The Internet
An exciting place

~22 billion

estimated* # of Internet connected devices in 2020

* Cisco Visual Networking Index 2018—2023

~30 billion

estimated* # of Internet connected devices in 2023

* Cisco Visual Networking Index 2018—2023

~4 exabytes

estimated* daily global IP traffic in 2017

* Cisco Visual Networking Index 2017—2022
If \[ \text{GB} = 1 \text{ Gigabyte} \]

\[ \text{volume(Great Wall of China)} = 1 \text{ exabyte} \]

\(~4 \text{ exabytes} \)

estimated daily global IP traffic in 2017

\(~13 \text{ exabytes} \)

estimated daily global IP traffic in 2022

\(~75\% \text{ of all Internet traffic} \)

estimated percentage of video traffic in 2017

\(~82\% \text{ of all Internet traffic} \)

estimated percentage of video traffic in 2022

The Internet

A tense place

Countries get disconnected for political reasons

Internet communications get congested for economical reasons

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… which it then repealed in 2017

http://nyti.ms/2CkTbRR

… but might restore soon


In Switzerland, network neutrality is enforced by the Swiss Telecommunications Act since 1/1/21


Some Internet communications are interfered against or heavily congested

Who should pay the other for Internet connectivity?

A primer on the conflict between Netflix and Comcast


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

Closer to us...

Internet infrastructures are regularly targeted by large-scale attacks

In February 2018, GitHub was targeted by a 1.35 Tbps Distributed Denial of Service (DDoS) attack

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

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.


All in all the Internet performed very well in these unprecedented times.

https://www.theregister.co.uk/2017/08/27/google_routing_blunder_sent_japans_internet_dark/

Despite being absolutely critical, the Internet infrastructure is inherently fragile.

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.

Source: [fb.com]

August 2017

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.

“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 go 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

Insights
Learn about some of our current research

Your dream team for the semester
+ Martin and Nasib who followed the lecture in previous years

Communication Networks
Course organization

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

Trinity using a port scanner (nmap) in Matrix Reloaded™
There will be two practical projects, to be done in group of maximum 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 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 Slack (a chat client) to discuss about the course and assignments.
Web, smartphone and desktop clients available.
Using Slack is highly recommended but facultative.
Use Slack to:
- ask questions
- chat with other students (e.g. your group)
- be informed about course announcements (also on our website)

Register today:
https://join.slack.com/t/comm-net22/signup
Register with your @ethz.ch email
Ping us if you prefer using another one
Use your real name
It greatly facilitates our organization
We never publish sensitive data on Slack e.g. your grades.
Communication Networks
Part 1: Overview

- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we characterize it?

Networks are composed of three basic components:

- End-systems send & receive data
- Switches & routers forward data to the destination

End-systems come in a wide-variety:

- Windows PC
- Linux server
- MAC laptop
- car
- navigator
- heart
- pacemaker
- smartphone
- iPad
- Home router
- Internet core router

Routers/switches vary in size and usage:

<table>
<thead>
<tr>
<th>Device</th>
<th>Dimension</th>
<th>Weight</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home router</td>
<td>~20 cm</td>
<td>0.5 kg</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>Internet core router</td>
<td>&gt;200 cm</td>
<td>700 kg</td>
<td>&gt;12 Tbps</td>
</tr>
<tr>
<td>Cisco Nexus 7k</td>
<td>~25 deployed</td>
<td>700 kg</td>
<td>&gt;12 Tbps</td>
</tr>
</tbody>
</table>


Switches/ routers @ETHZ ~25 deployed
Cisco Nexus 7k
Routers @ETHZ
~25 deployed
Next-generation programmable switches
up to **25.6 Tbps** of backplane capacity*

Barefoot Tofino Wedge 100BF-32X part of our NSG lab


---

**Communication Networks**

Part 1: Overview

- What is a network made of?
- How is it shared?
- How is it organized?
- How does communication happen?
- How do we characterize it?

---

**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>

---

**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

---

**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

---

**Communication Networks**

Part 1: Overview
Communication Networks | Mon 21 Feb 2022

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

Both are examples of statistical multiplexing

- **Reservation**: at the flow-level
- **On-demand**: at the packet-level

Consider that each source needs 10 Mbps

What do they get with:
- reservation
- on-demand

Assume the following peak demand and flow duration

<table>
<thead>
<tr>
<th>Source</th>
<th>Peak Rate</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13 Mbps</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>11 Mbps</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>10 Mbps</td>
<td></td>
</tr>
</tbody>
</table>

What does each source get with reservation and on-demand?
- First come first served
- Equal (10 Mbps)

Peak vs average rates

<table>
<thead>
<tr>
<th>Each flow has</th>
<th>Peak rate P</th>
<th>Average rate A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservation</td>
<td>P</td>
<td>A</td>
</tr>
</tbody>
</table>

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
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!

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

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

The two approaches are implemented using
circuit-switching or packet-switching, respectively

Reservation
On-demand

circuit-switching
packet-switching

Circuit switching relies on the Resource Reservation Protocol

(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

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.

![Circuit Establishment, Transfer, Teardown Times](chart.png)

Another problem of circuit switching is that it doesn’t route around trouble.

![Circuit Establishment, Switch Failure](diagram.png)

Pros and cons of circuit switching:

**Advantages**
- Predictable performance
- Simple and fast switching once circuit established

**Disadvantages**
- Complex circuit setup/teardown which adds delays to transfer
- Inefficient if traffic is bursty or short
- Requires new circuit upon failure

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

![Packet Switching Diagram](diagram.png)

Each packet contains a destination ( dst ).

To absorb transient overload, packet switching relies on buffers.

![Packet Switching Buffer](diagram.png)

What about packet switching?

Reservation vs On-demand:

- Reservation
- On-demand

Circuit-switching vs Packet-switching:

- Circuit-switching
- Packet-switching

Since packets are sent without global coordination, they can “clash” with each other.
Packet switching routes around trouble

Pros and cons of packet switching

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficient use of resources</td>
<td>Unpredictable performance</td>
</tr>
<tr>
<td>Simpler to implement</td>
<td>Requires buffer management and congestion control</td>
</tr>
</tbody>
</table>

Packet switching beats circuit switching with respect to resiliency and efficiency

Internet ❤ packets

Packet switching will be our focus for the rest of the course

The Internet is a network of networks

Internet Service Providers

So far, this is our vision of the Internet...

The real Internet is a "tad" more complex

http://www.opte.org
The Internet has a hierarchical structure

Tier-1
- international
  - have no provider

Tier-2
- national
  - provide transit to Tier-3s
  - have at least one provider

Tier-3
- local
  - do not provide any transit
  - have at least one provider

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

- total networks: $\sim 70,000$
- Tier-1 international: $\sim 12$
- Tier-2 national: $\sim 1,000$s
- Tier-3 local: 85-90%

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**
- 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.

---

**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?

---

Next Monday on Communication Networks

Routing concepts

---

**No exercise session**

this Thursday