The Internet

An *exciting* place
8 billion
8 billion

estimated* # of Internet connected devices in 2016

* Cisco Visual Networking Index 2017
11.6 billion

estimated* # of Internet connected devices in 2021

* Cisco Visual Networking Index 2017
\( \sim 3 \text{ exabytes} \)

estimated* daily global IP traffic in 2016

* Cisco Visual Networking Index 2017
If BGP = 1 Gigabyte
volume(Great Wall of China) = 1 exabyte
~3 exabytes

estimated* daily global IP traffic in 2016

* Cisco Visual Networking Index 2017
~6 exabytes

estimated* daily global IP traffic in 2020

* Cisco Visual Networking Index 2017
A few Internet services you might have heard of...
The Internet

A *tense* place
Countries get disconnected

Syria follows Egypt and disconnects from the internet

Also check: http://research.dyn.com/2012/11/could-it-happen-in-your-countr/
Internet traffic to/from Egypt in January 2011

Internet traffic to and from Egypt on January 27 - 28. At 5:20 pm EST, traffic to and from Egypt across 80 Internet providers around the world drops precipitously.

http://huff.to/1KxxoZF
Earlier this morning, the national fiber backbone of Iraq was taken offline in an effort to combat cheating on 6th grade placement exams. It was the fourth such outage in the past five days. 2017 marks the third year Iraq has used government-directed internet blackouts to combat cheating on student exams.

These recent outages are a continuation of a growing (and somewhat puzzling) trend by governments in many developing parts of the world to cut communications services in a desperate attempt to staunch rampant cheating on high-stakes student exams.
Iraq national backbone down for 1 hour for 4 of the last 5 days.

http://dyn.com/blog/iraq-downs-internet-to-combat-cheating-again/
Internet Freedom

Governments shut down the internet more than 50 times in 2016

Economic impact alone was £1.9bn, with greater fears over human rights and freedom of speech

http://www.wired.co.uk/article/over-50-internet-shutdowns-2016
Communications get eavesdropped on…

http://wapo.st/1UVKamr
Introduction
U.S. as World’s Telecommunications Backbone

- Much of the world’s communications flow through the U.S.
- A target’s phone call, e-mail or chat will take the **cheapest** path, **not the physically most direct** path – you can’t always predict the path.
- Your target’s communications could easily be flowing into and through the U.S.

International Internet Regional Bandwidth Capacity in 2011
Source: Telegeography Research

http://wapo.st/1LcAw6p
Some Internet communications are interfered against or heavily congested.
Can ISPs selectively slow down traffic?
The U.S. Federal Communications Commission (FCC) ordered Comcast to stop interfering with p2p traffic.

http://bit.ly/2ldKgJW
WASHINGTON — The Federal Communications Commission on Thursday released extensive details of how it would regulate broadband Internet providers as a public utility, producing official wording that almost certainly sets the stage for extended legal fights.

The release of the rules had been eagerly anticipated by advocates and lawmakers, as well as broadband and technology companies, since the agency approved new rules for Internet service two weeks ago. The details came in a 313-page document that included the new rules and the legal justifications for them.

The rules revealed how the strict laws would be modified for Internet providers, exempting the companies from the sort of price controls typically applied to utilities, for example. But the full text of the new order also raised uncertainties about broad and subjective regulation. One catchall provision, requiring “just and reasonable” conduct, allows the F.C.C., to decide what is acceptable on a case-by-case basis.

Opponents of the rules, including many of the leading Internet providers, spent Thursday poring over the document. It was not known who would file the first legal challenges, or exactly what legal arguments would be made. Many experts, though, said the document included plenty of opportunity for...
Trump's F.C.C. Pick Quickly Targets Net Neutrality Rules

WASHINGTON — In his first days as President Trump's pick to lead the Federal Communications Commission, Ajit Pai has aggressively moved to roll back consumer protection regulations created during the Obama presidency.

Mr. Pai took a first swipe at net neutrality rules designed to ensure equal access to content on the internet. He stopped nine companies from providing discounted high-speed internet service to low-income individuals. He withdrew an effort to keep prison phone rates down, and he scrapped a proposal to break open the cable box market.

In total, as the chairman of the F.C.C., Mr. Pai released about a dozen actions in the last week, many buried in the agency's website and not publicly announced, stunning consumer advocacy groups and telecom analysts. They said Mr. Pai's message was clear: The F.C.C., an independent agency, will mirror the Trump administration's rapid unwinding of government regulations that businesses fought against during the Obama administration.

“With these strong-arm tactics, Chairman Pai is showing his true stripes,” said Matt Warsh, the executive director of the consumer group Free Press.
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 Time Warner, Comcast, Verizon were miserable.

http://bit.ly/1thPzro
Situation massively improved after Netflix agreed to paid direct connection to the providers

Median download throughput across Cogent in NYC over time from different ISPs (higher is better)

Netflix starts to pay

The Internet infrastructure is a fragile environment
United Airlines Blames Router for Grounded Flights

After a computer problem caused nearly two hours of grounded flights for United Airlines this morning and ongoing delays throughout the day, the airline announced the culprit: a faulty router.

Spokeswoman Jennifer Dohm said that the router problem caused “degraded network connectivity,” which affected various applications.

A computer glitch in the airline’s reservations system caused the Federal Aviation Administration to impose a groundstop at 8:26 a.m. E.T. Planes that were in the air continued to operate, but all planes on the ground were held. There were reports of agents writing tickets by hand. The ground stop was lifted around 9:47 a.m. ET.
The outage was due to one faulty Internet device
Facebook, Tinder, Instagram suffer widespread issues

UPDATED: Tuesday, Jan. 27 / 4:32 a.m. EST — A Facebook spokeswoman told Mashable that the outage was due to a change to the site’s configuration systems, and not a hacker attack. "Earlier this evening many people had trouble accessing Facebook and Instagram. This was not the result of a third party attack but instead occurred after we introduced a change that affected our configuration systems. We moved quickly to fix the problem, and both services are back to 100% for everyone," she said.

UPDATED: Tuesday, Jan. 27 / 2:14 a.m. EST — Facebook, Tinder and Twitter appear to be back to normal after a 40 minute outage and mass freak out.

By Jenni Ryall
Australia
Jan 27, 2015
The outage was due to a change to the site’s configuration systems.
“Human factors are responsible for 50% to 80% of network outages”

Internet advertisements rates suggest that The Internet was more stable than normal on Sept 11
Internet advertisements rates suggest that
The Internet was more stable than normal on Sept 11

Information suggests that operators were watching the news instead of making changes to their infrastructure
Fun fact: most BGP route leaks happen on Wednesdays, but in the weekend us humans collectively take a break! :-)
Internet scalability is at risk with no more IPv4 addresses and a slow IPv6 deployment.
Communication Networks

Course goals
Knowledge

Understand how the Internet works and why

from your network plug...

...to Google's data-center
Insight

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?
Skill
Build, operate and configure networks
Skill

Build, operate and configure networks

Trinity using a port scanner (nmap) in Matrix Reloaded™
Software-Defined Network
Software-Defined Network

enable network programmability
So far, network devices have been completely locked down.
SDN opens up the network devices, enabling network innovation

- **SDN controller**
  - open-source software
  - standardized interface (OpenFlow)
  - standardized hardware

- **SDN device**
The hype around SDN is huge, both in the industry and in academia.
Communication Networks

Course organization
Our website: http://comm-net.ethz.ch
check it out regularly

Communication Networks 2017

Professor: Laurent Vanbever (email)
Assistants:
- Tobias Stöhr
- Rüdiger Stricker
- Alexander Dietmiler
- Thomas Hotzendorf
- Roland Maier
- Maximilian Schütz
Lecture: Monday, 10 am - 12 pm in ETF C 1
Exercise sessions: Exact schedule will be decided after the first lecture.
Slack: comm-net17.asap.io

Learn how the Internet works and how to operate it

It is hard to think of a technology that has more changed the way we live than the Internet. From the very way we communicate, access and exchange information, shop, pay, move, entertain, interact with nature, at the same time, the Internet is inexorably growing, at an ever faster pace from 3 billion of connected hosts in 2013 to an estimated 4 billion in 2019.
At the end of this course, you will be able to:
1. understand how the Internet works from your laptop to Google's datacenter at the other end of the planet;
2. build and operate an Internet like network infrastructure;
3. identify the right set of metrics to evaluate the performance or the adequacy of a network and propose ways to improve it (if any).
The course is an introductory one, meaning no prior networking background is needed. The course will include some programming assignments (in Python) for which the material covered in Technische Informatik 1 (257-0013-00) and Technische Informatik 2 (257-0014-00) will be useful.

Grading and organization

The course is graded 70% based on the final exam and 30% based on the practical assignments (see details). The final exam is a written open book exam. You will not be tested on material we didn’t cover during the lecture. All written material (books, notes, lab exercises etc.) is allowed. All electronic devices are prohibited, except for non-connected calculators. The exam will be in English.
I’ll use the textbook Computer Networking A Top-Down Approach (5th Edition) by Kurose and Ross as a reference and as a source of examples. Older versions of the book are fine too but sections number won’t necessarily match.

Exercises and projects

In addition to the lectures, there will be a set of exercises (the exact schedule of which will be fixed after the first lecture) along with two projects to be done in groups of maximum 3 students (the composition of which will be decided by the students themselves at the beginning of the first project):
1. Internet Routing (week 6 to 8): You’ll build and operate your own network! We’ll then interconnect networks together and form a mini-Internet. We’ll test out your Internet during a live class-wide Internet hackathon.
2. Reliable Communication (week 10 to 12): You’ll implement a simple transport protocol that can ensure reliable transmission.
Each project will be available online and will be introduced in class along with instructions on the report and on the specific grading scheme.
You should submit your work on an assignment (by email, according to the assignment instructions) before its due time. All assignments are due by 11:59pm on their selected days. If you submit your assignment after the due date, it will be graded late and at a reduced grade.
The course will be split into three parts

Part 1
Overview
2 lectures

Part 2
Concepts
2 lectures

Part 3
Today’s Internet
~9 lectures
The lectures will be accompanied by exercises, there will be two sessions per week (to ease scheduling)

<table>
<thead>
<tr>
<th>Available slots</th>
<th>Tue</th>
<th>8-10</th>
<th>vote <em>today</em> on comm-net.ethz.ch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10-12</td>
<td></td>
<td></td>
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<td></td>
<td>13-15</td>
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<td></td>
<td>15-17</td>
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<tr>
<td>Wed</td>
<td>13-15</td>
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<td>15-17</td>
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<td>13-15</td>
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<td></td>
<td>15-17</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Your final grade

Exam
- 80%
  written, open book

Projects
- 20%
  mandatory
Your final grade

- Exam: 80%
  - written, open book
- Projects: 20%
  - mandatory
There will be two practical projects, to be done in group of maximum three students.

#1 Build and operate a small Internet

#2 Implement an interoperable reliable protocol

Detailed instructions will follow.
“Internet Hackathon”
sometime in week 8
2016 edition
The course follows the textbook

Computer Networking: a Top–Down Approach

6th edition
ok to use the 5th
see sections indicated
on comm-net.ethz.ch
We’ll use Slack (chat client) to discuss about the course and assignments.

Web, smartphone and desktop clients available.
Register today using your real name

> https://comm-net17.slack.com/signup

Web, smartphone and desktop clients available
Communication Networks
List any technologies, principles, applications... used after typing in:

> www.google.ch

and pressing enter in your browser
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?
Communication Networks

Part 1: Overview

#1

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
End-systems come in a wide-variety
Switches & routers forward data to the destination.
Routers vary in size and usage

<table>
<thead>
<tr>
<th>Home router</th>
<th>Internet core router</th>
</tr>
</thead>
<tbody>
<tr>
<td>~20 cm</td>
<td>&gt;200cm</td>
</tr>
<tr>
<td>0.5 kg</td>
<td>700 kg</td>
</tr>
<tr>
<td>1 Gbps</td>
<td>1.2 Tbps</td>
</tr>
</tbody>
</table>
Cisco Nexus 7k

Routers @ETHZ

~25 deployed
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
The *Internet* is a network of networks
phone company
Conceptually, the last mile of the Internet looks like this

home PC  Internet connection  switch
In practice, it looks more like this…
Digital Subscriber Line (DSL) brings high BW to households over phone lines
Digital Subscriber Line (DSL) brings high BW to households over **phone lines**

Why?
Digital Subscriber Line (DSL) brings high BW to households over phone lines

DSL is composed of 3 channels:

- **downstream data channel** tens to few hundred Mbps
- **upstream data channel** few Mbps to few tens Mbps
- **2-ways phone channel**
DSL is composed of 3 channels:

- **downstream data channel**: tens to few hundred Mbps
- **upstream data channel**: few Mbps to few tens Mbps
- **2-ways phone channel**

Why is there such an asymmetry?
cable company
Conceptually, the last mile of the Internet looks like this
In practice, it looks more like this...
Many households share the same access

cable head end

CMTS

fiber

switch
Cable Access Technologies (CATV) brings high BW to the households via cable TV

- **downstream data channel** tends to hundreds of Mbps
- **upstream data channel** tens of Mbps

Unlike ADSL, the medium is shared between households
university net
With respect to DSL and cable providers, enterprise access networks is *much* simpler.
Ethernet is the most widely used Local Area Network technology

Twisted pair copper

1Gbps, 10 Gbps, 40 Gbps, 100 Gbps, ...

symmetric
ADSL, CATV and Ethernet are only few examples of access technologies...

<table>
<thead>
<tr>
<th>Technology</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular</td>
<td>smart phones</td>
</tr>
<tr>
<td>Satellite</td>
<td>remote areas</td>
</tr>
<tr>
<td>FTTH</td>
<td>household</td>
</tr>
<tr>
<td>Fibers</td>
<td>Internet backbone</td>
</tr>
<tr>
<td>Infiniband</td>
<td>High performance computing</td>
</tr>
</tbody>
</table>

...
Communication Networks

Part 1: Overview

What is a network made of?

#2 How is it shared?

How is it organized?

How does communication happen?

How do we characterize it?
Up to now, we’ve seen what the last mile of the Internet looks like
What about the rest of the network?
3 requirements for a network topology

Should tolerate failures
several paths between each source and destination

Possess enough sharing to be feasible & cost-effective
number of links should not be too high

Provide adequate per-node capacity
number of links should not be too small
Compare these three designs in terms of sharing, resiliency, and per-node capacity.
Switched networks provide reasonable and flexible compromise.

- **Design**: switched

- **Advantages**: sharing and per-node capacity can be adapted to fit the network needs

- **Disadvantages**: require smart devices to perform: forwarding, routing, resource allocation
Links and switches are shared between flows
There exist two approaches to sharing: reservation and on-demand.

**Reservation:**
- Principle: Reserve the bandwidth you need in advance.

**On-demand:**
- Principle: Send data when you need it.
Both are examples of **statistical multiplexing**

- **Reservation** at the flow-level
- **On-demand** at the packet-level
Between reservation and on-demand: Which one do you pick?

Consider that each source needs 10 Mbps

What do they get with:

- reservation
- on-demand
Assume the following peak demand and flow duration

source 1

source 2

source 3

10 Mbps

11 Mbps

13 Mbps

time
Assume the following peak demand and flow duration

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

- source 1: 10 Mbps
- source 2: 11 Mbps
- source 3: 13 Mbps

first-come first-served equal (10 Mbps)
**Peak vs average rates**

Each flow has

<table>
<thead>
<tr>
<th>Peak rate</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average rate</td>
<td>A</td>
</tr>
</tbody>
</table>

Reservation must reserve $P$, but level of utilization is $A/P$

*e.g.*, $P=100$ Mbps, $A=10$ Mbps, level of utilization=10%

On-demand can achieve higher level of utilizations 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
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!
In practice, the two approaches are implemented using circuit-switching or packet-switching, respectively.
Reservation  
On-demand  
imlem.  
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 Resource Reservation Protocol establishes a circuit within each switch.
There exist many kinds of circuits

Time-based multiplexing
- divide time in slots
- allocate one slot per circuit

Frequency-based multiplexing
- divide spectrum in frequency bands
- allocate one band per circuit
Let’s walk through an 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.
Another problem of circuit switching is that it doesn’t route around trouble.

A is forced to signal a new circuit to restore communication.
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?

- Reservation
- Circuit-switching

- On-demand
- Packet-switching
In packet switching, data transfer is done using independent packets.

Each packet contains destination (dst).
Since packets are sent without global coordination, they can “clash” with each other
To absorb transient overload, packet switching relies on buffers
To absorb transient overload, packet switching relies on buffers.
Packet switching routes around trouble

A

s1

s2

s3

s4

s5

B

switch fails

route recomputed
on the fly by s2

Packet switching routes around trouble
Pros and cons of packet switching

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

**Disadvantages**
- Unpredictable performance
- Requires buffer management and congestion control
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.
Communication Networks

Part 1: Overview

What is a network made of?

How is it shared?

#3 How is it organized?

How does communication happen?

How do we characterize it?
So far, this is our vision of the Internet...
In practice, the Internet is a “bit” more complex
access ISP
access ISP
access ISP
access ISP
access ISP
access ISP
The Internet has a hierarchical structure

Tier–1
- have no provider
  - international

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

Tier–3
- do not provide any transit
  - local
- have at least one provider
Tier1 ISPs

Tier2 ISPs

access ISP

customer

provider

Tier1 ISPs

Tier2 ISPs

access ISP

customer

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

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

Total networks: ~50,000
Some networks have an incentive to connect directly, to reduce their bill wrt 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.
Communication Networks

Part 1: Overview

#1 What is a network made of?
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