tr>
<th>Tier</th>
<th>Description</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier-1</td>
<td>International</td>
<td>Tier-1 ISPs</td>
</tr>
<tr>
<td>Tier-2</td>
<td>National</td>
<td>Tier-2 ISPs</td>
</tr>
<tr>
<td>Tier-3</td>
<td>Local</td>
<td>Tier-3 ISPs</td>
</tr>
</tbody>
</table>

Provider customer

access ISP
The distribution of networks in Tiers is extremely skewed towards Tier-3s

<table>
<thead>
<tr>
<th>Tier</th>
<th>Have no provider</th>
<th>Provide transit to Tier-3s</th>
<th>Do not provide any transit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tier-1</td>
<td>~12</td>
<td>~1,000s</td>
<td>85–90%</td>
</tr>
<tr>
<td>Tier-2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tier-3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Some networks have an incentive to connect directly, to reduce their bill with their own provider.

This is known as "peering".

Interconnecting each network to its neighbors one-by-one is not cost effective.

Physical costs
- of provisioning or renting physical links

Bandwidth costs
- a lot of links are not necessarily fully utilized

Human costs
- to manage each connection individually

Internet eXchange Points (IXPs) solve these problems by letting many networks connect in one location.

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