Communication Networks

Prof. Laurent Vanbever

Communication Networks

Spring 2018

Laurent Vanbever

nsg.ee.ethz.ch

ETH Zürich

February 19 2018

Materials inspired from Scott Shenker & Jennifer Rexford

The Internet

An *exciting* place

17.1 billion

17.1 billion

estimated* # of Internet connected devices
in 2016

* Cisco Visual Networking Index 2016—2021

27.1 billion

estimated* # of Internet connected devices
in 2021

* Cisco Visual Networking Index 2016—2021

~3 exabytes

estimated* daily global IP traffic
in 2016

* Cisco Visual Networking Index 2017

If  = 1 Gigabyte

~3 exabytes

estimated* daily global IP traffic
in 2016

* Cisco Visual Networking Index 2017

~9 exabytes

estimated* daily global IP traffic
in 2021

* Cisco Visual Networking Index 2017

~55% of all IP traffic

estimated* percentage of video traffic
in 2016

* Sandvine 2016 Global Internet Phenomena

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

~80% of all IP traffic

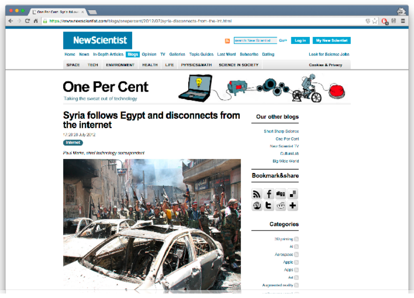
estimated* percentage of video traffic
in 2021

* Cisco Visual Networking Index 2017

The Internet

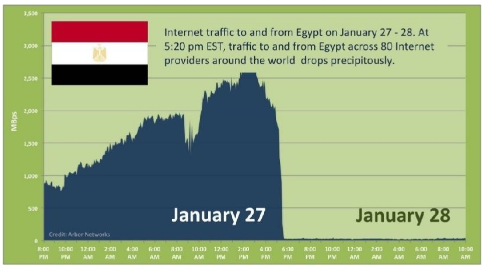
A *tense* place

Countries get disconnected
for political reasons

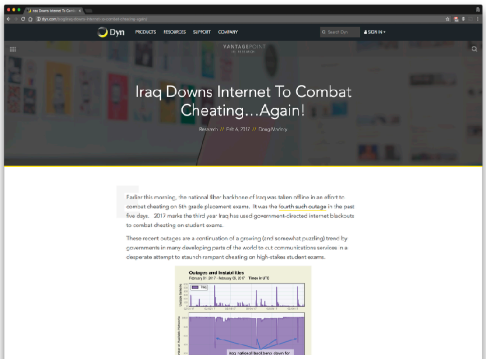


Also check: http://research.dyn.com/2012/11/could-it-happen-in-your-countr/

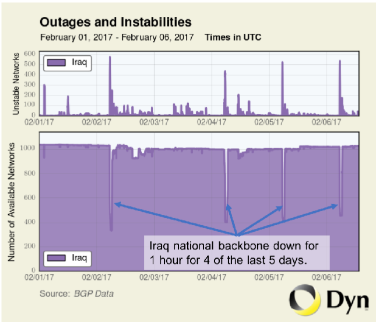
Internet traffic to/from Egypt in January 2011



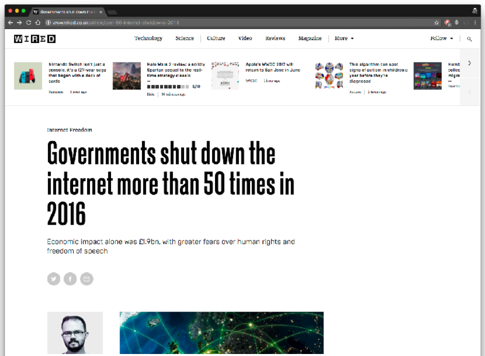
http://huff.to/1KxxoZF



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



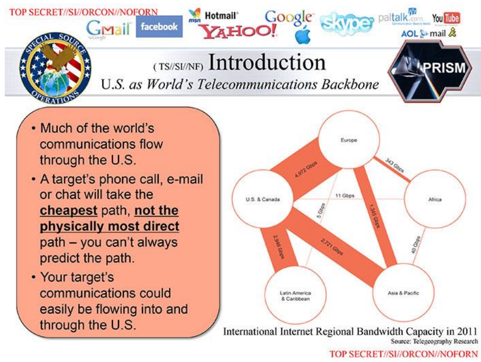
http://dyn.com/blog/iraq-downs-internet-to-combat-cheating-again/



http://www.wired.co.uk/article/over-50-internet-shutdowns-2016

Communications get eavesdropped on…

http://wapo.st/1UVKamr



http://wapo.st/1LcAw6p

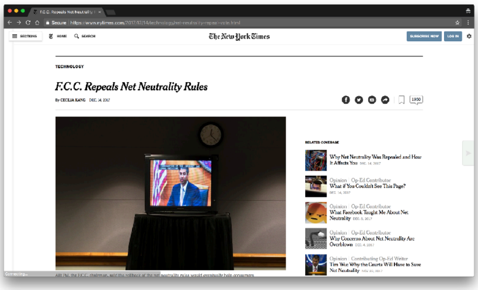
Some Internet communications
are interfered against or heavily congested

Can ISPs selectively slow down traffic?

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

http://nyti.ms/2kZUnDA

… which it then repealed in 2017

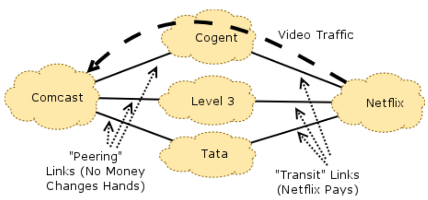


http://nyti.ms/2CkTbRR

Some Internet communications are interfered against or heavily congested

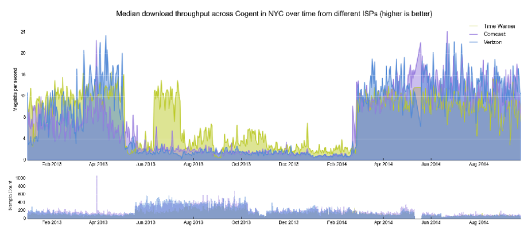
Who should pay the other for Internet connectivity?

A primer on the conflict between Netflix and Comcast



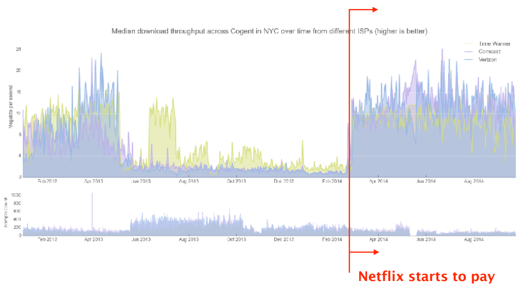
https://freedom-to-tinker.com/blog/feamster/why-your-netflix-traffic-is-slow-and-why-the-open-internet-order-wont-necessarily-make-it-faster/

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



http://bit.ly/1thPzro

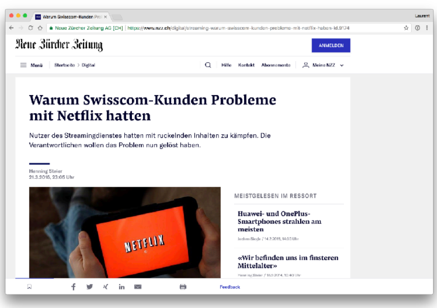
Situation massively improved after Netflix agreed to paid direct connection to the providers



Netflix starts to pay

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

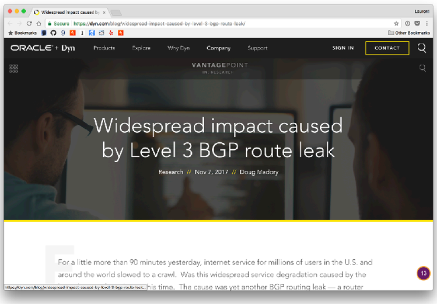
The Internet

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

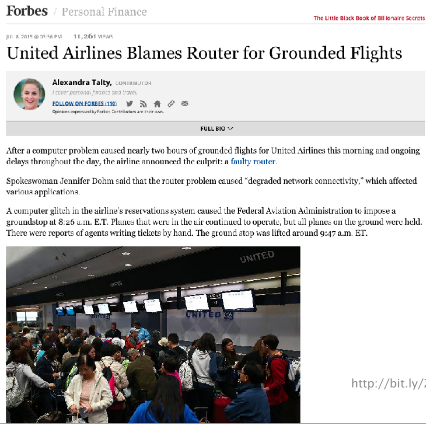
UPDATED: "Configuration Issue" Halts Trading on NYSE

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

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.

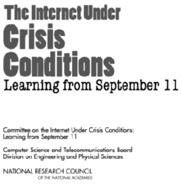
FULL BIO

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.

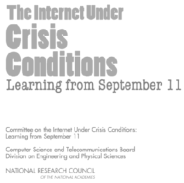
Spokeswoman Jennifer Dohm said that the router problem caused “degraded network connectivity,” which affected various applications.

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.

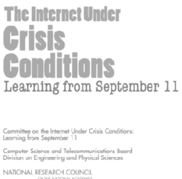
http://bit.ly/2sBJ2jf



National Research Council. The Internet Under Crisis Conditions: Learning from September 11



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



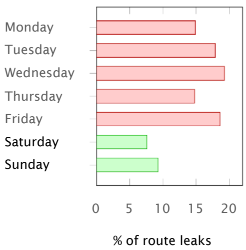
Internet advertisements rates suggest that The Internet was more stable than normal on Sept 11

Information suggests that operators were watching the news instead of making changes to their infrastructure

“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)

“Cost per network outage can be as high as 750 000$”

Smart Management for Robust Carrier Network Health and Reduced TCO!, NANOG54, 2012

Communication Networks

Course goals

Knowledge

Understand how the Internet works and why

from your network plug…

…to Google's data-center

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?

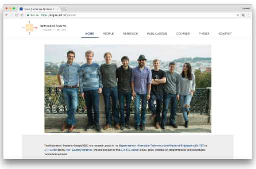
Naming Layering Routing Reliability Sharing

How do you communicate reliably using unreliable mediums?

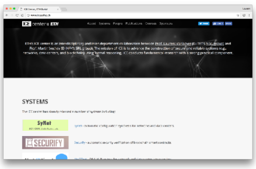
Naming Layering Routing Reliability Sharing

How do you divide scarce resources among competing parties?

Insights
Current research developments



NSG @ETH
nsg.ee.ethz.ch



ICE @ETH
ice.ethz.ch

Skills
Build, operate and configure networks

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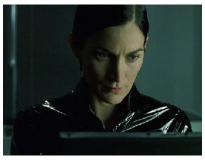
Build, operate and configure networks



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

Communication Networks
Course organization

Your **dream team** for the semester

Tobias

Roland

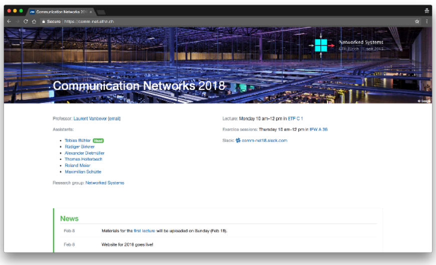
Thomas

Rüdiger

Alexander

Maximilian

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



Slides, exercises, project, extra readings, previous exams, ...

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

Part 1	Part 2	Part 3
Overview	Concepts	Today's Internet
2 lectures	2 lectures	~9 lectures

Your final grade

Exam	Projects
80%	20%
written, open book	mandatory

Your final grade

Exam	Projects
80%	20%
written, open book	mandatory

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

#1 Build and operate a real, working “Internet”

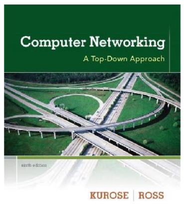
#2 Implement an interoperable reliable protocol

Detailed instructions will follow

“Internet Hackathon”
sometime around week 8-9

2016 edition

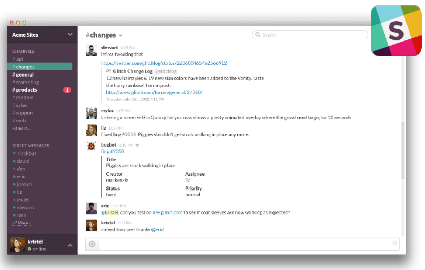
The course follows the textbook
Computer Networking: a Top-Down Approach



6th edition
ok to use the 5th

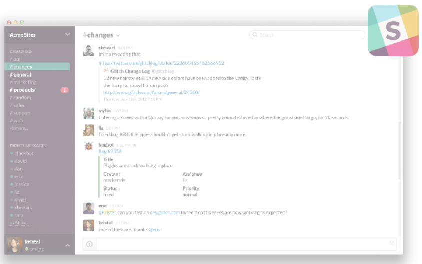
see sections indicated
on comm-net.ethz.ch

We’ll use Slack (chat client)
to discuss about the course and assignments

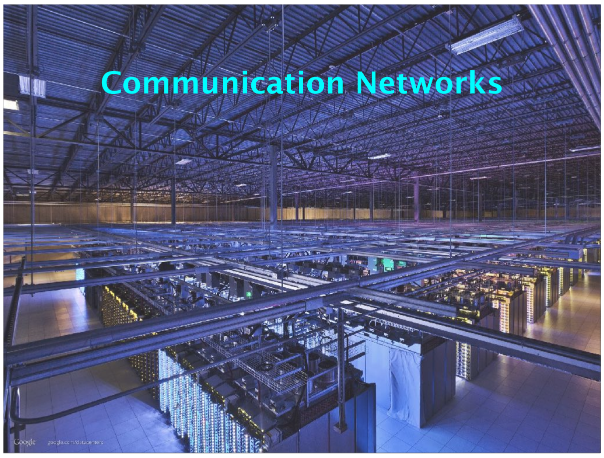


Web, smartphone and desktop clients available

Register today using your *real* name
> https://comm-net18.slack.com/signup



Web, smartphone and desktop clients available



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?

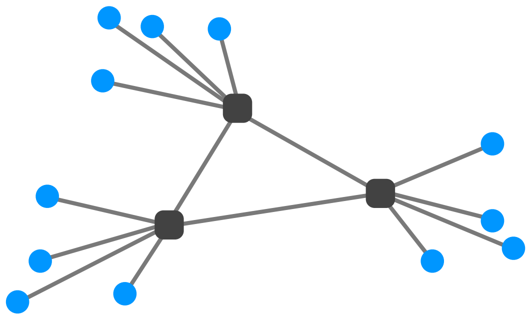
How is it shared?

How is it organized?

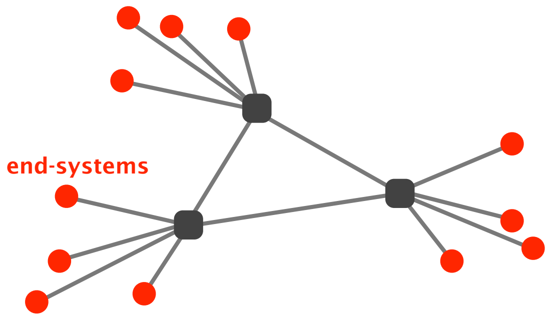
How does communication happen?

How do we characterize it?

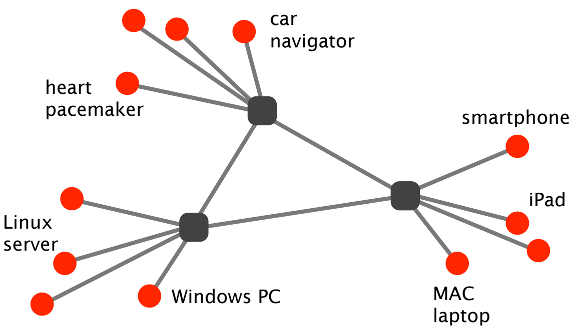
Networks are composed of three basic components



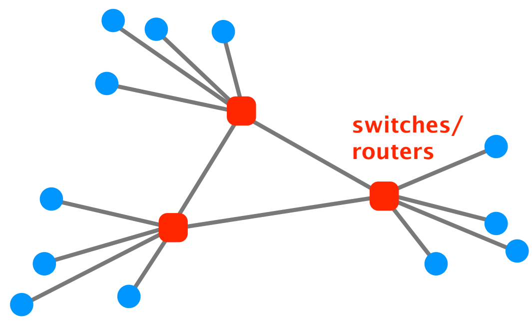
End-systems send & receive data



End-systems come in a wide-variety



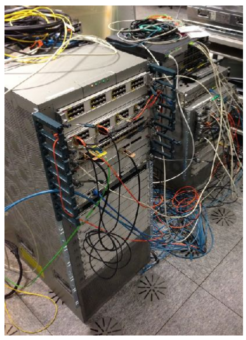
Switches & routers forward data to the destination



Routers vary in size and usage

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

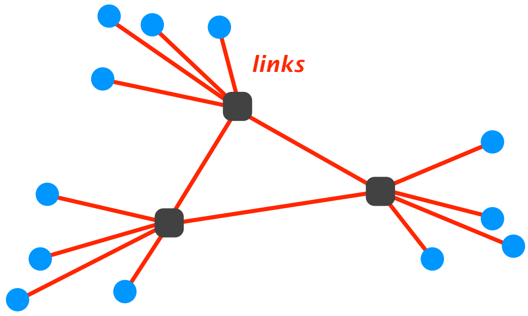


Cisco Nexus 7k

Routers @ETHZ

~25 deployed

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

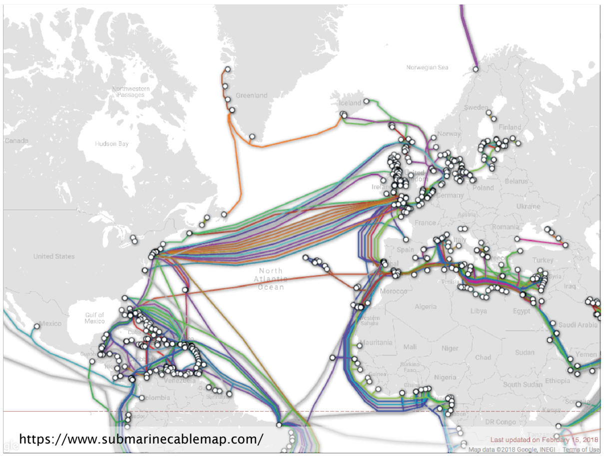


Links, too, vary in size and usage

Copper
ADSL, RJ-45,…

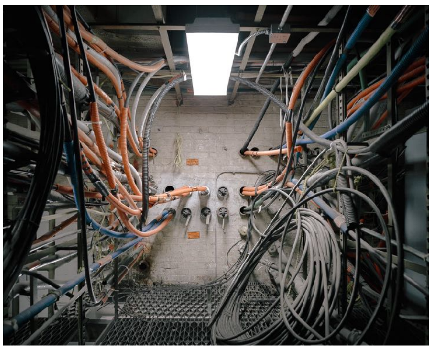
Optical fibers

Wireless link



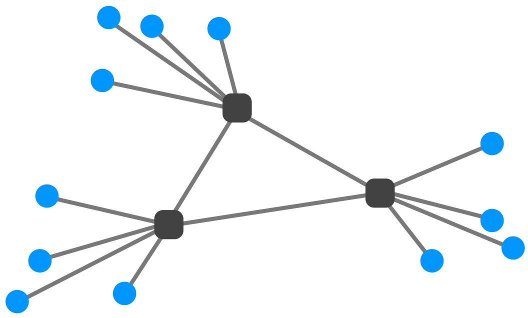
https://www.submarinecablemap.com/

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

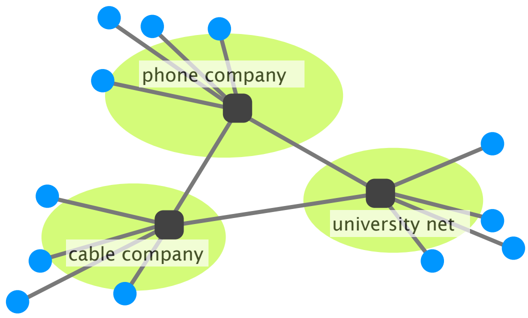


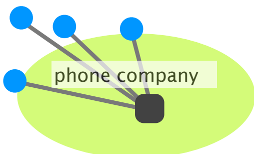
Somewhere in Manhattan…   http://www.petergarritano.com/the-internet.html

The *Inter* net is a network of networks



Internet Service Providers





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

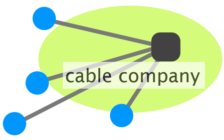
DSL is composed of 3 channels:

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

Why is there such an asymmetry?

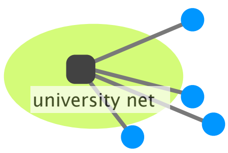


Cable Access Technologies (CATV) brings
high BW to the households via cable TV

coaxial copper & fiber

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

Unlike ADSL, the medium is shared between households



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…

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?

Up to now, we've seen what the last mile of the Internet looks like

What about the rest of the network?

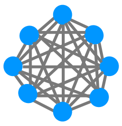
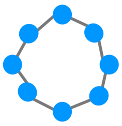
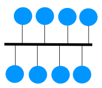
3 requirements for a network topology

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

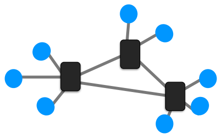
Provide adequate per-node capacity
number of links should not be too small

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

design	full-mesh	chain	bus
			
advantages			
disadvantages			

Switched networks provide reasonable and flexible compromise

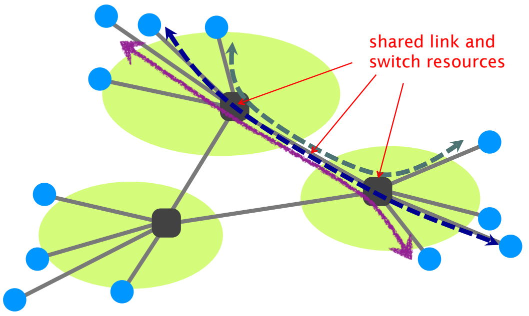
design: switched



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



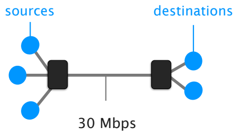
There exist two approaches to sharing:
reservation and on-demand

	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?

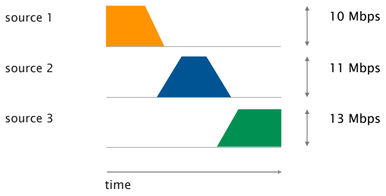


Consider that each source needs 10 Mbps

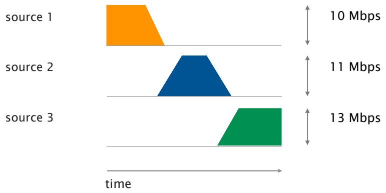
What do they get with:

- 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

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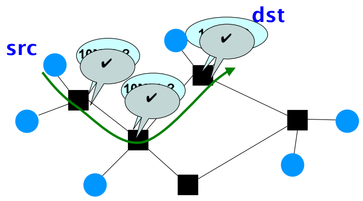
That's why the phone network used reservations
... and why the Internet does not!

In practice, the two approaches are implemented using circuit-switching or packet-switching, respectively

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

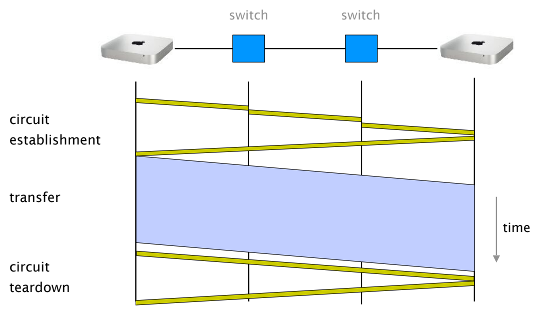
	Reservation	On-demand
implem.	circuit-switching	packet-switching

Circuit switching relies on the Resource Reservation Protocol



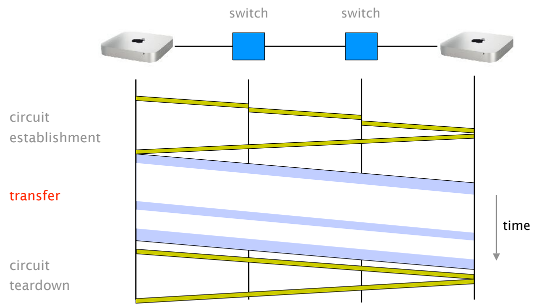
(1) src sends a reservation request for 10Mbps to dst
(2) switches “establish a circuit”
(3) src starts sending data
(4) src sends a “teardown circuit” message

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

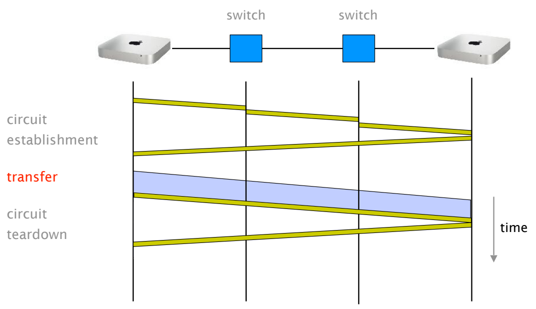


The efficiency of the transfer depends on how utilized the circuit is once established

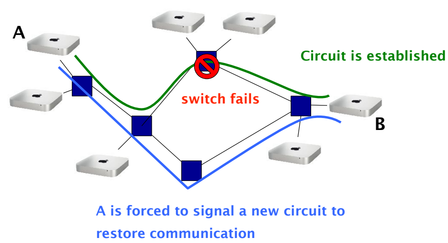
This is an example of poor efficiency.
The circuit is mostly idle due to traffic bursts



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



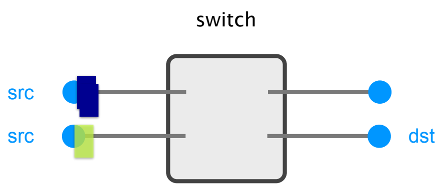
Pros and cons of circuit switching

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	On-demand
circuit-switching	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

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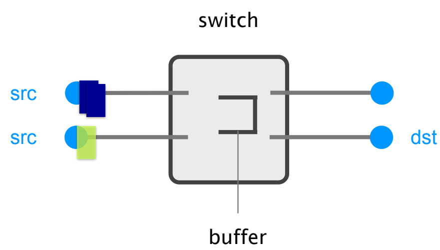
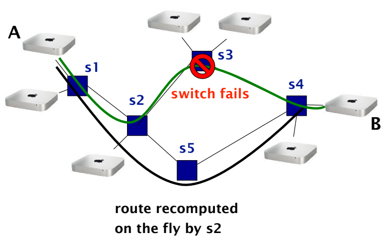


Packet switching routes around trouble



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?

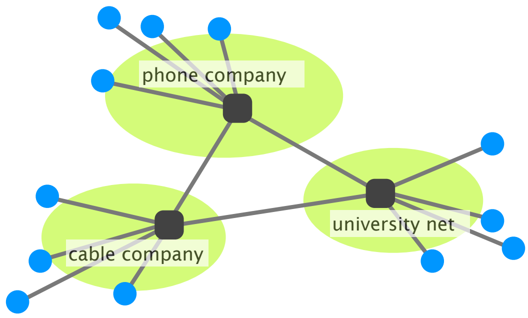
How is it shared?

#3 How is it organized?

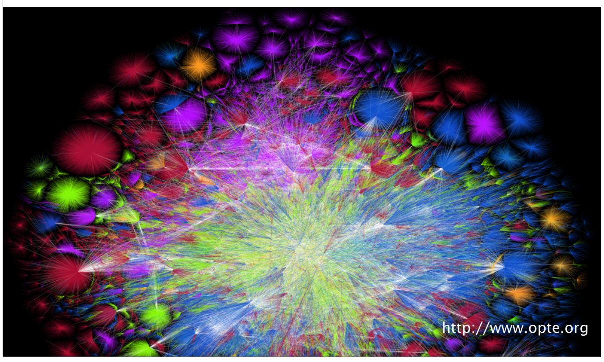
How does communication happen?

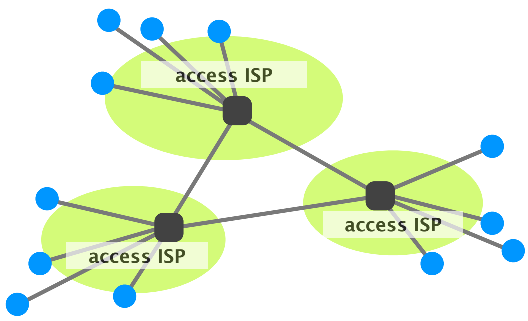
How do we characterize it?

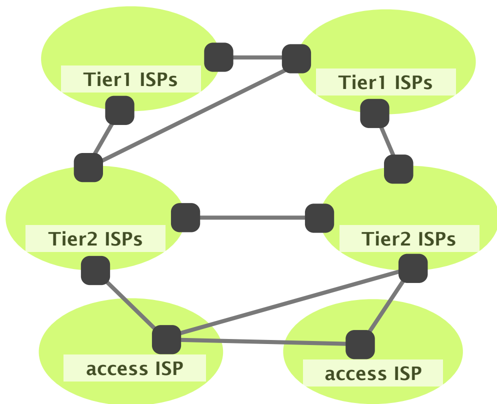
So far, this is our vision of the Internet…



The real Internet is a "tad" more complex

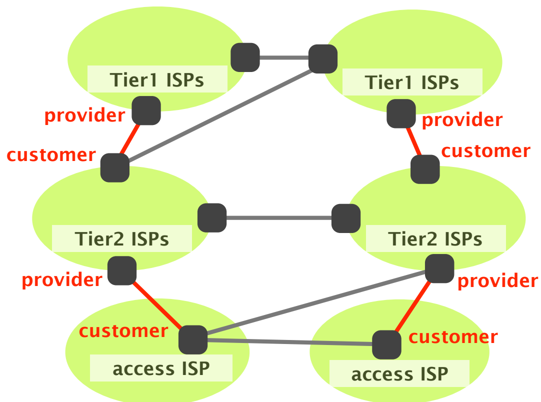






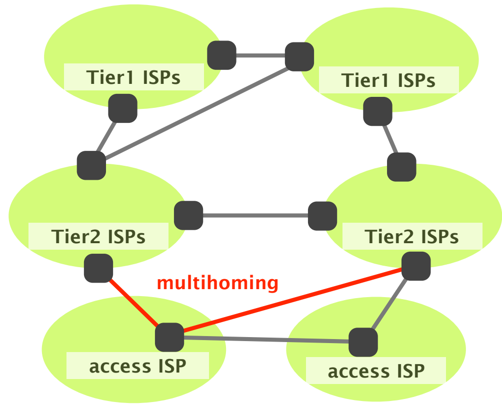
The Internet has a hierarchical structure

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



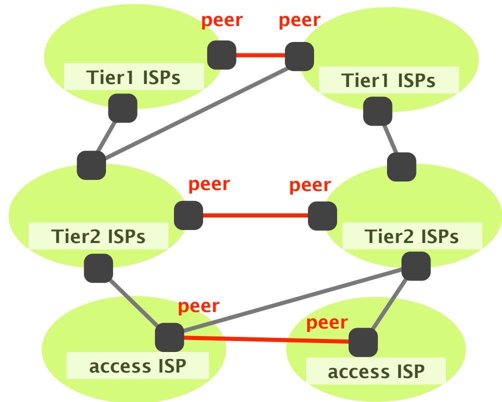
The distribution of networks in Tiers
is extremely skewed towards Tier-3s

	total	~50,000 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"



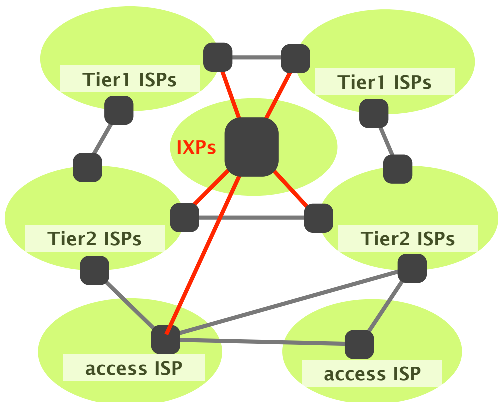
Interconnecting each network to its neighbors
one-by-one is not cost effective

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

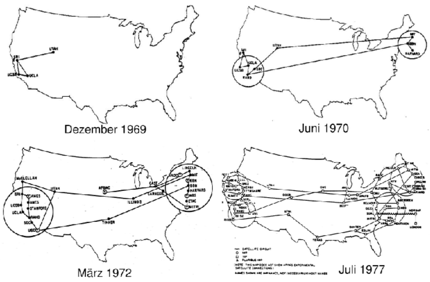
People start to want to use networks for other things
defense, (not personal) computers, …

… 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?

Stanford: *Yes! We see the L*

UCLA: We typed the O… Do you see it?

Stanford: *Yes! We see the O*

UCLA: 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 Jabobson 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

Communication Networks
Part 1: Overview

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#3	How is it organized?
#4	How does communication happen?
#5	How do we characterize it?