Communication Networks

Prof. Laurent Vanbever

Communication Networks

Spring 2021

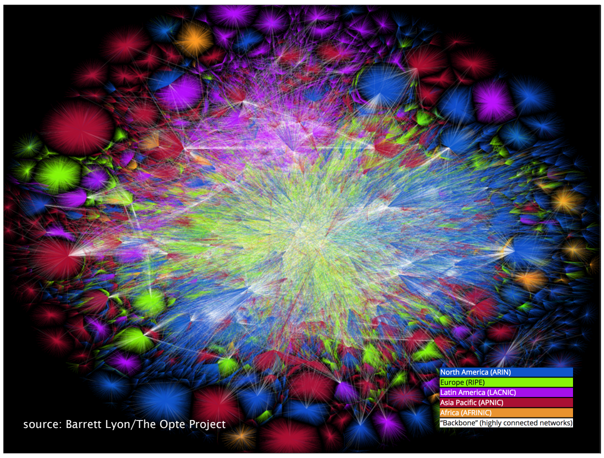
Laurent Vanbever

nsg.ee.ethz.ch

Feb 22 2020

Lecture starts at 10:15

Materials inspired from Scott Shenker & Jennifer Rexford



source: Barrett Lyon/The Opte Project

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 Gigabyte

~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

Upstream		Downstream		Aggregate	
BitTorrent	18.37%	**Netflix**	**35.15%**	Netflix	32.72%
YouTube	13.13%	**YouTube**	**17.53%**	YouTube	17.31%
Netflix	10.33%	**Amazon Video**	**4.26%**	HTTP - OTHER	4.14%
SSL - OTHER	8.55%	HTTP - OTHER	4.19%	Amazon Video	3.96%
Google Cloud	6.98%	iTunes	2.91%	SSL - OTHER	3.12%
iCloud	5.98%	Hulu	2.68%	BitTorrent	2.85%
HTTP - OTHER	3.70%	SSL - OTHER	2.53%	iTunes	2.67%
Facebook	3.04%	Xbox One Games Download	2.18%	Hulu	2.47%
FaceTime	2.50%	Facebook	1.89%	Xbox One Games Download	2.15%
Skype	1.75%	BitTorrent	1.73%	Facebook	2.01%
	69.32%		74.33%		72.72%

sandvine

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

http://bit.ly/2GlwI8G

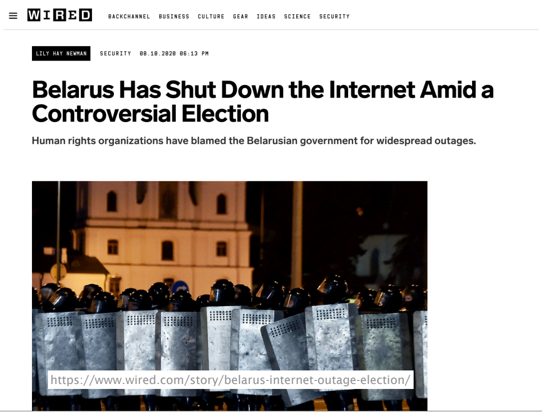
~82% of all Internet traffic

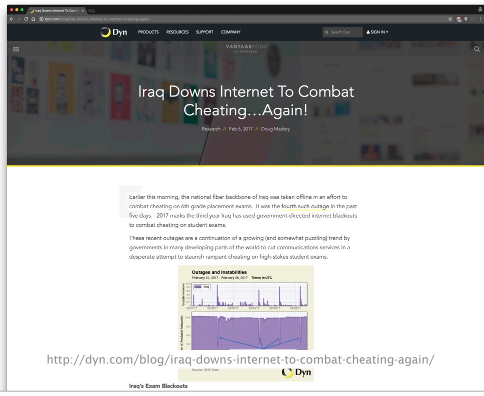
estimated* percentage of **video traffic**
in 2022

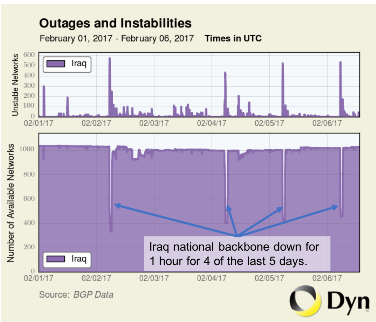
* Cisco Visual Networking Index 2017—2022

The Internet
A *tense* place

Countries get disconnected
for political reasons







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

https://www.independent.co.uk/news/world/africa/algeria-iraq-shut-down-internet-students-cheating-exams-facebook-a8410341.html

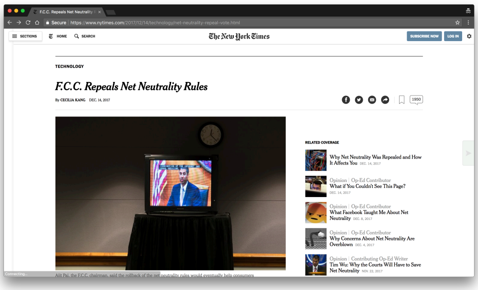
Some Internet communications
are interfered against or heavily congested

Can ISPs selectively slow down traffic?

The U.S. Federal Communications Commission (FCC) set network neutrality rules in 2015

http://nyti.ms/2kZUnDA

… which it then repealed in 2017



http://nyti.ms/2CkTbRR

… but might bring back in 2021?

https://www.forbes.com/sites/waynerash/2021/01/26/net-neutrality-likely-to-return-with-new-fcc-chair/

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

Art. 12e[41] 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.

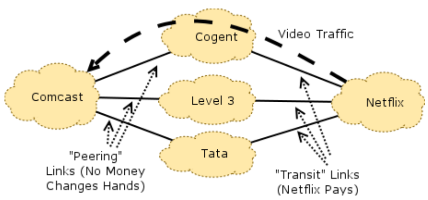
[3] Sie dürfen neben dem Zugang zum Internet über denselben Anschluss andere Dienste anbieten, die für bestimmte Inhalte, Anwendungen oder Dienste optimiert sein müssen, um die Qualitätsanforderungen der Kundinnen und Kunden zu erfüllen. Die anderen Dienste dürfen nicht als Ersatz für Internetzugangsdienste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

[41] Eingefügt durch Ziff. I des BG vom 22. März 2019, in Kraft seit 1. Jan. 2021 (*AS 2020 6159*; BBl **2017** 6559).

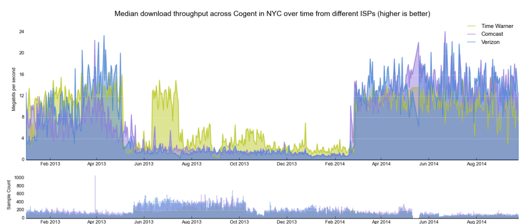
https://www.fedlex.admin.ch/eli/cc/1997/2187_2187_2187/fr#art_12_e

A primer on the conflict between Netflix and Comcast



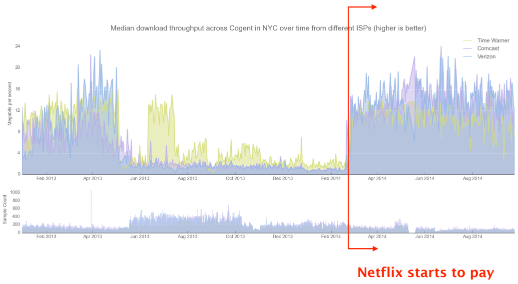
https://freedom-to-tinker.com/blog/feamster/why-your-netflix-traffic-is-slow-and-why-the-open-internet-order-wont-necessarily-make-it-faster/

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



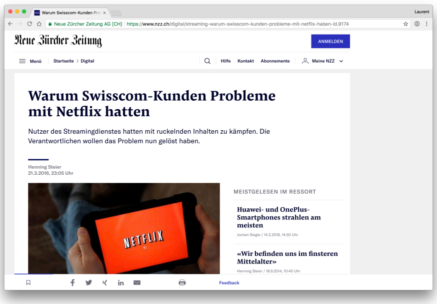
http://bit.ly/1thPzro

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



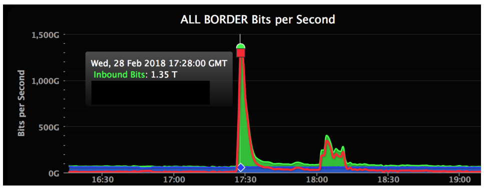
http://arstechnica.com/tech-policy/2014/04/netflix-and-verizon-reach-interconnection-deal-to-speed-up-video/

Closer to us…



https://www.nzz.ch/digital/streaming-warum-swisscom-kunden-probleme-mit-netflix-haben-ld.9174

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

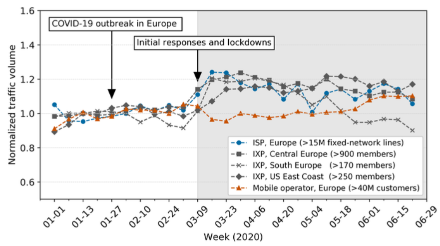
In June 2020, Amazon was targeted by
a 2.30 Tbps DDoS attack (largest to date)

https://www.bbc.com/news/technology-53093611

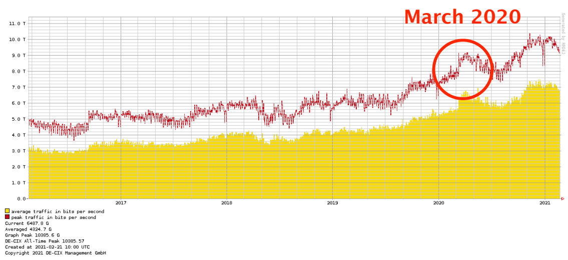
The Internet

A *vital* place during a pandemic

Following the lockdown in March 2020,
(wired) networks saw traffic increasing by 15–20%

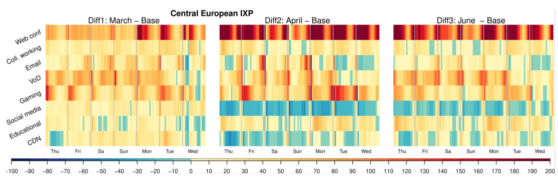


https://labs.ripe.net/Members/oliver_gasser/the-lockdown-effect-implications-of-the-covid-19-pandemic-on-internet-traffic



https://www.de-cix.net/en/locations/germany/frankfurt/statistics

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



https://labs.ripe.net/Members/oliver_gasser/the-lockdown-effect-implications-of-the-covid-19-pandemic-on-internet-traffic

Overall, the Internet performed well
in these unpreceeding times


Measuring the Internet 13 May 2020

EN FR ES

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.

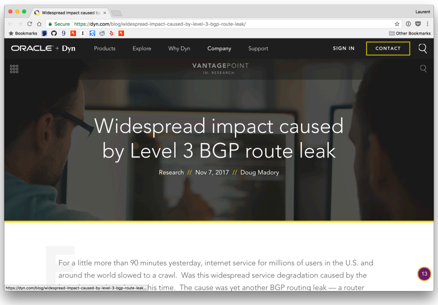
[source]

The Internet

A *fragile* place

Despite being absolutely critical,
Internet communications are inherently fragile

November 2017



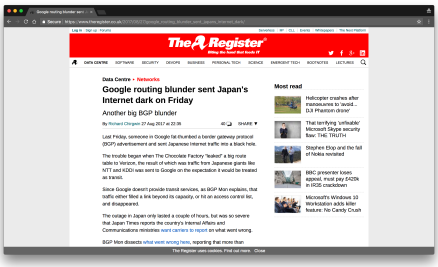
https://dyn.com/blog/widespread-impact-caused-by-level-3-bgp-route-leak/

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.

August 2017



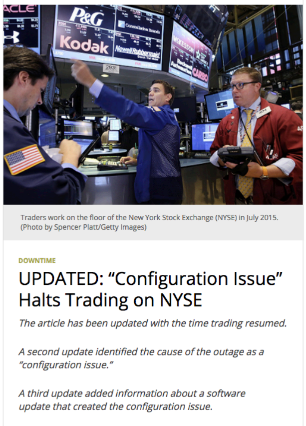
https://www.theregister.co.uk/2017/08/27/google_routing_blunder_sent_japans_internet_dark/

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


Traders work on the floor of the New York Stock Exchange (NYSE) in July 2015. (Photo by Spencer Platt/Getty Images)

DOWNTIME

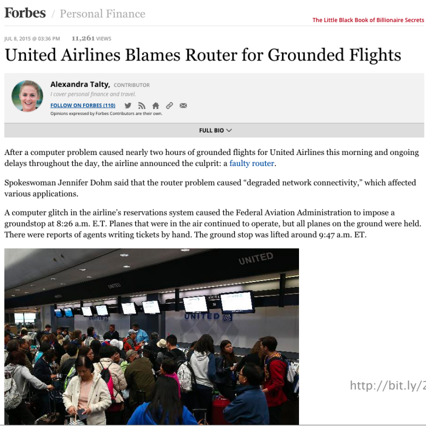
UPDATED: "Configuration Issue" Halts Trading on NYSE

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"


Forbes / Personal Finance

The Little Black Book of Billionaire Secrets

JUL 8, 2015 @ 03:36 PM 11,261 VIEWS

United Airlines Blames Router for Grounded Flights

Alexandra Talty, CONTRIBUTOR

I cover personal finance and travel

FOLLOW ON FORBES (110)

Opinions expressed by Forbes Contributors are their own.

FULL BIO

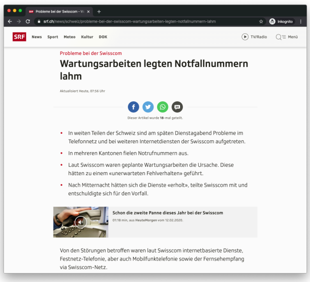
After a computer problem caused nearly two hours of grounded flights for United Airlines this morning and ongoing delays throughout the day, the airline announced the culprit: a faulty router.

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.

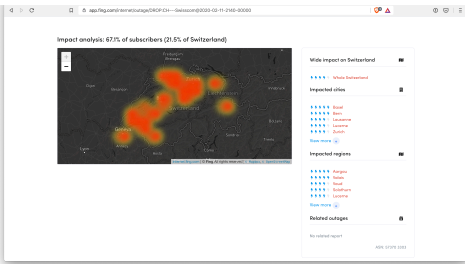
http://bit.ly/2sBJ2jf

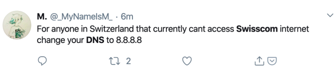
Planned maintenance work in Swisscom's network shuts down emergency numbers (11.02.2020)



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

https://www.srf.ch/news/schweiz/probleme-bei-der-swisscom-wartungsarbeiten-legten-notfallnummern-lahm

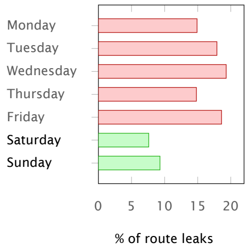




"Human factors are responsible for 50% to 80% of network outages"

Juniper Networks, *What's Behind Network Downtime?*, 2008

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



source: Job Snijders (NTT)

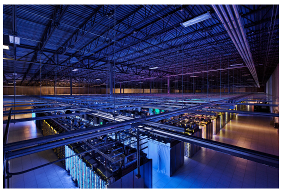
Communication Networks

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

Naming Layering Routing Reliability Sharing

How do you address computers, services, protocols?

Naming Layering Routing Reliability Sharing

How do you manage complexity?

Naming Layering Routing Reliability Sharing

How do you go from A to B?

Naming Layering Routing Reliability Sharing

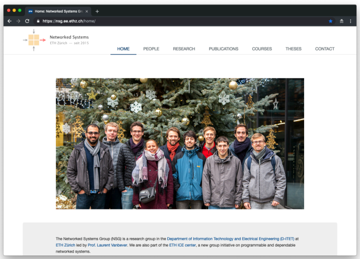
How do you communicate reliably using unreliable mediums?

Naming Layering Routing Reliability **Sharing**

How do you **divide scarce resources among competing parties?**

Insights

Some of our current research works

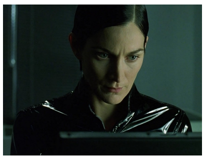


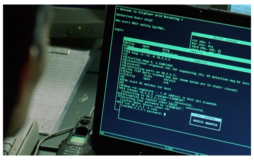
Networked Systems Group

nsg.ee.ethz.ch

Skills

Build, operate and configure networks





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

Communication Networks

Course organization

Your **dream team** for the semester

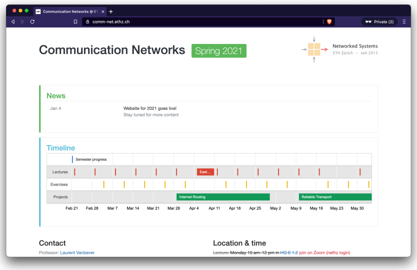
Rüdiger [head] Tobias [head] Coralie Rai Thomas

Hendrik Lukas

followed the lecture in previous years

Our website: https://comm-net.ethz.ch

check it out regularly!



Slides, exercises, projects, extra readings, and previous exams

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The course will be **split in three parts**

Part 1	Part 2	Part 3
Overview	Concepts	Today's Internet
~1.5 lectures	~1.5 lectures	~10 lectures

Your final grade

Exam	Projects
70%	30%
written, open book	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 maximum three students

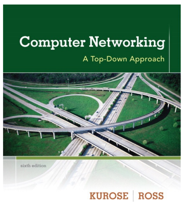
#1 Build and operate a real, working "Internet" (20%)

#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

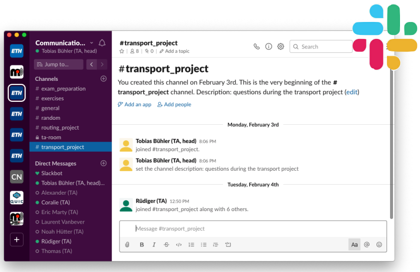


6th edition

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

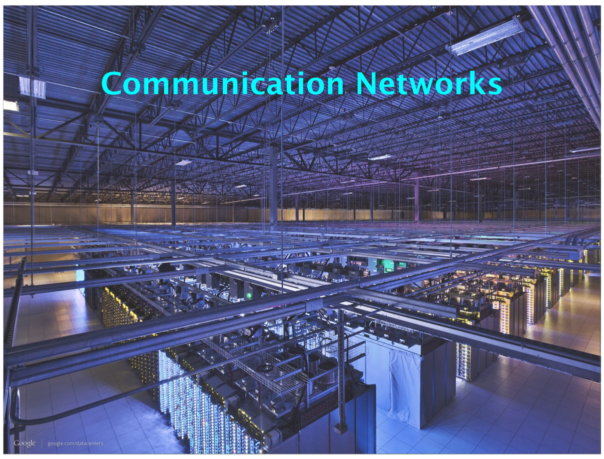
- ask questions
- chat with other students (e.g. your group)
- be informed about course announcements (also on our website)

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
Part 1: Overview

ETH

#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?

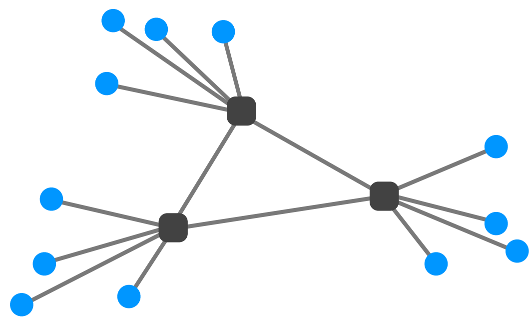
How is it shared?

How is it organized?

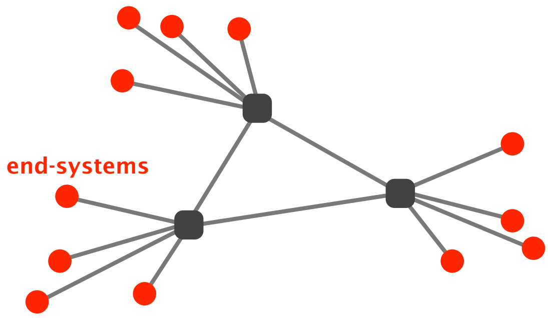
How does communication happen?

How do we characterize it?

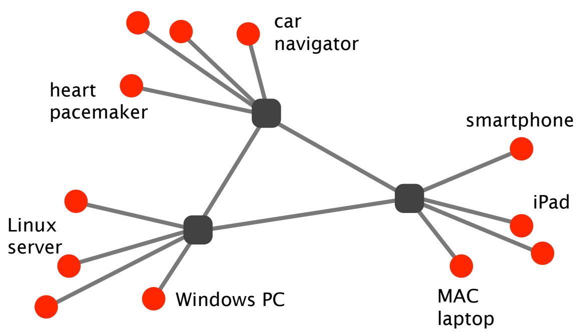
Networks are composed of three basic components



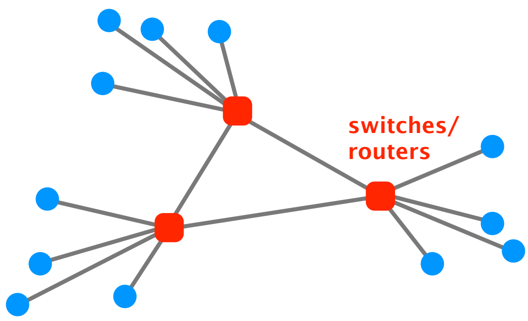
End-systems send & receive data



End-systems come in a wide-variety



Switches & routers forward data to the destination



Routers/switches vary in size and usage

Home router		Internet core router
~20 cm		>200cm
0,5 kg		700kg
1 Gbps		>12 Tbps
		(>920 Tbps in multi-chassis*)

*https://www.cisco.com/c/en/us/products/collateral/routers/carrier-routing-system/data_sheet_c78-726136.html

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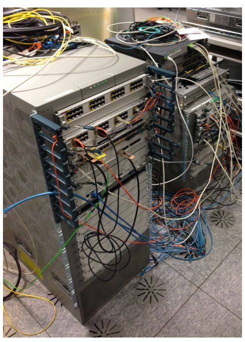
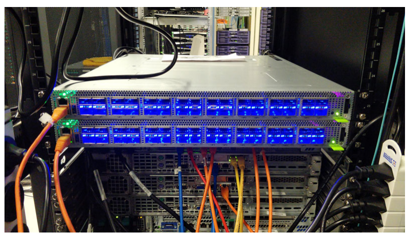


Cisco Nexus 7k

Routers @ETHZ

~25 deployed

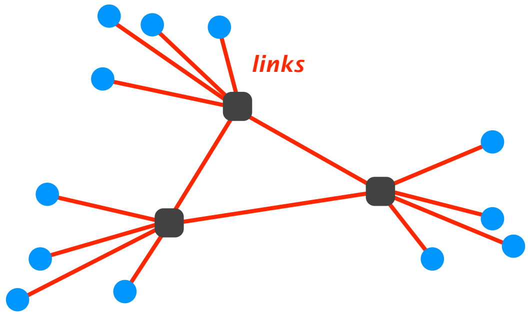
Next-generation programmable switches
up to 12.8 Tbps of backplane capacity*



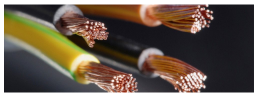
Barefoot Tofino Wedge 100BF-32X part of our NSG lab

* https://www.barefootnetworks.com/products/brief-tofino-2/

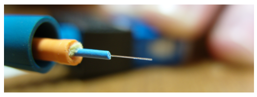
Links connect end-systems to switches
and switches to each other



Links, too, vary in size and usage

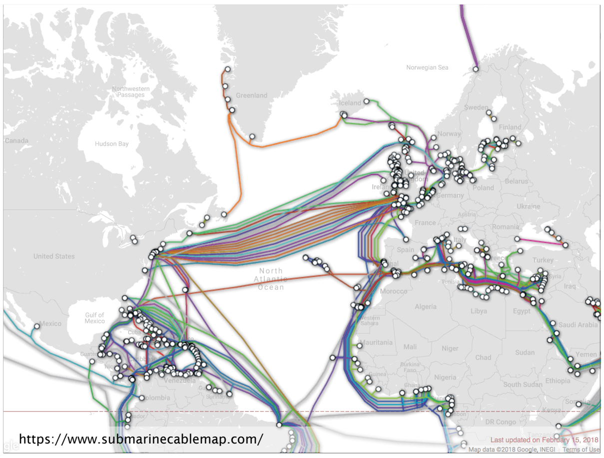


Copper
ADSL, RJ-45,...



Optical fibers

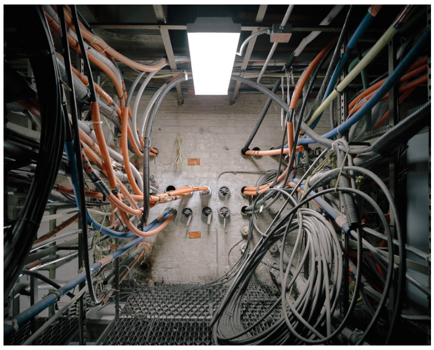
Wireless link



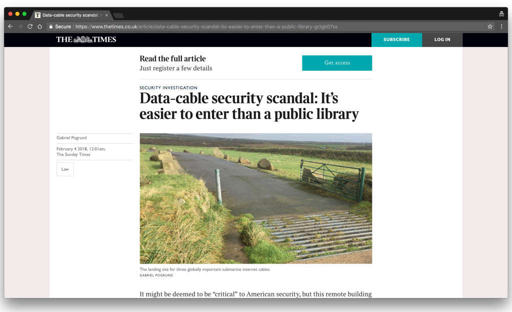
https://www.submarinecablemap.com/

http://marine.orange.com/en/Ships-and-submarine-vehicles/Cable-ships/Le-Rene-Descartes

https://www.wired.com/story/google-cramming-more-data-new-atlantic-cable



Somewhere in Manhattan... http://www.petergarritano.com/the-internet.html



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SECURITY INVESTIGATION

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

https://www.thetimes.co.uk/article/data-cable-security-scandal-its-easier-to-enter-than-a-public-library-gclgb07ss

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?

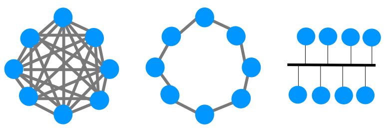
3 must-have requirements of a good network topology

Tolerate failures
several paths between each source and destination

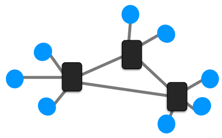
Possess enough sharing to be feasible & cost-effective
number of links should not be too high

Provide adequate per-node capacity
number of links should not be too small

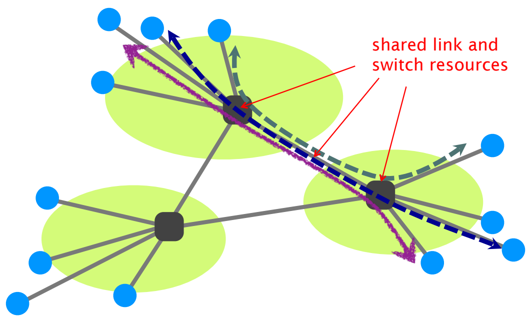
Compare these three designs in terms of sharing, resiliency, and per-node capacity

design	full-mesh	chain	bus
			
advantages			
disadvantages			

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



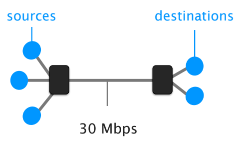
There exist two approaches to sharing: reservation and on-demand

	Reservation	On-demand
principle	reserve the bandwidth you need in advance	send data when you need

Both are examples of statistical multiplexing

	Reservation	On-demand
multiplexing	at the flow-level	at the packet-level

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

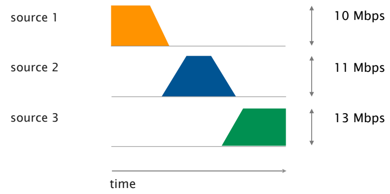


Consider that each source needs 10 Mbps

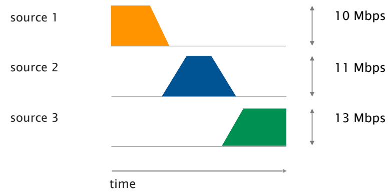
What do they get with:

- reservation
- on-demand

Assume the following peak demand and flow duration



Assume the following peak demand and flow duration



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

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

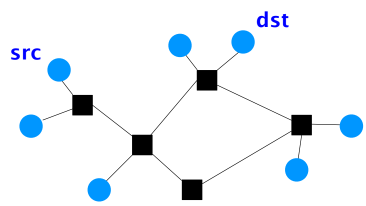
… and why the Internet does not!

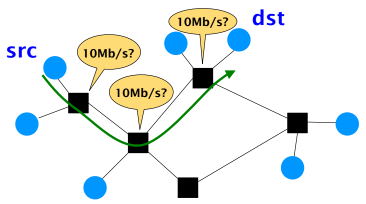
The two approaches are implemented using circuit-switching or packet-switching, respectively

	Reservation	On-demand
implem.	circuit-switching	packet-switching

	Reservation	On-demand
implem.	circuit-switching	packet-switching

Circuit switching relies on the Resource Reservation Protocol



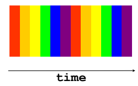


(1) src sends a reservation request for 10Mbps to dst
(2) switches "establish a circuit"
(3) src starts sending data
(4) src sends a "teardown circuit" message

There exist many kinds of circuits

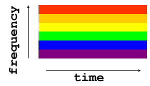
Time-based multiplexing

- divide time in slots
- allocate one slot per circuit

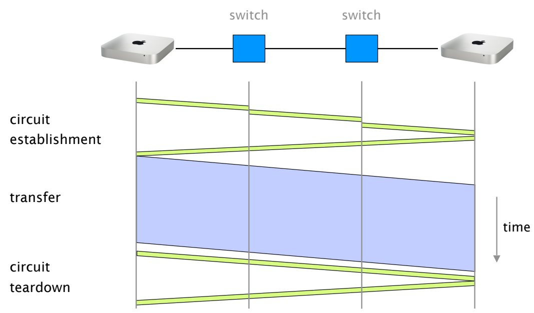


Frequency-based multiplexing

- divide spectrum in frequency bands
- allocate one band per circuit

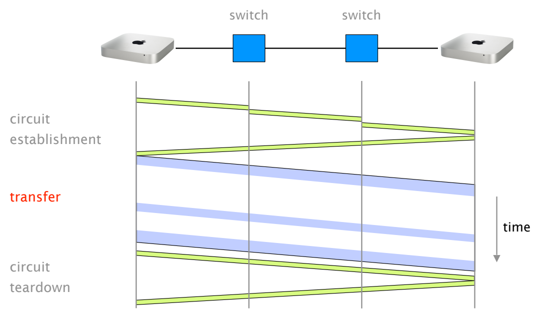


Let's walk through example of data transfer using circuit switching

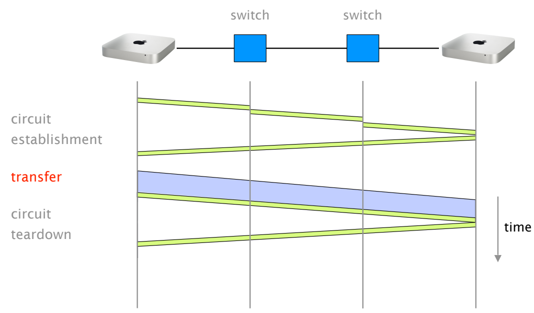


The efficiency of the transfer depends on how utilized the circuit is once established

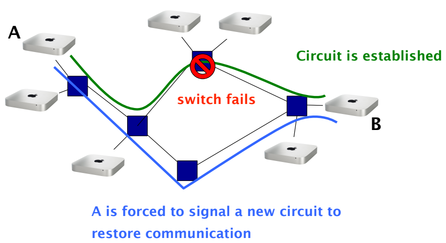
This is an example of poor efficiency. The circuit is mostly idle due to traffic bursts



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



Pros and cons of circuit switching

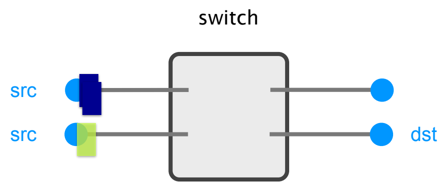
advantages	disadvantages
predictable performance	inefficient if traffic is bursty or short
simple & fast switching once circuit established	complex circuit setup/teardown which adds delays to transfer
	requires new circuit upon failure

What about packet switching?

Reservation — circuit-switching

On-demand — packet-switching

In packet switching,
data transfer is done using independent packets

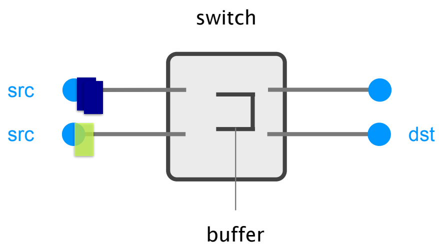


Each packet contains a destination (dst)

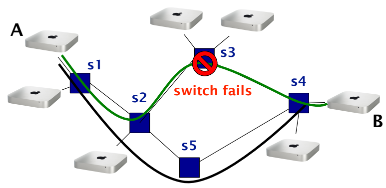
Since packets are sent without global coordination,
they can “clash” with each other

To absorb transient overload,
packet switching relies on buffers

To absorb transient overload,
packet switching relies on buffers



Packet switching routes around trouble



Pros and cons of packet switching

advantages	disadvantages
efficient use of resources	unpredictable performance
simpler to implement	requires buffer management and congestion control
route around trouble	

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?

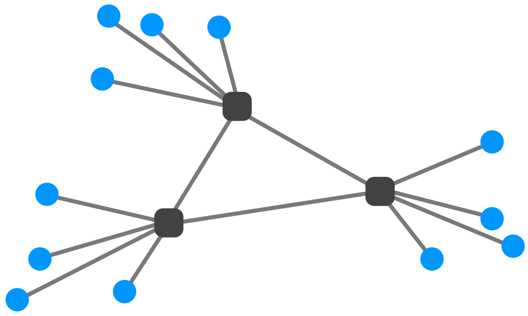
How is it shared?

#3 How is it organized?

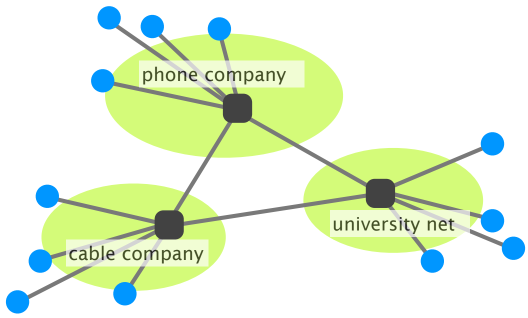
How does communication happen?

How do we characterize it?

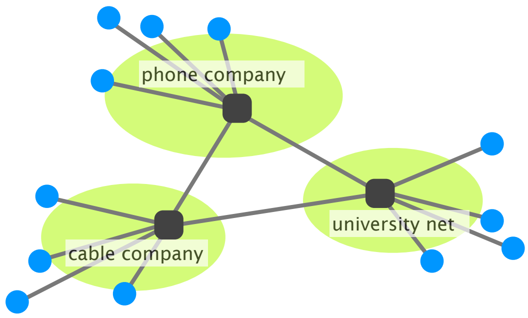
The *Inter*net is a network of networks



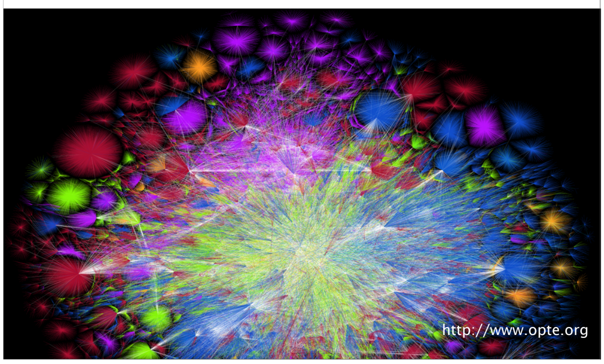
Internet Service Providers

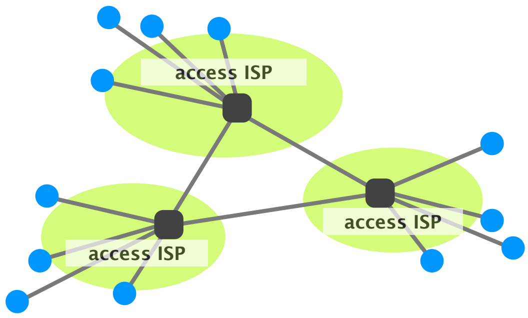


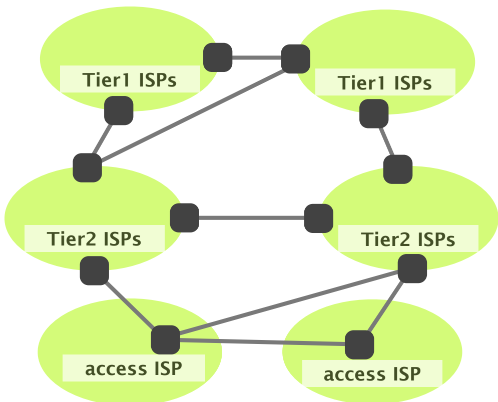
So far, this is our vision of the Internet…



The real Internet is a "tad" more complex

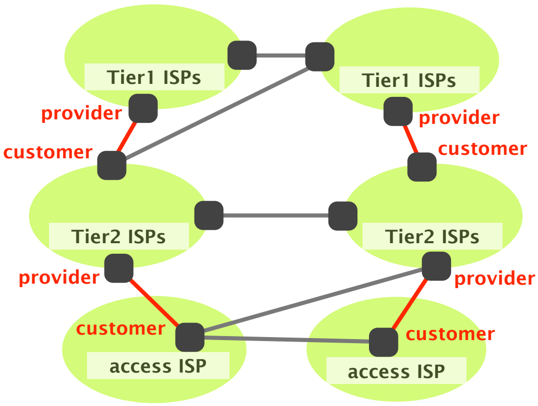






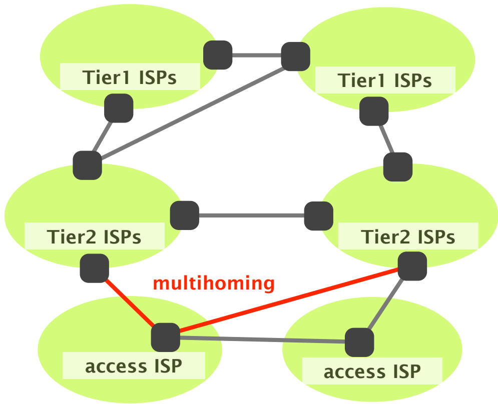
The Internet has a hierarchical structure

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



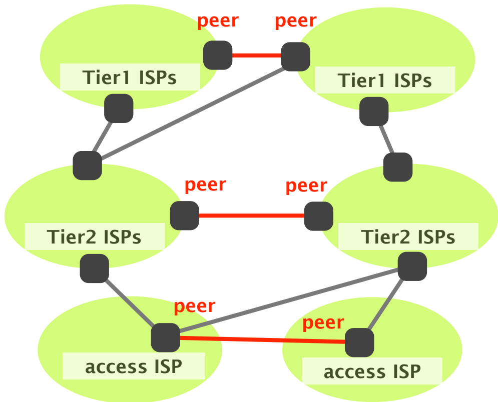
The distribution of networks in Tiers
is extremely skewed towards Tier-3s

		total ~70,000 networks
Tier-1 international	have no provider	~12
Tier-2 national	provide transit to Tier-3s have at least one provider	~1,000s
Tier-3 local	do not provide any transit have at least one provider	85-90%



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

This is known as "peering"



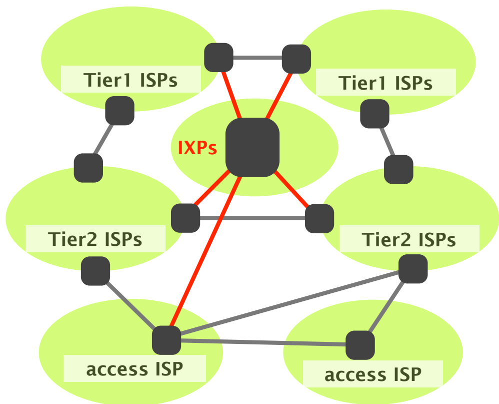
Interconnecting each network to its neighbors
one-by-one is not cost effective

Physical costs
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

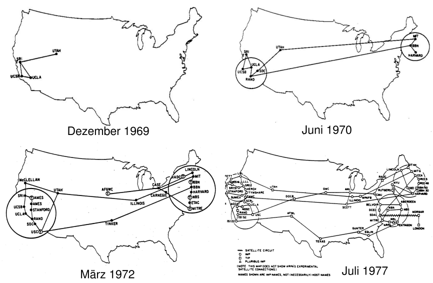
From this wish arose three crucial questions

Paul Baran
RAND
How can we design a more resilient network?
lead to the invention of packet switching

Len Kleinrock
UCLA
How can we design a more efficient network?
(also) lead to the invention of packet switching

Bob Kahn
DARPA
How can we connect all these networks together?
lead to the invention of the Internet as we know it

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

UCLA We typed the L… Do you see it?
Yes! We see the L Stanford

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

We typed the G. system crashes

http://ftp.cs.ucla.edu/csd/first_words.html

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)
Swiss made

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

1998	IPv6 standardization
2004	Facebook goes online
2006	Google buys YouTube
2007	Netflix starts to stream videos
2007	First iPhone Mobile Internet access

Fast Internet access everywhere,
every device needs an Internet connection

2009	Mining of the Bitcoin genesis block
	Fast mobile Internet access: 4G/LTE
	Internet of Things (IoT) boom Cars & refrigerators in the Internet
2018	Only 26% of the Alexa Top 1000 websites reachable over IPv6 http://www.worldipv6launch.org/measurements/
Soon?	Fully encrypted transport protocols For example QUIC

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