The Internet

An *exciting* place
~22 billion
~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 1 Byte = 1 Gigabyte
volume(Great Wall of China) = 1 exabyte
~4 exabytes

estimated* daily global IP traffic in 2017

* Cisco Visual Networking Index 2017—2022
~13 exabytes

estimated* daily global IP traffic
in 2022

* Cisco Visual Networking Index 2017—2022
~75% of all Internet traffic estimated* percentage of video traffic in 2017

* Cisco Visual Networking Index 2017—2022
<table>
<thead>
<tr>
<th>Upstream</th>
<th>Downstream</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>BitTorrent</td>
<td>Netflix</td>
<td>Netflix</td>
</tr>
<tr>
<td>18.37%</td>
<td>35.15%</td>
<td>32.72%</td>
</tr>
<tr>
<td>YouTube</td>
<td>YouTube</td>
<td>YouTube</td>
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<tr>
<td>13.13%</td>
<td>17.53%</td>
<td>17.31%</td>
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<tr>
<td>Netflix</td>
<td>Amazon Video</td>
<td>HTTP - OTHER</td>
</tr>
<tr>
<td>10.33%</td>
<td>4.26%</td>
<td>4.14%</td>
</tr>
<tr>
<td>SSL - OTHER</td>
<td>HTTP - OTHER</td>
<td>Amazon Video</td>
</tr>
<tr>
<td>8.55%</td>
<td>4.19%</td>
<td>3.96%</td>
</tr>
<tr>
<td>Google Cloud</td>
<td>iTunes</td>
<td>SSL - OTHER</td>
</tr>
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<td>6.98%</td>
<td>2.91%</td>
<td>3.12%</td>
</tr>
<tr>
<td>iCloud</td>
<td>Hulu</td>
<td>BitTorrent</td>
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<tr>
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<td>2.68%</td>
<td>2.85%</td>
</tr>
<tr>
<td>HTTP - OTHER</td>
<td>SSL - OTHER</td>
<td>iTunes</td>
</tr>
<tr>
<td>3.70%</td>
<td>2.53%</td>
<td>2.67%</td>
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<td>Facebook</td>
<td>Xbox One Games Download</td>
<td>Hulu</td>
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<tr>
<td>3.04%</td>
<td>2.18%</td>
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<td>FaceTime</td>
<td>Facebook</td>
<td>Xbox One Games Download</td>
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<td>1.89%</td>
<td></td>
</tr>
<tr>
<td>Skype</td>
<td>BitTorrent</td>
<td>Facebook</td>
</tr>
<tr>
<td>1.75%</td>
<td>1.73%</td>
<td>2.01%</td>
</tr>
<tr>
<td>69.32%</td>
<td>74.33%</td>
<td>72.72%</td>
</tr>
</tbody>
</table>

Table 1 - Top 10 Peak Period Applications - North America, Fixed Access

~82% of all Internet traffic estimated* percentage of video traffic in 2022

* Cisco Visual Networking Index 2017—2022
The Internet

A tense place
Countries get disconnected for political reasons
Myanmar coup: How the military disrupted the internet

By Christopher Giles
BBC Reality Check

4 February

Belarus Has Shut Down the Internet Amid a Controversial Election

Human rights organizations have blamed the Belarusian government for widespread outages.
Iraq Downs Internet To Combat Cheating…Again!

Research // Feb 6, 2017 // Doug Medley

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.

http://dyn.com/blog/iraq-downs-internet-to-combat-cheating-again/
Outages and Instabilities
February 01, 2017 - February 06, 2017  Times in UTC

Iraq national backbone down for 1 hour for 4 of the last 5 days.

Source: BGP Data

http://dyn.com/blog/iraq-downs-internet-to-combat-cheating-again/
Algeria and Iraq shut down internet nationwide to stop students cheating in exams

'Shutting down digital communication often disproportionately harms marginalised and vulnerable groups, cripples the local economy, and creates cascades of chaos'

Chris Baynes | Thursday 21 June 2018 22:25 | 180 shares |
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
Some Internet communications are interfered against or heavily congested.
Can ISPs selectively slow down traffic?
The U.S. Federal Communications Commission (FCC) set network neutrality rules in 2015

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 314-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
... which it then repealed in 2017

http://nyti.ms/2CkTbRR
We’re disappointed in the decision to gut #NetNeutrality protections that ushered in an unprecedented era of innovation, creativity & civic engagement. This is the beginning of a longer legal battle. Netflix stands w/ innovators, large & small, to oppose this misguided FCC order.

10:26 AM - 14 Dec 2017

335,726 Retweets  831,986 Likes
... but might bring back in 2021?
In Switzerland, network neutrality is enforced by the Swiss Telecommunications Act—since 1/1/21

— Art. 12e Offenes Internet

1 Die Anbieterinnen von Internetzugängen übertragen Informationen, ohne dabei zwischen Sendern, Empfängern, Inhalten, Diensten, Diensteklassen, Protokollen, Anwendungen, Programmen oder Endgeräten technisch oder wirtschaftlich zu unterscheiden.

2 Sie dürfen Informationen unterschiedlich übertragen, wenn dies erforderlich ist, um:
   a. eine gesetzliche Vorschrift oder einen Gerichtsentscheid zu befolgen;
   b. die Integrität oder Sicherheit des Netzes, der über dieses Netz erbrachten Dienste oder der angeschlossenen Endgeräte zu gewährleisten;
   c. einer ausdrücklichen Aufforderung der Kundin oder des Kunden nachzukommen; oder
   d. vorübergehende und aussergewöhnliche Netzwerküberlastungen zu bekämpfen; dabei sind gleiche Arten von Datenverkehr gleich zu behandeln.

3 Sie dürfen neben dem Zugang zum Internet über denselben Anschluss andere Dienste anbieten, die für bestimmte Inhalte, Anwendungen oder Dienste optimiert sein müssen, um die Qualitätsanforderungen der Kundinnen und Kunden zu erfüllen. Die anderen Dienste dürfen nicht als Ersatz für Internetzugangsdienste nutzbar sein oder angeboten werden, und sie dürfen nicht die Qualität der Internetzugangsdienste verschlechtern.

4 Behandeln sie Informationen bei der Übertragung technisch oder wirtschaftlich unterschiedlich, so müssen sie die Kundinnen und Kunden sowie die Öffentlichkeit darüber informieren.


A primer on the conflict between Netflix and Comcast

Due to congestion, throughput across Cogent to Comcast, Time Warner and Verizon were miserable

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

Warum Swisscom-Kunden Probleme mit Netflix hatten

Nutzer des Streamingdienstes hatten mit ruckelnden Inhalten zu kämpfen. Die Verantwortlichen wollen das Problem nun gelöst haben.

Henning Steier
21.3.2016, 23:05 Uhr

MEISTGELESEN IM RESSORT

Huawei- und OnePlus-Smartphones strahlen am meisten
Jochen Sagte / 14.2.2018, 14:30 Uhr

«Wir befinden uns im finsteren Mittelalter»
Henning Steier / 18.3.2014, 10:40 Uhr

In February 2018, GitHub was targeted by a 1.35 Tbps Distributed Denial of Service (DDoS) attack from a normal ~0.1 Tbps to 1.35 Tbps.

Source: Akamai
In June 2020, Amazon was targeted by a 2.30 Tbps DDoS attack (largest to date)

Amazon 'thwarts largest ever DDoS cyber-attack'

© 18 June 2020

The Internet

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

Unsurprisingly, we see a strong increase in web conferencing, video, and gaming traffic.
Overall, the Internet performed well in these unpreceeding times.

The Internet Is Resilient Enough to Withstand Coronavirus – But There’s a Catch

By David Belson
Former Senior Director, Internet Research and Analysis

Earlier this year, as COVID-19 began to dominate our lives, the world turned to the Internet. This sudden shift to distance learning, working from home, and families sheltering in place drove up online streaming demand, placing additional load on Internet application platforms like Zoom, Netflix, and educational tools such as Kahoot. There was also a dramatic traffic increase across supporting network providers.
The Internet

A *fragile* place
Despite being absolutely critical, Internet communications are inherently fragile.
For a little more than 90 minutes yesterday, internet service for millions of users in the U.S. and around the world slowed to a crawl. Was this widespread service degradation caused by the same or a different reason as his time. The cause was yet another BGP routing leak — a router
For a little more than 90 minutes [...],

Internet service for millions of users in the U.S. and around the world slowed to a crawl.

The cause was yet another BGP routing leak, a router misconfiguration directing Internet traffic from its intended path to somewhere else.
Google routing blunder sent Japan’s Internet dark on Friday

Another big BGP blunder

By Richard Chirgwin 27 Aug 2017 at 22:35

Last Friday, someone in Google fat-thumbbed a border gateway protocol (BGP) advertisement and sent Japanese Internet traffic into a black hole.

The trouble began when The Chocolate Factory “leaked” a big route table to Verizon, 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.

Since Google doesn’t provide transit services, as BGP Mon explains, that traffic either filled a link beyond its capacity, or hit an access control list, and disappeared.

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

BGP Mon dissects what went wrong here, reporting that more than...
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.
People also often mistakenly destroy their own infrastructure
DOWNTIME

UPDATED: “Configuration Issue” Halts Trading on NYSE

The article has been updated with the time trading resumed.

A second update identified the cause of the outage as a “configuration issue.”

A third update added information about a software update that created the configuration issue.
NYSE network operators identified the culprit of the 3.5 hour outage, blaming the incident on a “network configuration issue”
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.
Planned maintenance work in Swisscom’s network shuts down emergency numbers (11.02.2020)

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

swissWerwolf @swissWerwolf · 17s
swisscom dns nicht erreichbar. nur mit workaround auf andere dns server kommt ich ins internet und hotline ist angeblich überlastet

Daniel Schär @ScharDaniel · 25s
Langsam reicht es mit euch!!! Ich hab die Schnauze gestrichen vollllll!!! Das 4 mal ein Unterbruch innerhalb 1.5 Wochen.. Sowas nennt sich #swisscom!! Schämt euch!!!

Nadine Alexandra @Gleisturbine · 41s
Huch? Hat Swisscom Internetprobleme im Unterland?
Die Apps laden nicht mehr auf dem Handy, die Homebase-Internetverbindung zum Router ist praktisch tot? Weird.
Impact analysis: 67.1% of subscribers (21.5% of Switzerland)
For anyone in Switzerland that currently can't access **Swisscom** internet change your **DNS** to 8.8.8.8
“Human factors are responsible for 50% to 80% of network outages”

Ironically, this means that data networks work better during week-ends…

source: Job Snijders (NTT)
Communication Networks
Course goals
Knowledge
Understand how the Internet works and why

from your network plug...

...to mega-scale data-centers
Insights

Key concepts and problems in Networking

Naming   Layering   Routing   Reliability   Sharing
How do you address computers, services, protocols?
How do you manage complexity?
Naming    Layering    Routing    Reliability    Sharing

How do you go from A to B?
Naming    Layering    Routing    Reliability    Sharing

How do you communicate reliably using unreliable mediums?
How do you divide scarce resources among competing parties?
Insights

Some of our current research works

Networked Systems Group
nsg.ee.ethz.ch
Skills

Build, operate and configure networks

Trinity using a port scanner (nmap) in Matrix Reloaded™
Your dream team for the semester

Rüdiger [head]  Tobias [head]  Coralie  Rai  Thomas

followed the lecture in previous years

Hendrik  Lukas
Our website: https://comm-net.ethz.ch
check it out regularly!

Slides, exercises, projects, extra readings, and previous exams
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 a 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://comm-net21.slack.com

Register with your @ethz.ch email

Ping us if you prefer using another one

Use your real name

It greatly facilitates our organization…

We will never use Slack to distribute sensitive data
e.g. your project grades
Communication Networks
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/switches vary in size and usage

Home router

- ~20 cm
- 0.5 kg
- 1 Gbps

Internet core router

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

Cisco Nexus 7k

Routers @ETHZ

~25 deployed
Next-generation programmable switches up to 12.8 Tbps of backplane capacity

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

* https://www.barefootnetworks.com/products/brief-tofino-2/
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
Somewhere in Manhattan...  
http://www.petergarritano.com/the-internet.html
Data-cable security scandal: It’s easier to enter than a public library

It might be deemed to be “critical” to American security, but this remote building
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
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?
3 must-have requirements of a good network topology

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.

- **Full-mesh** design advantages and disadvantages
- **Chain** design advantages and disadvantages
- **Bus** design advantages and disadvantages
Switched networks provide a reasonable and flexible compromise in design. They offer advantages such as sharing and per-node capacity that can be adapted to fit the network needs. However, they require smart devices to perform tasks like forwarding, routing, and resource allocation.
Links and switches are shared between flows

shared link and switch resources
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 you need
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

Time

10 Mbps

11 Mbps

13 Mbps
Assume the following peak demand and flow duration:

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

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

- Reservation: first-come first-served
- On-demand: 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 \( A/P \)

\[ P=100 \text{ Mbps}, \ A=10 \text{ Mbps}, \text{ level of utilization}=10\% \]

On-demand can usually achieve higher level of utilization depending 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!
The two approaches are implemented using circuit-switching or packet-switching, respectively.

- **Reservation**
- **On-demand**

Implementations:
- circuit-switching
- packet-switching
Reservation

On-demand

implem. 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
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.

Circuit is established

A is forced to signal a new circuit to restore communication

A

switch fails

B

Circuit is established
Pros and cons of circuit switching

advantages

predictable performance

simple & fast switching
once circuit established

disadvantages

inefficient if traffic is bursty or short

complex circuit setup/teardown
which adds delays to transfer

requires new circuit upon failure
What about packet switching?
In packet switching, data transfer is done using independent packets.

Each packet contains a 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

switch fails

route recomputed
on the fly by s2
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>
<tr>
<td>route around trouble</td>
<td></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
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?
The *Internet* is a network of networks
Internet Service Providers

- phone company
- cable company
- university net
So far, this is our vision of the Internet...
The real Internet is a “tad” more complex
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
Tier1 ISPs

Tier2 ISPs

Tier2 ISPs

Tier1 ISPs

access ISP

customer

provider

customer

provider

customer

provider

customer

access ISP
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></td>
<td>international</td>
<td></td>
</tr>
<tr>
<td>Tier-2</td>
<td>provide transit to Tier-3s</td>
<td>~1,000s</td>
</tr>
<tr>
<td></td>
<td>national</td>
<td></td>
</tr>
<tr>
<td>Tier-3</td>
<td>do not provide any transit</td>
<td>85–90%</td>
</tr>
<tr>
<td></td>
<td>local</td>
<td></td>
</tr>
</tbody>
</table>

total ~70,000 networks
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.
A brief overview of Internet history
The Internet history starts in the late 50’s, with people willing to communicate differently.

Telephone network is *the* communication system entirely based on circuit switching.

People start to want to use networks for other things—defense, (not personal) computers, …

… but knew that circuit-switching will not make it too inefficient for bursty loads and not resilient.
From this wish arose three crucial questions:

- How can we design a more resilient network? (also) lead to the invention of packet switching
- How can we design a more efficient network? (also) lead to the invention of packet switching
- How can we connect all these networks together? lead to the invention of the Internet as we know it

Paul Baran  RAND
Len Kleinrock  UCLA
Bob Kahn  DARPA
The 60s saw the creation of packet switching and the **Advanced Research Projects Agency Network**
The first message ever exchanged on the Internet was “lo”

Oct. 29 1969
Leonard Kleinrock @UCLA tries to log in a Stanford computer

We typed the L... Do you see it?
Yes! We see the L

We typed the O... Do you see it?
Yes! We see the O

We typed the G. system crashes

The 70s saw the creation of Ethernet, TCP/IP and the e-mail

1971  Network Control Program
predecessor of TCP/IP

1972  Email & Telnet

1973  Ethernet

1974  TCP/IP
paper by Vint Cerf & Bob Kahn
In the 80s, TCP/IP went mainstream

1983  NCP to TCP/IP Flag day
      Domain Name Service (DNS)

1985  NSFNet (TCP/IP) succeeds to ARPANET

198x  Internet meltdowns due to congestion

1986  Van Jacobson saves the Internet
      (with congestion control)
The 90s saw the creation of the Web as well as the Internet going commercial

1989  Arpanet is decommissioned

Birth of the Web
Tim Berners Lee (CERN)

1993  Search engines invented (Excite)

1995  NSFNet is decommissioned

1998  Google reinvents search
The new millennium brings the Web 2.0, focus on user-generated content

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>IPv6 standardization</td>
</tr>
<tr>
<td>2004</td>
<td>Facebook goes online</td>
</tr>
<tr>
<td>2006</td>
<td>Google buys YouTube</td>
</tr>
<tr>
<td>2007</td>
<td>Netflix starts to stream videos</td>
</tr>
<tr>
<td>2007</td>
<td>First iPhone</td>
</tr>
<tr>
<td></td>
<td>Mobile Internet access</td>
</tr>
</tbody>
</table>
Fast Internet access everywhere, every device needs an Internet connection

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>Mining of the Bitcoin genesis block</td>
</tr>
<tr>
<td></td>
<td>Fast mobile Internet access: 4G/LTE</td>
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<tr>
<td></td>
<td>Internet of Things (IoT) boom</td>
</tr>
<tr>
<td></td>
<td>Cars &amp; refrigerators in the Internet</td>
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<tr>
<td>2018</td>
<td>Only 26% of the Alexa Top 1000 websites reachable over IPv6</td>
</tr>
<tr>
<td></td>
<td>Soon? Fully encrypted transport protocols</td>
</tr>
<tr>
<td></td>
<td>For example QUIC</td>
</tr>
</tbody>
</table>

http://www.worldipv6launch.orgmeasurements/
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?
No exercise session this Thursday

Next Monday on Communication Networks

Routing concepts