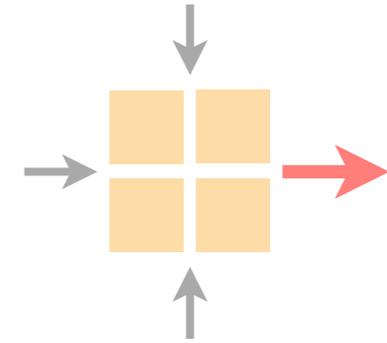


# Communication Networks

Spring 2018



Laurent Vanbever

[nsg.ee.ethz.ch](mailto: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



**volume(Great Wall of China) = 1 exabyte**

~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	<b>35.15%</b>	Netflix	32.72%
YouTube	13.13%	YouTube	<b>17.53%</b>	YouTube	17.31%
Netflix	10.33%	Amazon Video	<b>4.26%</b>	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%



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

<http://bit.ly/2Glwl8G>

~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

The image is a screenshot of a web browser displaying a NewScientist article. The browser's address bar shows the URL: <https://www.newscientist.com/blogs/onepercent/2012/07/syria-disconnects-from-the-int.html>. The NewScientist logo is at the top left, with a search bar and 'Log In' and 'My New Scientist' buttons to the right. A navigation menu includes 'Home', 'News', 'In-Depth Articles', 'Blogs', 'Opinion', 'TV', 'Galleries', 'Topic Guides', 'Last Word', 'Subscribe', 'Dating', and 'Look for Science Jobs'. Below this is a secondary menu with categories: 'SPACE', 'TECH', 'ENVIRONMENT', 'HEALTH', 'LIFE', 'PHYSICS&MATH', 'SCIENCE IN SOCIETY', and 'Cookies & Privacy'. The main content area features the 'One Per Cent' logo with the tagline 'Taking the sweat out of technology' and an illustration of a person on a bicycle connected to various electronic devices. The article title is 'Syria follows Egypt and disconnects from the internet', dated '17:20 20 July 2012', with a tag 'Internet' and author 'Paul Marks, chief technology correspondent'. A photograph shows a street scene in Syria with a destroyed car and armed people. To the right, there are sections for 'Our other blogs' (listing 'Short Sharp Science', 'One Per Cent', 'New Scientist TV', 'Cultural Lab', and 'Big Wide World'), 'Bookmark & share' (with social media icons), and 'Categories' (listing various tech topics like '3D printing', 'AI', 'Aerospace', etc.).

**NewScientist** Search New Scientist Go! Log In My New Scientist

Home News In-Depth Articles **Blogs** Opinion TV Galleries Topic Guides Last Word Subscribe Dating Look for Science Jobs

SPACE TECH ENVIRONMENT HEALTH LIFE PHYSICS&MATH SCIENCE IN SOCIETY Cookies & Privacy

**One Per Cent**  
Taking the sweat out of technology

**Syria follows Egypt and disconnects from the internet**  
17:20 20 July 2012  
Internet  
Paul Marks, chief technology correspondent

**Our other blogs**

- Short Sharp Science
- One Per Cent
- New Scientist TV
- Cultural Lab
- Big Wide World

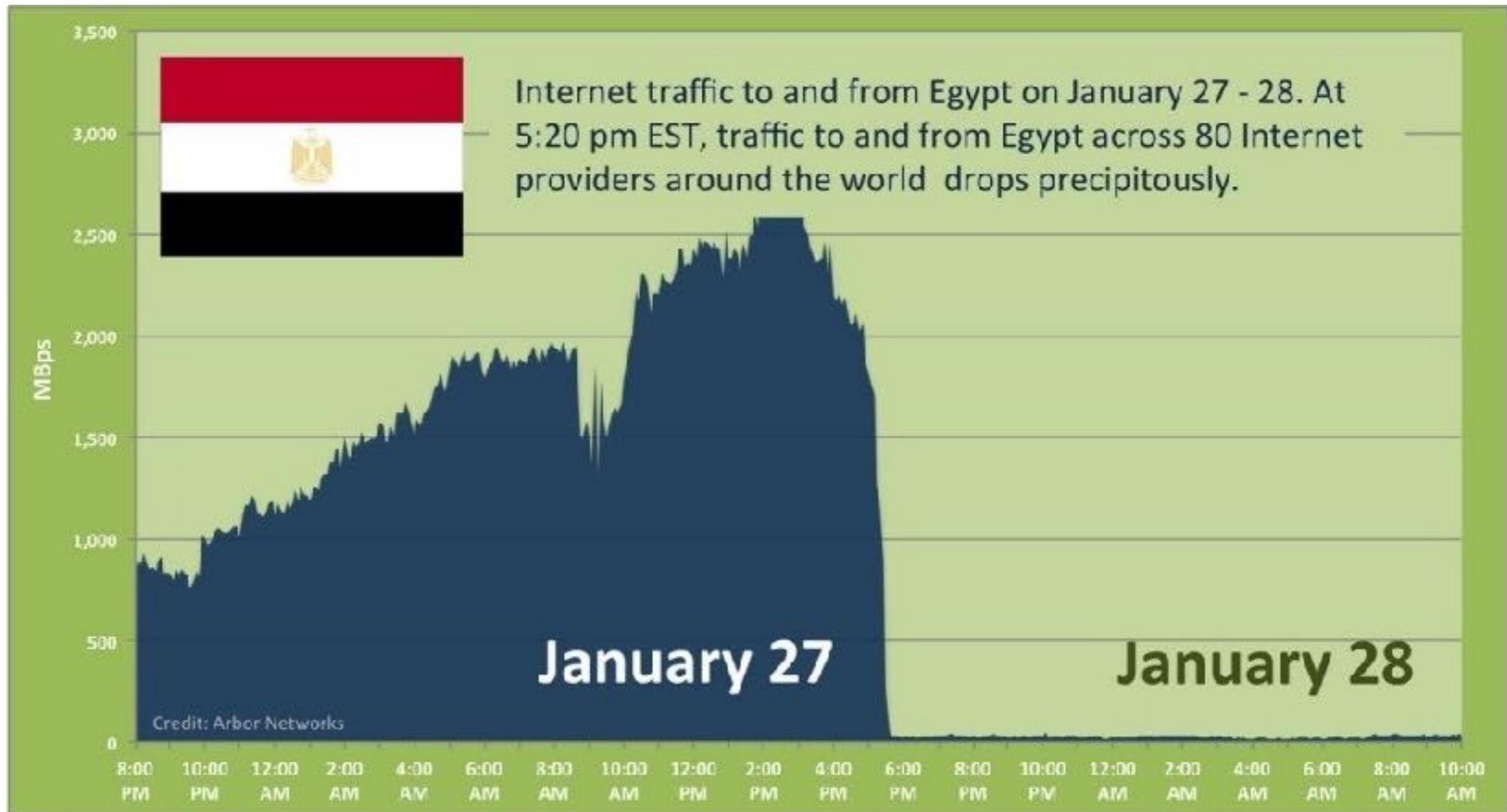
**Bookmark & share**

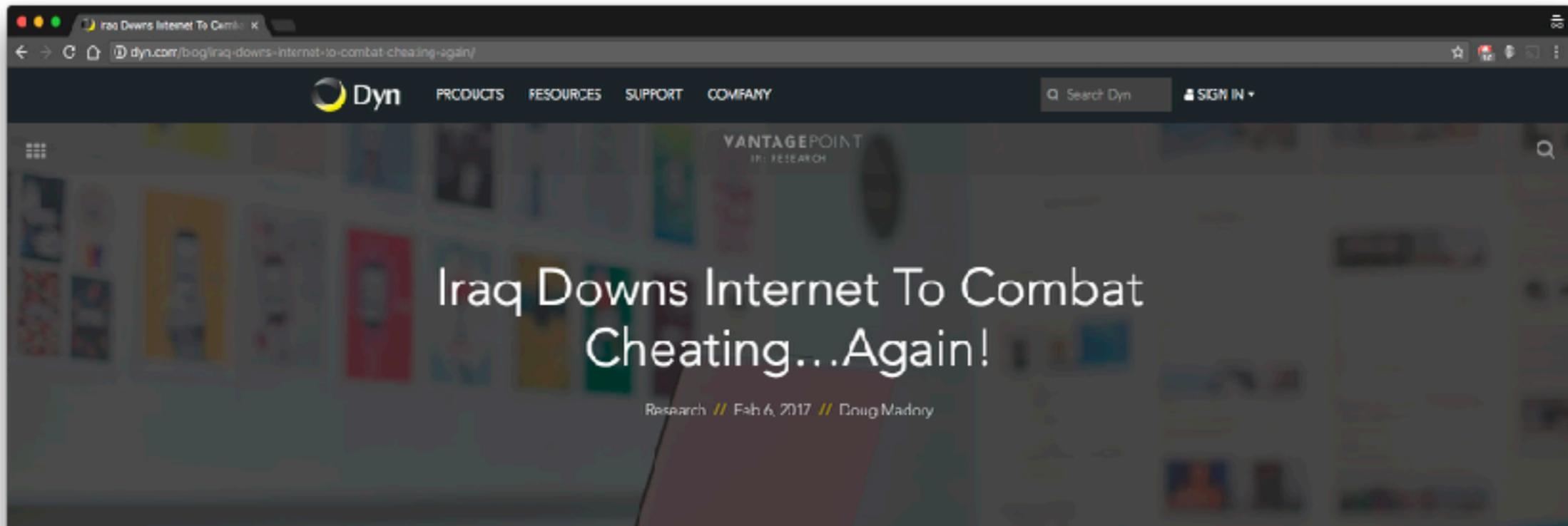
**Categories**

- 3D printing
- AI
- Aerospace
- Apps
- App:2
- Art
- Augmented reality
- Autonomous cars
- cybersecurity
- data science
- design
- disruptive innovation
- education
- energy
- environment
- ethics
- finance
- food
- health
- history
- innovation
- internet
- intelligent systems
- lab
- law
- life
- machine learning
- marketing
- materials
- medicine
- mobile
- nanotechnology
- new materials
- robotics
- space
- teaching
- technology
- transport
- urban planning
- virtual reality
- wearables
- work

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

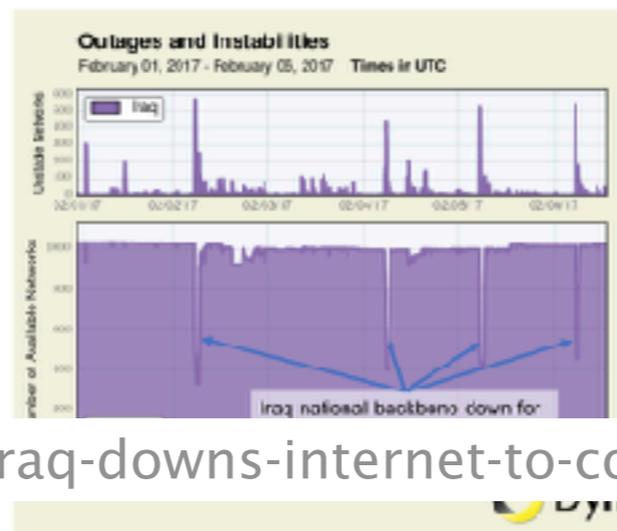
# Internet traffic to/from Egypt in January 2011





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.

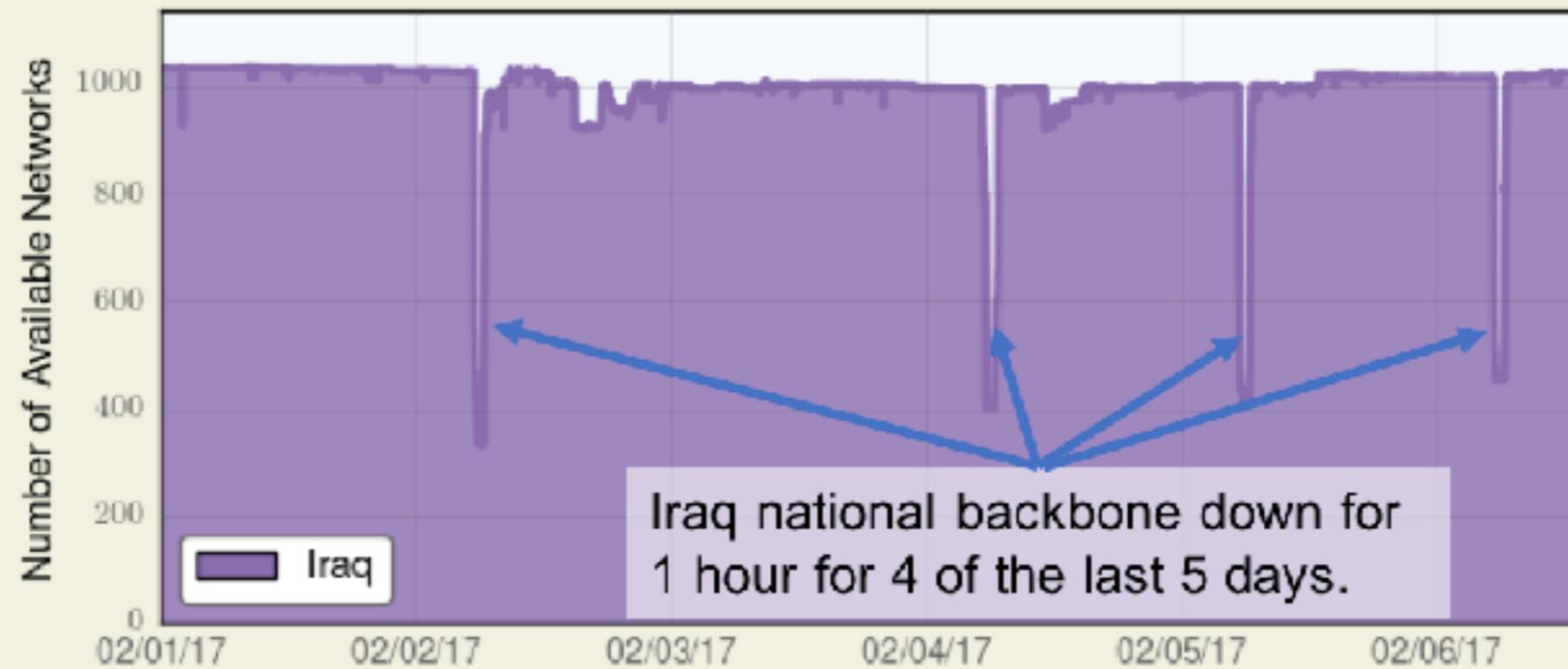
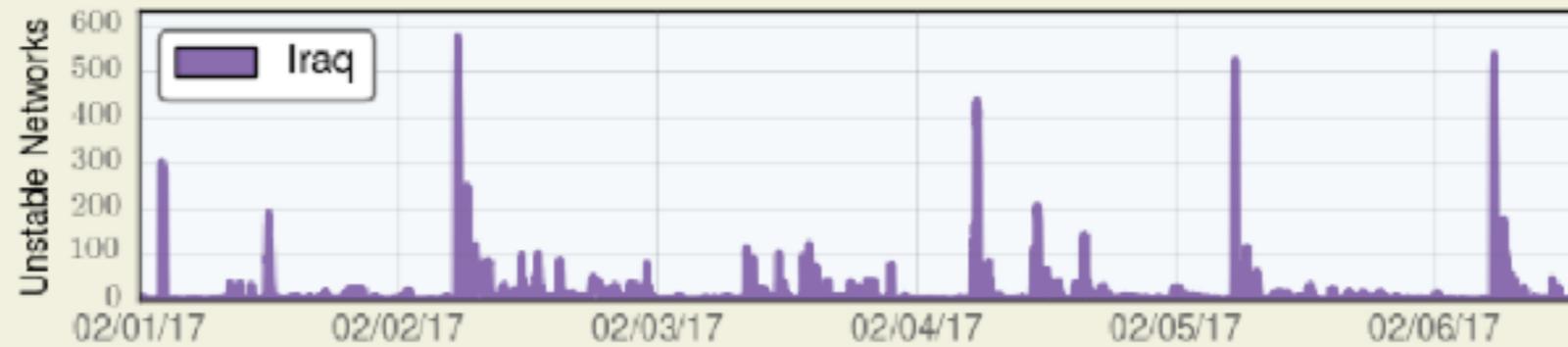
These recent outages are a continuation of a growing (and somewhat puzzling) trend by governments in many developing parts of the world to cut communications services in a desperate attempt to staunch rampant cheating on high-stakes student exams.



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

## Outages and Instabilities

February 01, 2017 - February 06, 2017 Times in UTC



Source: BGP Data



Horizontal carousel of article teasers including: Nintendo Switch isn't just a console, it's a 127-year saga that began with a deck of cards; Halo Wars 2 review: a solidly Spartan sequel to the real-time strategy classic; Apple's WWDC 2017 will return to San Jose in June; This algorithm can spot signs of autism in children a year before they're diagnosed.

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>

By MATT KAMEN

Published 3 January 2017



# Communications get eavesdropped on...

**National Security**

## NSA infiltrates links to Yahoo, Google data centers worldwide, Snowden documents say

2896 | Save for Later | Reading List

**TCP SECRET/SINOFORM**

### Current Efforts - Google

**TCP SECRET/SINOFORM**

In this slide from a National Security Agency presentation on "Google Cloud Exploitation," a sketch shows where the "Public Internet" meets the internal "Google Cloud" where user data resides. Two engineers with close ties to Google exploded in profanity when they saw the drawing.

By **Barton Gellman and Ashkan Soltani** October 30, 2013

The National Security Agency has secretly broken into the main communications links that connect Yahoo and Google data centers around the world, according to documents obtained from former NSA contractor [redacted] and interviews with knowledgeable officials.

Edwards Snowden and interviews with knowledgeable officials. The world, according to documents obtained from former NSA contractor.

**Most Read**

1. U.S. says meeting for Syria cease-fire delayed, not canceled as Russia claims
2. U.S. airstrikes target suspected Islamic State base in Libya
3. The so-called "Islamic rape of Europe" is part of a long and racist history
4. The voyages of the Dawnlight: Where is it headed? And what is it carrying?
5. Islamic State faces new trouble in Fallujah as Sunni tribesmen revolt

**Our Online Games**

Play right from this page

- Mahjong Dimensions**  
Genre(s): Strategy  
It's 3D Mahjongg - you don't ever need to wear 3D glasses!
- The Sunday Crossword by Evan Birnholz**  
Evan Birnholz  
The Sunday crossword by

<http://wapo.st/1UVKamr>

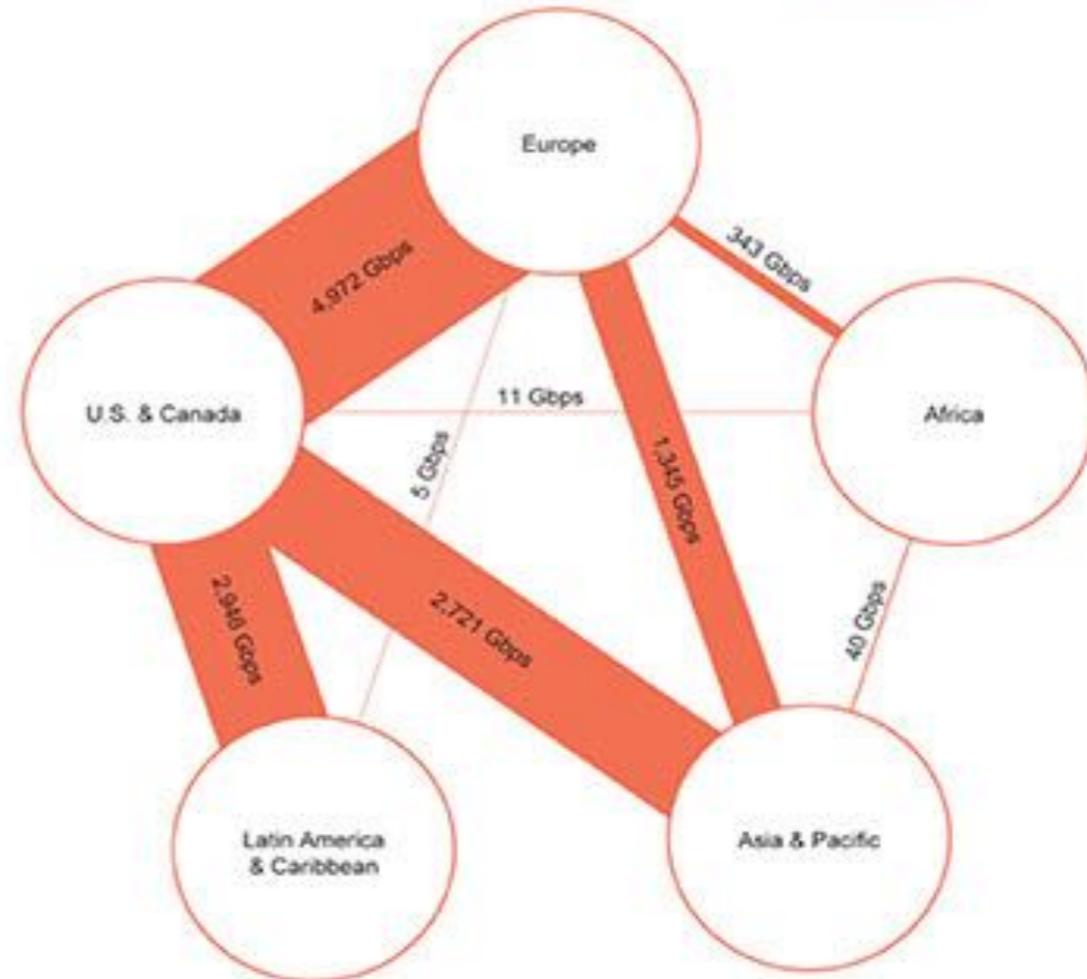


# (TS//SI//NF) Introduction

## U.S. as World's Telecommunications Backbone



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



International Internet Regional Bandwidth Capacity in 2011

Source: Telegeography Research

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

The screenshot shows a web browser displaying a New York Times article. The browser's address bar shows the URL: <https://www.nytimes.com/2015/03/12/technology/fcc-releases-net-neutrality-rules.html>. The page header includes the New York Times logo and navigation links. The article title is "F.C.C. Sets Net Neutrality Rules" by Rebecca L. Ritzy, dated March 12, 2015. Below the title is a video player with the title "The New Net Neutrality Rules" and a thumbnail image of a hand clicking a mouse. To the right of the video is a "RELATED COVERAGE" section with two links: "F.C.C. Approves Net Neutrality Rules, Classifying Broadband Internet Service as a Utility" and "NEWS ANALYSIS: The Push for Net Neutrality Arose From Lack of Choice".

**TECHNOLOGY**

## F.C.C. Sets Net Neutrality Rules

By REBECCA L. RITZY MARCH 12, 2015

**RELATED COVERAGE**

- F.C.C. Approves Net Neutrality Rules, Classifying Broadband Internet Service as a Utility** FEB 16, 2015
- NEWS ANALYSIS: The Push for Net Neutrality Arose From Lack of Choice** FEB 25, 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 [313-page document](#) that included the new rules and the legal justifications for them.

The rules revealed how the strict laws would be modified for Internet providers, exempting the companies from the sort of price controls typically

<http://nyti.ms/2kZUnDA>

... which it then repealed in 2017

The image is a screenshot of a web browser displaying a news article from The New York Times. The browser's address bar shows the URL: <https://www.nytimes.com/2017/12/14/technology/net-neutrality-repeal-vote.html>. The page features the New York Times logo at the top center, with navigation links for 'SECTIONS', 'HOME', and 'SEARCH' on the left, and 'SUBSCRIBE NOW' and 'LOG IN' on the right. The article is categorized under 'TECHNOLOGY' and has the main headline 'F.C.C. Repeals Net Neutrality Rules' by Cecilia Kang, dated Dec. 14, 2017. A large photograph shows a television set on a stand displaying a man in a suit, likely an FCC official, with an American flag in the background. To the right of the main image is a 'RELATED COVERAGE' section with five links, each with a small thumbnail image and a date. The bottom of the page shows a 'Connecting...' status bar and a partial line of text: 'All but the F.C.C. chairman, said the rollback of the net neutrality rules would eventually help consumers'.

TECHNOLOGY

## F.C.C. Repeals Net Neutrality Rules

By CECILIA KANG DEC. 14, 2017

RELATED COVERAGE

- Why Net Neutrality Was Repealed and How It Affects You DEC. 14, 2017
- Opinion | Op-Ed Contributor What if You Couldn't See This Page? DEC. 14, 2017
- Opinion | Op-Ed Contributor What Facebook Taught Me About Net Neutrality DEC. 5, 2017
- Opinion | Op-Ed Contributor Why Concerns About Net Neutrality Are Overblown DEC. 4, 2017
- Opinion | Contributing Op-Ed Writer Tim Wu: Why the Courts Will Have to Save Net Neutrality NOV. 22, 2017

Connecting... All but the F.C.C. chairman, said the rollback of the net neutrality rules would eventually help consumers

<http://nyti.ms/2CkTbRR>



**Netflix US** 

@netflix

Follow 

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



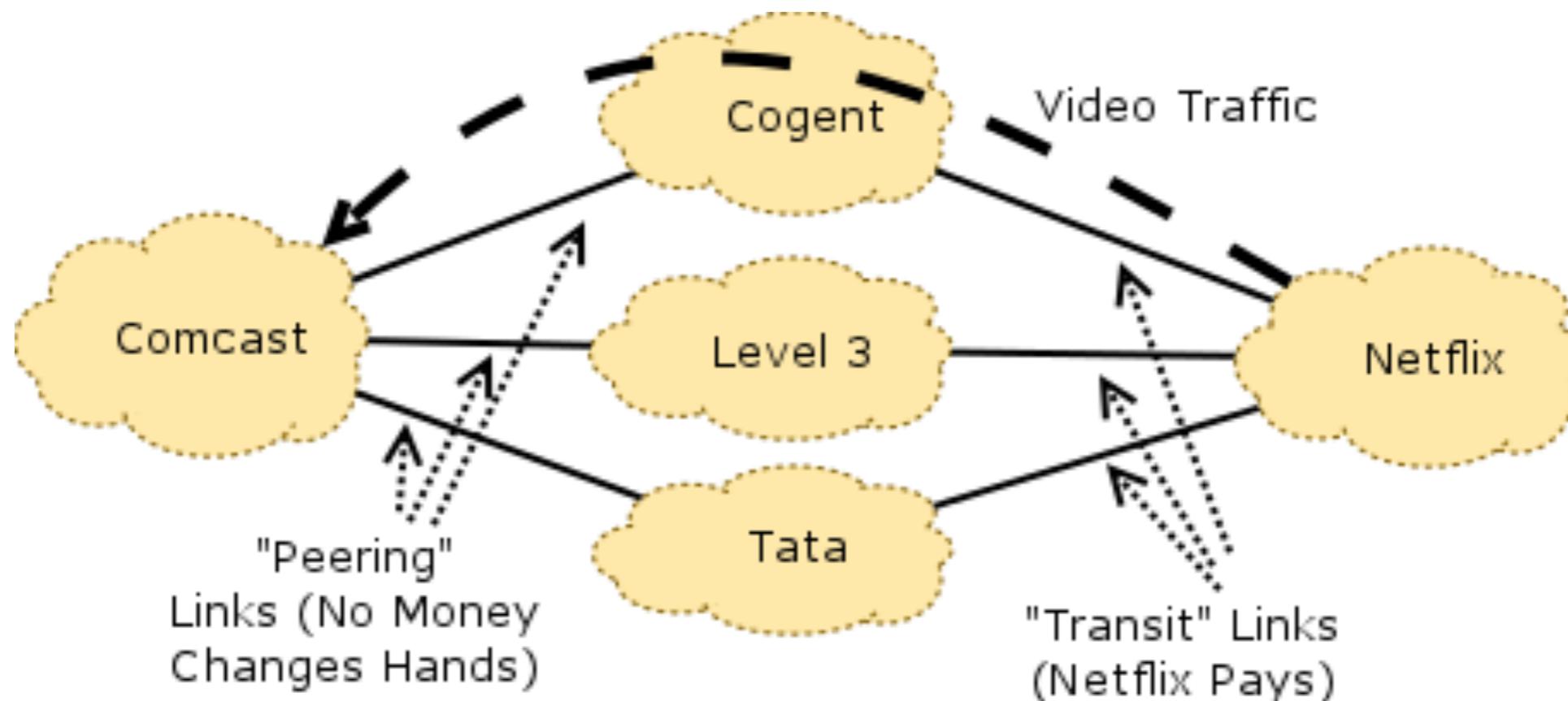
 7.1K  336K  832K

Some Internet communications  
are interfered against or heavily congested



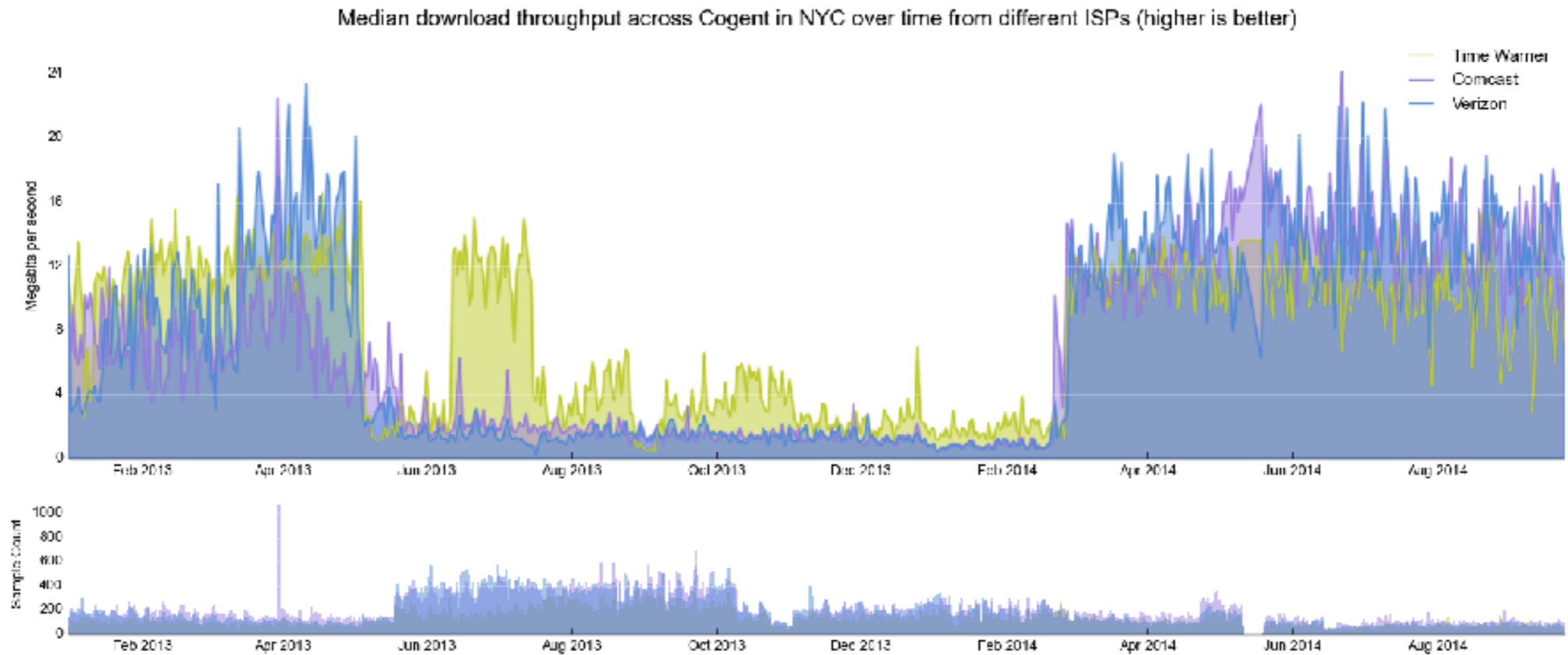
Who should pay the other for Internet connectivity?

# A primer on the conflict between Netflix and Comcast



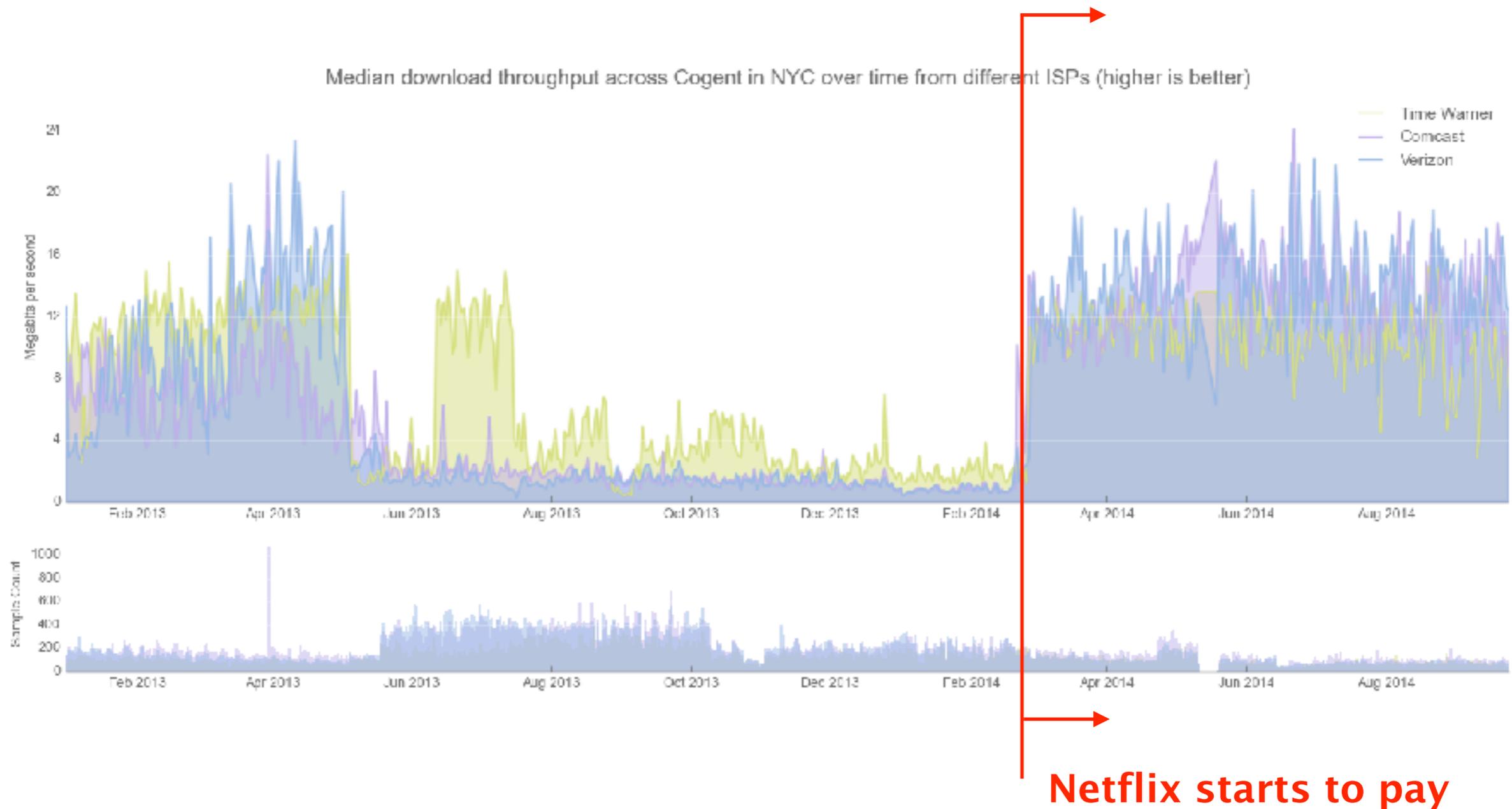
<https://freedom-to-tinker.com/blog/feamster/why-your-netflix-traffic-is-slow-and-why-the-open-internet-order-wont-necessarily-make-it-faster/>

# 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



Closer to us...



The screenshot shows a web browser window displaying a news article from the Neue Zürcher Zeitung (NZZ). The browser's address bar shows the URL: <https://www.nzz.ch/digital/streaming-warum-swisscom-kunden-probleme-mit-netflix-haben-ld.9174>. The page header includes the NZZ logo, a search bar, and navigation links for 'Hilfe', 'Kontakt', 'Abonnements', and 'Meine NZZ'. The main article title is 'Warum Swisscom-Kunden Probleme mit Netflix hatten'. The sub-headline reads: 'Nutzer des Streamingdienstes hatten mit ruckelnden Inhalten zu kämpfen. Die Verantwortlichen wollen das Problem nun gelöst haben.' The author is Henning Steier, and the article was published on 21.3.2016 at 23:05 Uhr. A photograph shows a person holding a tablet displaying the Netflix logo. To the right, a 'MEISTGELESEN IM RESSORT' section lists two other articles: 'Huawei- und OnePlus-Smartphones strahlen am meisten' and '«Wir befinden uns im finsternen Mittelalter»'. The footer contains social media icons and a 'Feedback' link.

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**  
Inchun Sieje / 14.2.2016, 14:50 Uhr

**«Wir befinden uns im finsternen Mittelalter»**  
Henning Steier / 15.3.2014, 10:40 Uhr

<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

The image is a screenshot of a web browser displaying a blog post on the Dyn website. The browser's address bar shows the URL: <https://dyn.com/blog/widespread-impact-caused-by-level-3-bgp-route-leak/>. The page header includes the Oracle + Dyn logo and navigation links for Products, Explore, Why Dyn, Company, and Support. There are also buttons for SIGN IN and CONTACT, and a search icon. The main content area features a large, dark background image of two people looking at a screen. Overlaid on this image is the title "Widespread impact caused by Level 3 BGP route leak" in white text. Below the title, it says "Research // Nov 7, 2017 // Doug Madary". The beginning of the article text is visible: "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...". A small circular badge with the number "13" is in the bottom right corner of the article preview.

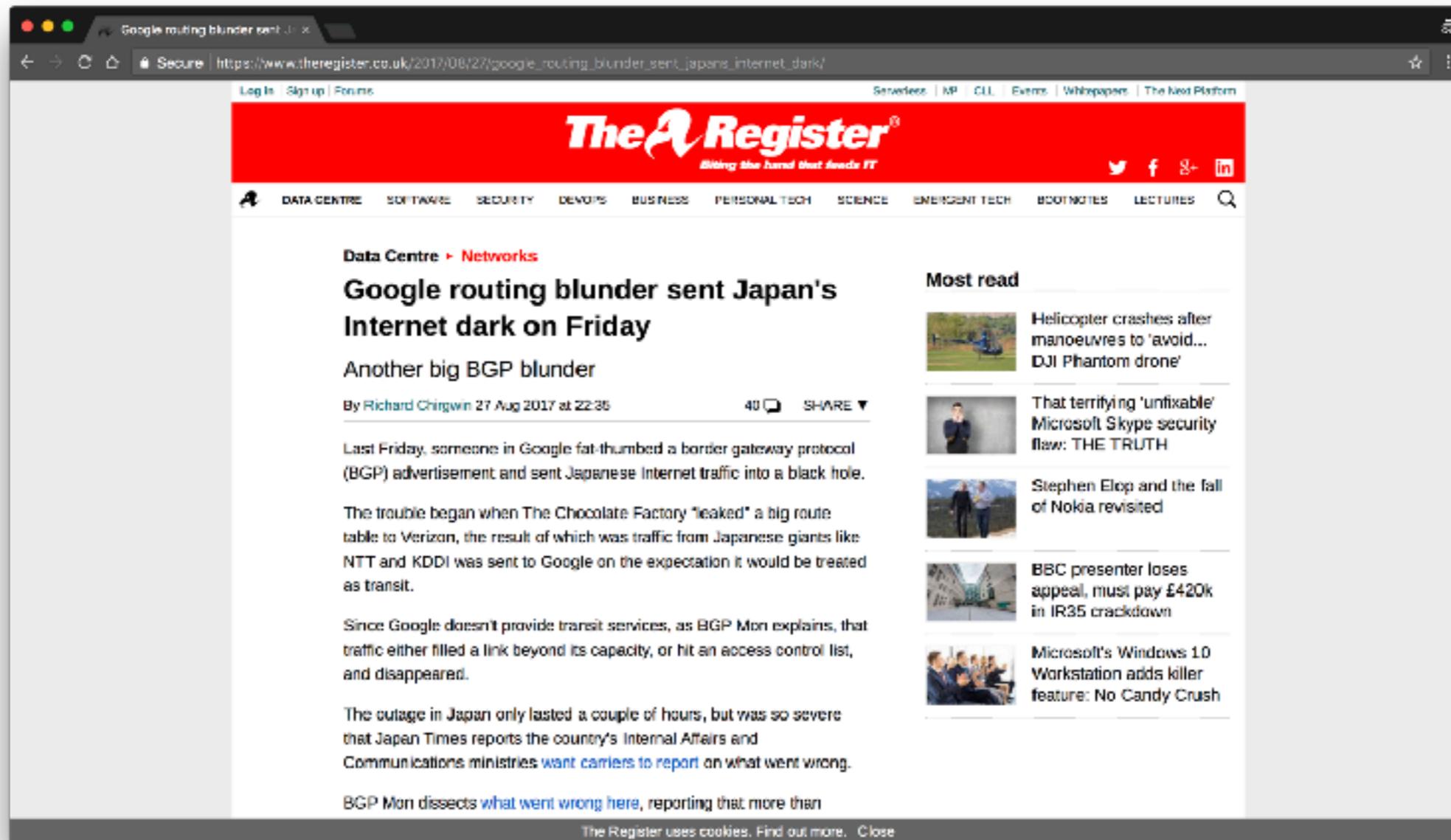
<https://dyn.com/blog/widespread-impact-caused-by-level-3-bgp-route-leak/>

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”

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>

# **The Internet Under Crisis Conditions**

Learning from September 11

Committee on the Internet Under Crisis Conditions:  
Learning from September 11

Computer Science and Telecommunications Board  
Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL  
OF THE NATIONAL ACADEMIES

# The Internet Under Crisis Conditions

Learning from September 11

Committee on the Internet Under Crisis Conditions:  
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Computer Science and Telecommunications Board  
Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL  
OF THE NATIONAL ACADEMIES

Internet advertisements rates  
suggest that

The Internet was **more stable  
than normal on Sept 11**

# The Internet Under Crisis Conditions

Learning from September 11

Committee on the Internet Under Crisis Conditions:  
Learning from September 11

Computer Science and Telecommunications Board  
Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL  
OF THE NATIONAL ACADEMIES

Internet advertisements rates  
suggest that

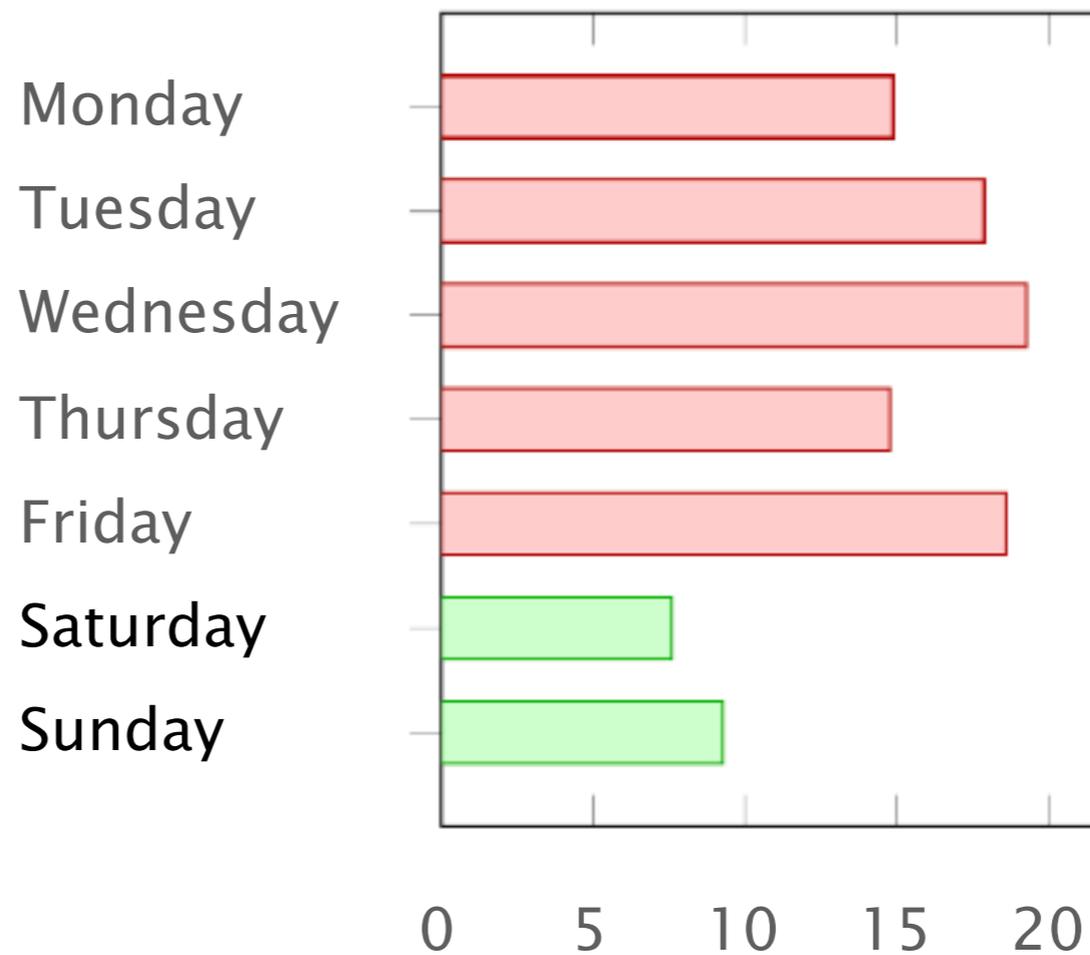
The Internet was **more stable  
than normal** on Sept 11

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...



% of route leaks

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

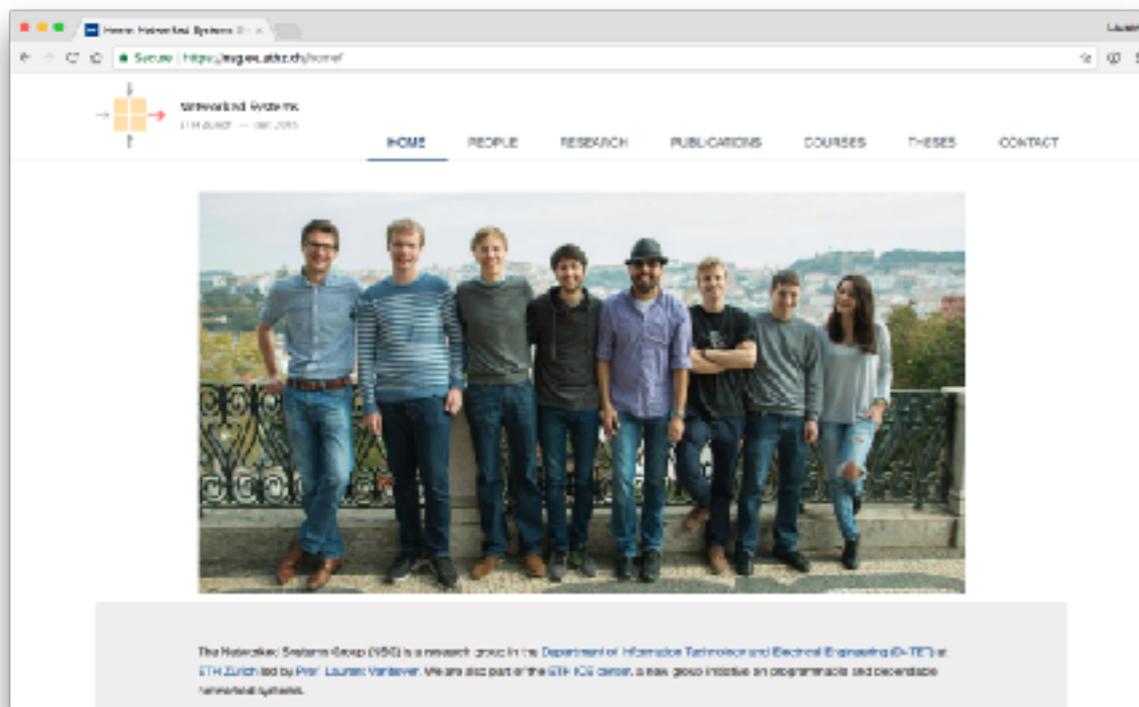
How do you **communicate reliably using unreliable mediums?**

Naming    Layering    Routing    Reliability    **Sharing**

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

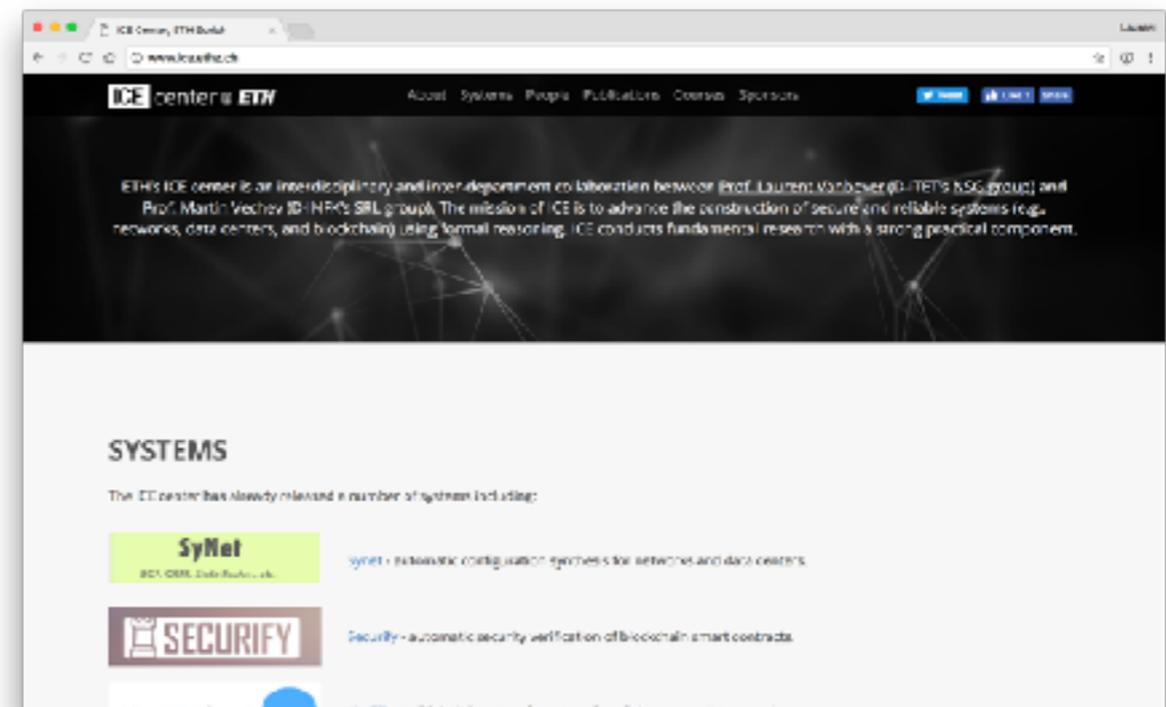
# Insights

## Current research developments



NSG @ETH

[nsg.ee.ethz.ch](https://nsg.ee.ethz.ch)



ICE @ETH

[ice.ethz.ch](http://ice.ethz.ch)

## Skills

Build, operate and configure networks

# 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



Tobias



Roland



Thomas



Rüdiger

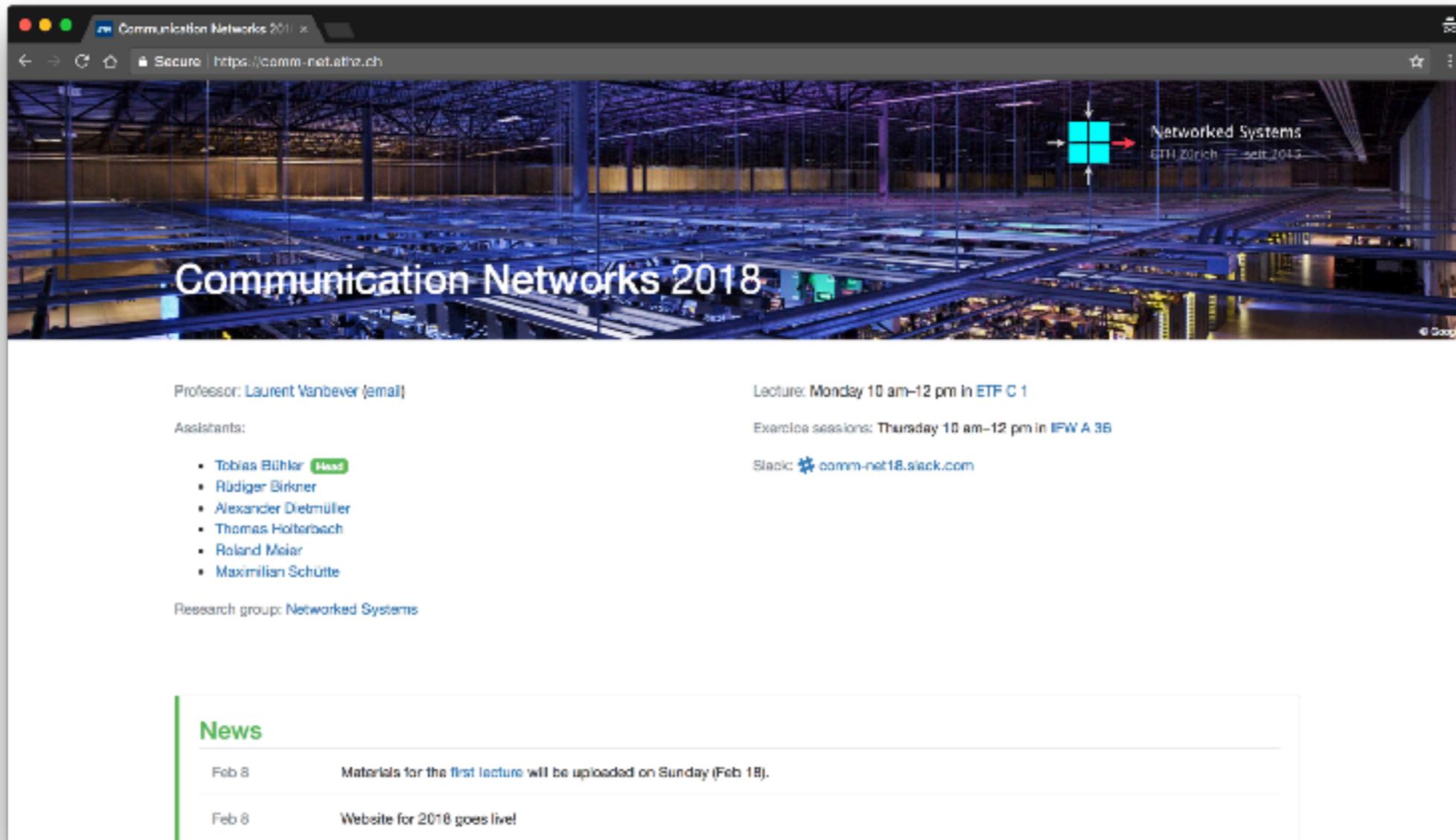


Alexander



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

Overview

2 lectures

Part 2

Concepts

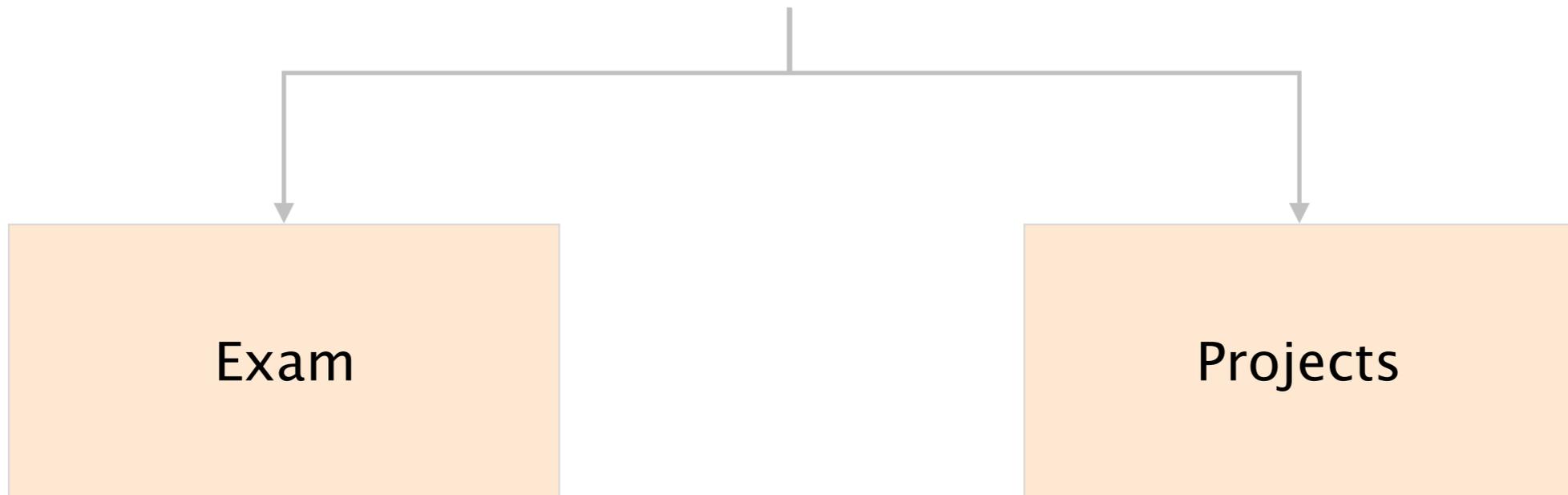
2 lectures

Part 3

Today's Internet

~9 lectures

# Your final grade



Exam

Projects

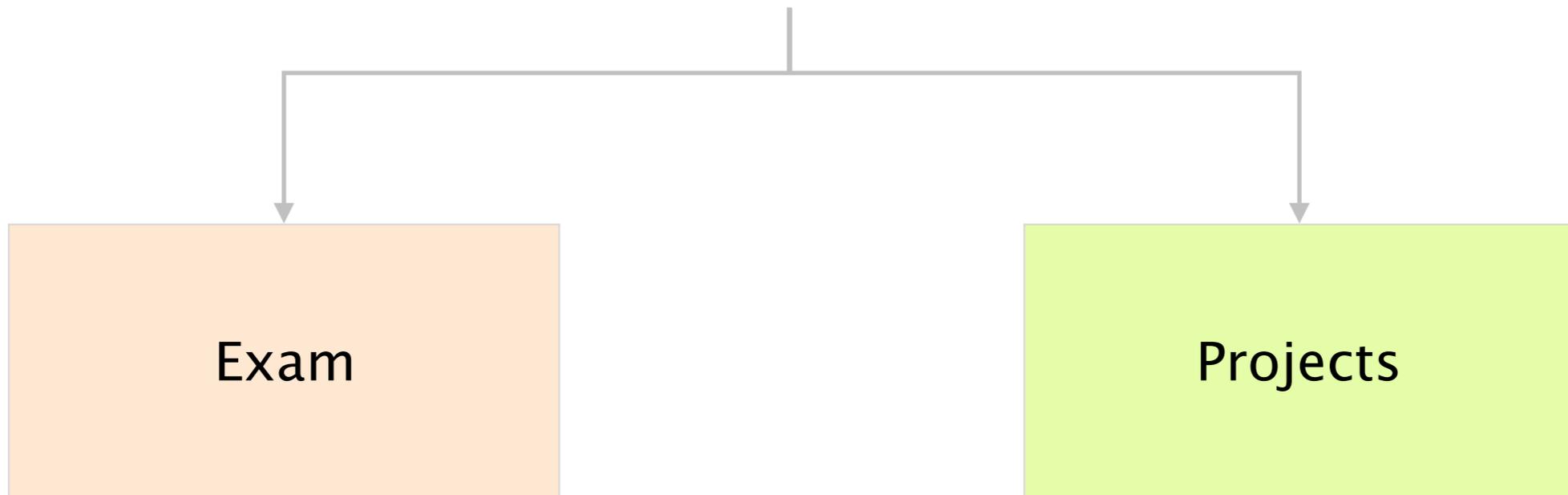
80%

written, open book

20%

mandatory

# Your final grade



**80%**

written, open book

**20%**

**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

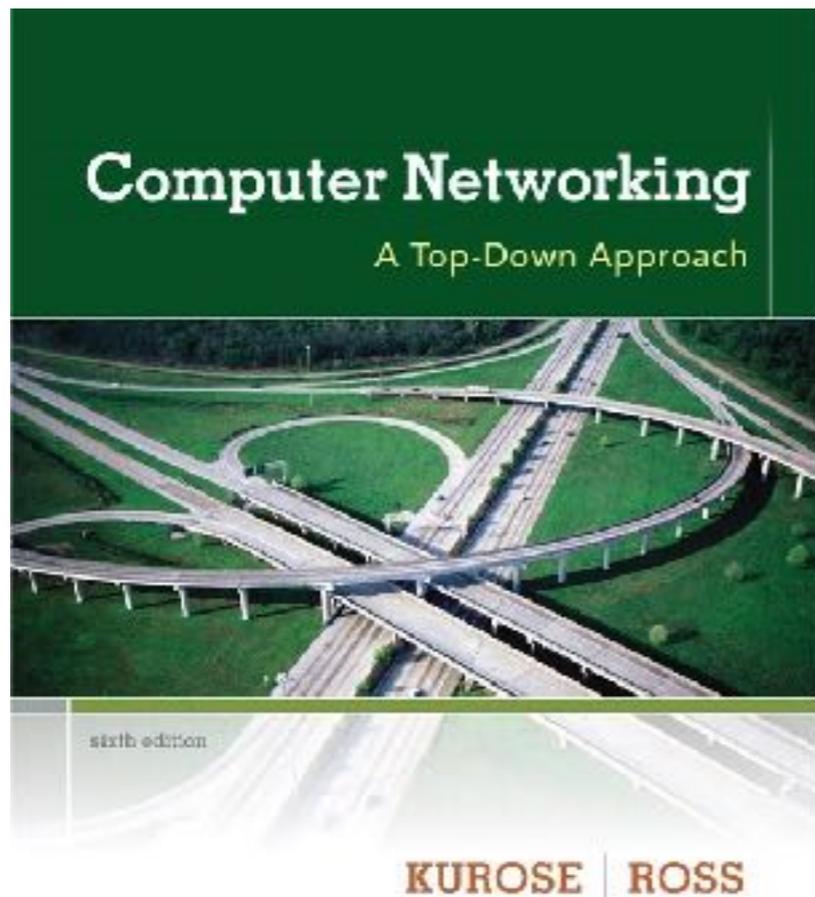
# “Internet Hackathon”

sometime around week 8-9

2016 edition



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

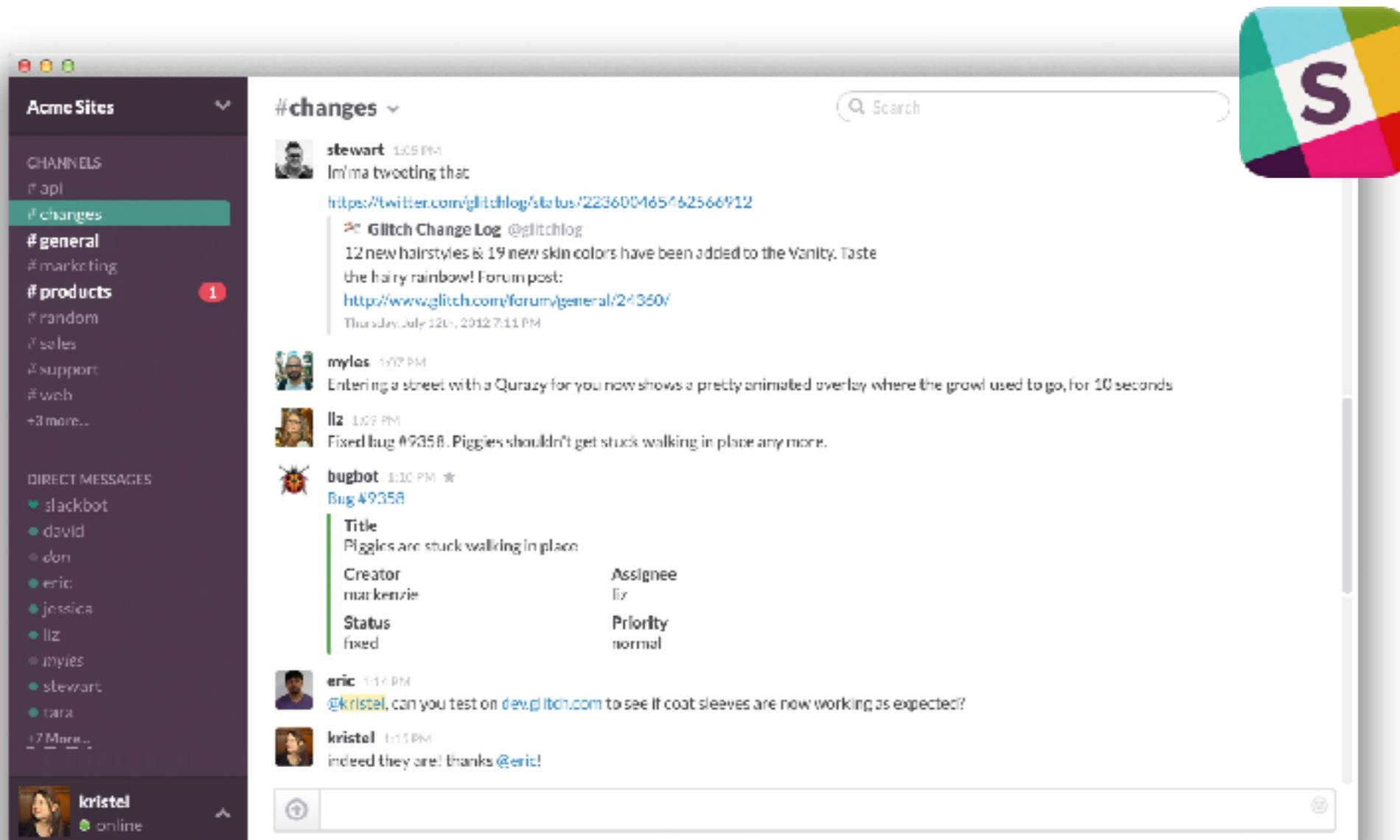


6th edition

ok to use the 5th

see sections indicated  
on [comm-net.ethz.ch](http://comm-net.ethz.ch)

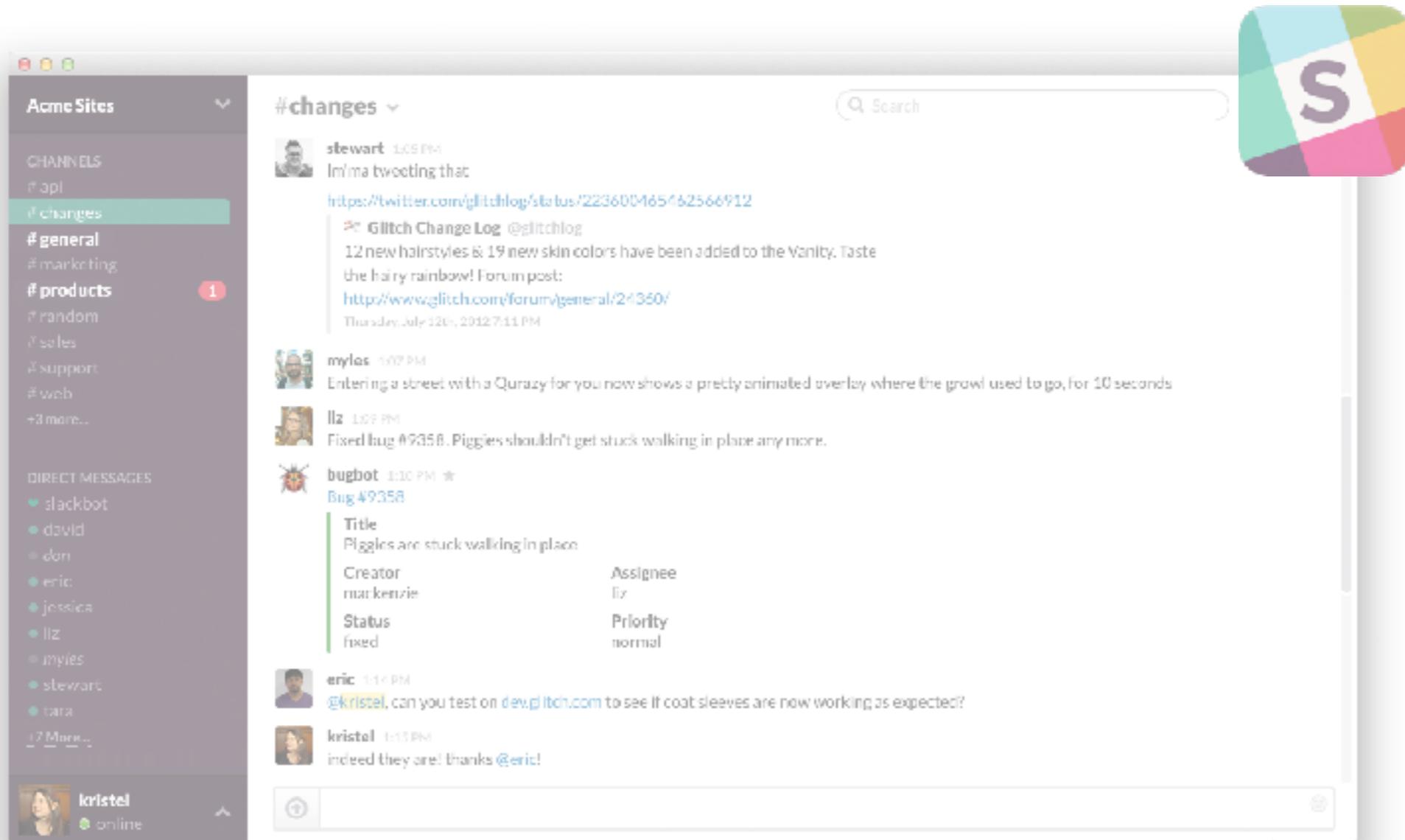
We'll use **Slack** (chat client)  
to discuss about the course and assignments



Web, smartphone and desktop clients available

Register **today** using your *real* name

> <https://comm-net18.slack.com/signup>



Web, smartphone and desktop clients available

# Communication Networks

A wide-angle, high-angle photograph of a vast data center. The room is filled with rows of server racks, each illuminated with a soft blue glow. The ceiling is a complex network of metal beams and pipes, with numerous overhead lights. The floor is a light-colored, polished surface that reflects the ambient light. The overall atmosphere is one of a highly organized and technologically advanced environment.

List any

technologies, principles, applications...

used after typing in:

> [www.google.ch](http://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?

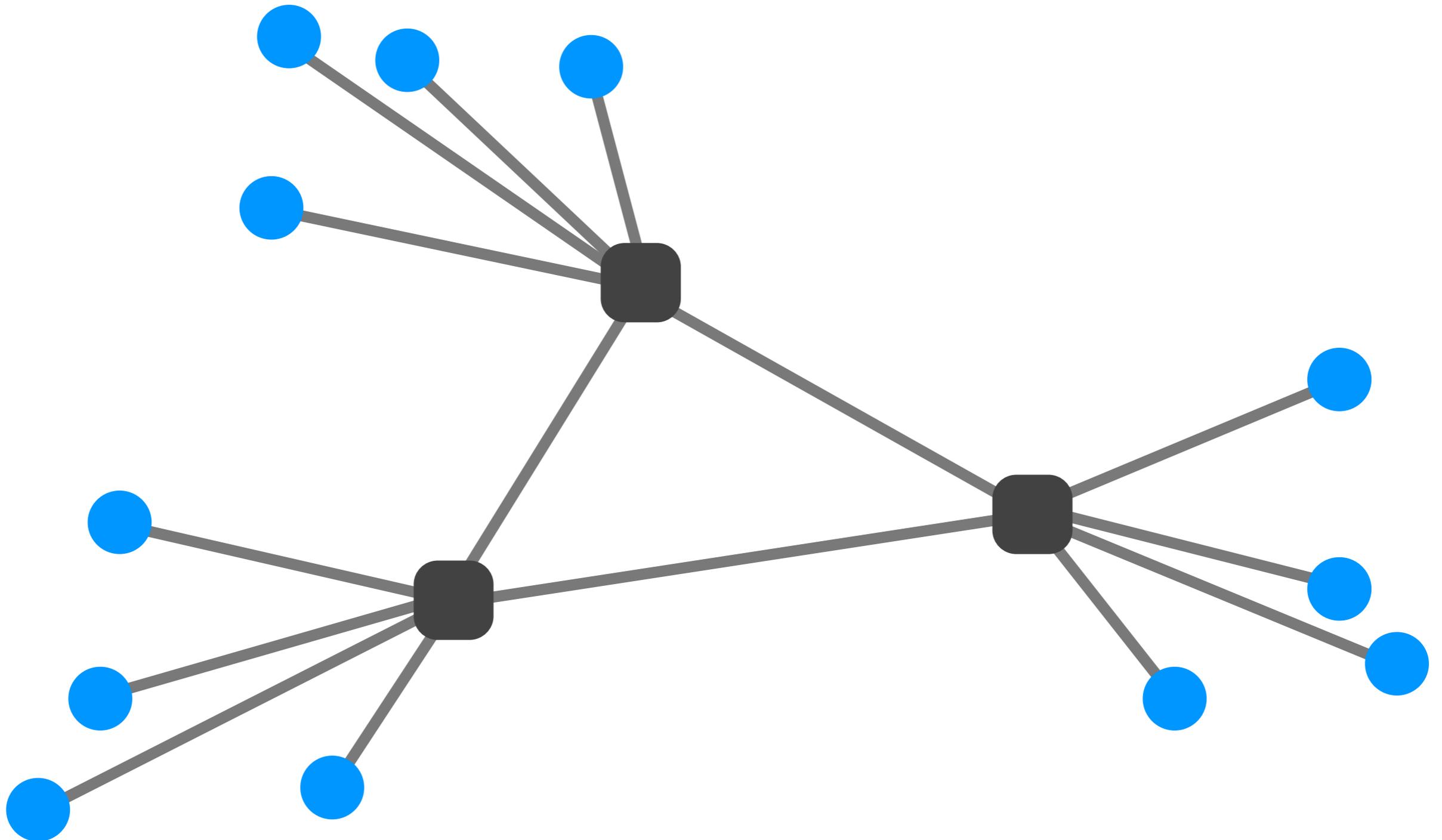
How is it shared?

How is it organized?

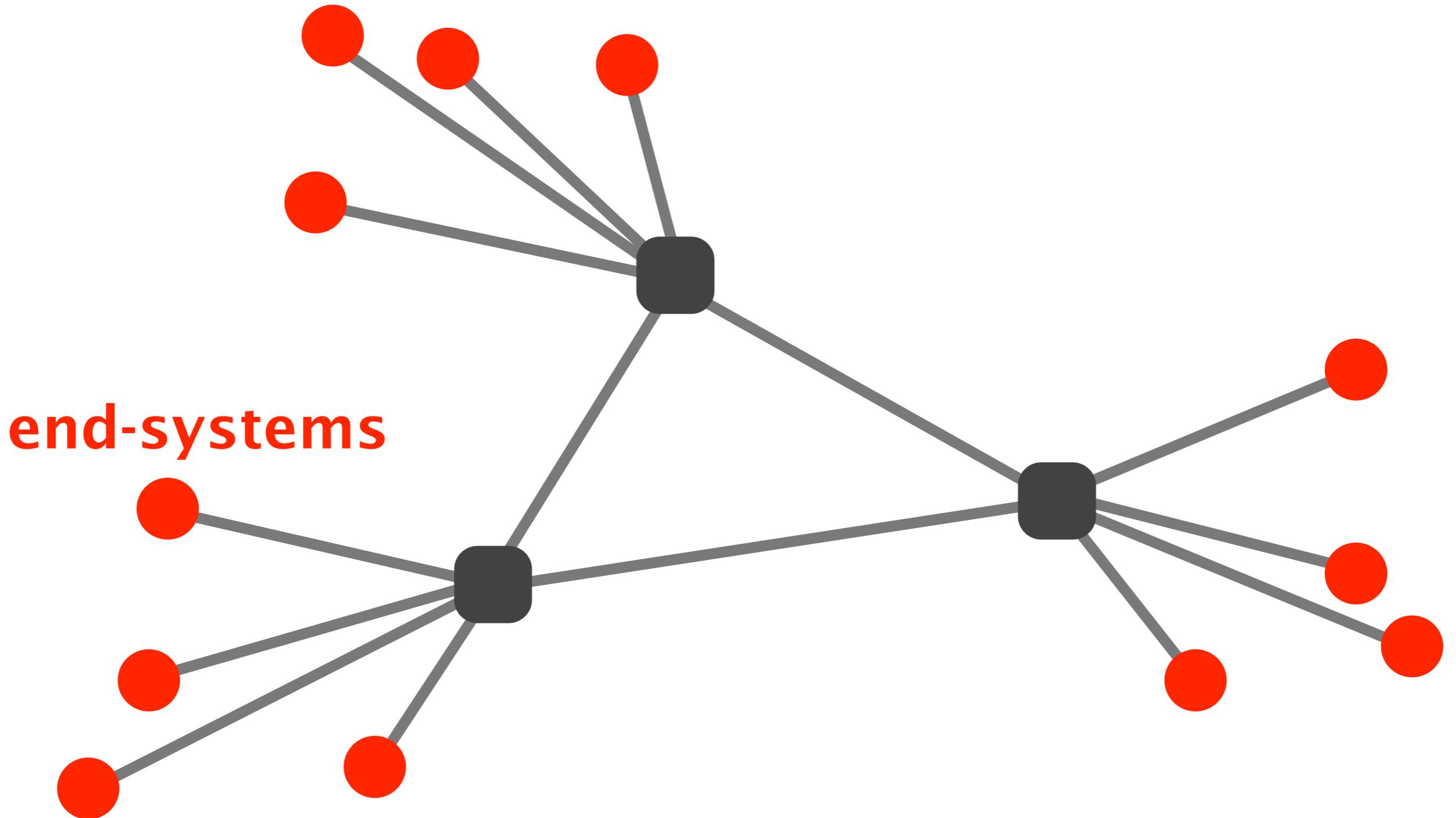
How does communication happen?

How do we characterize it?

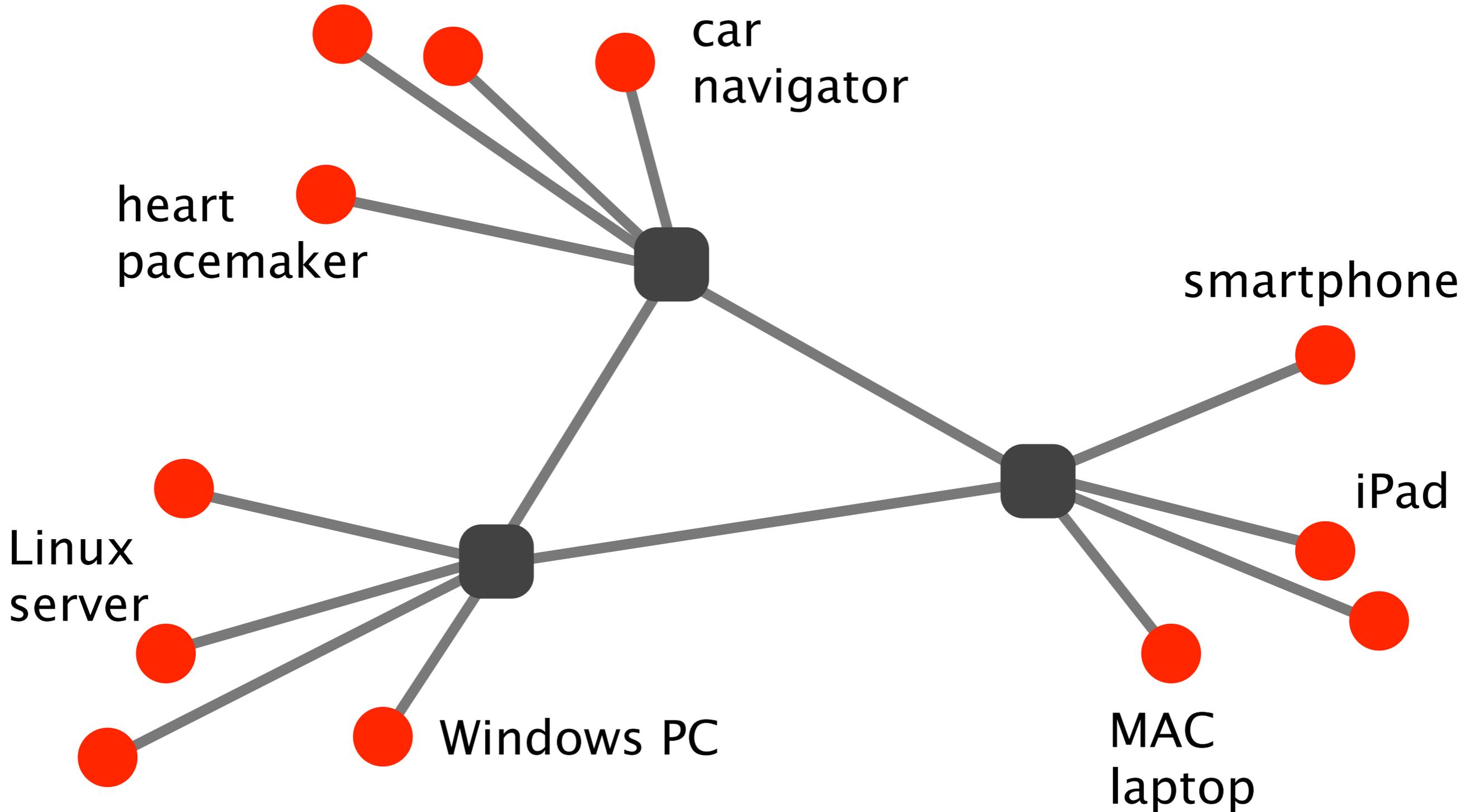
Networks are composed of three basic components



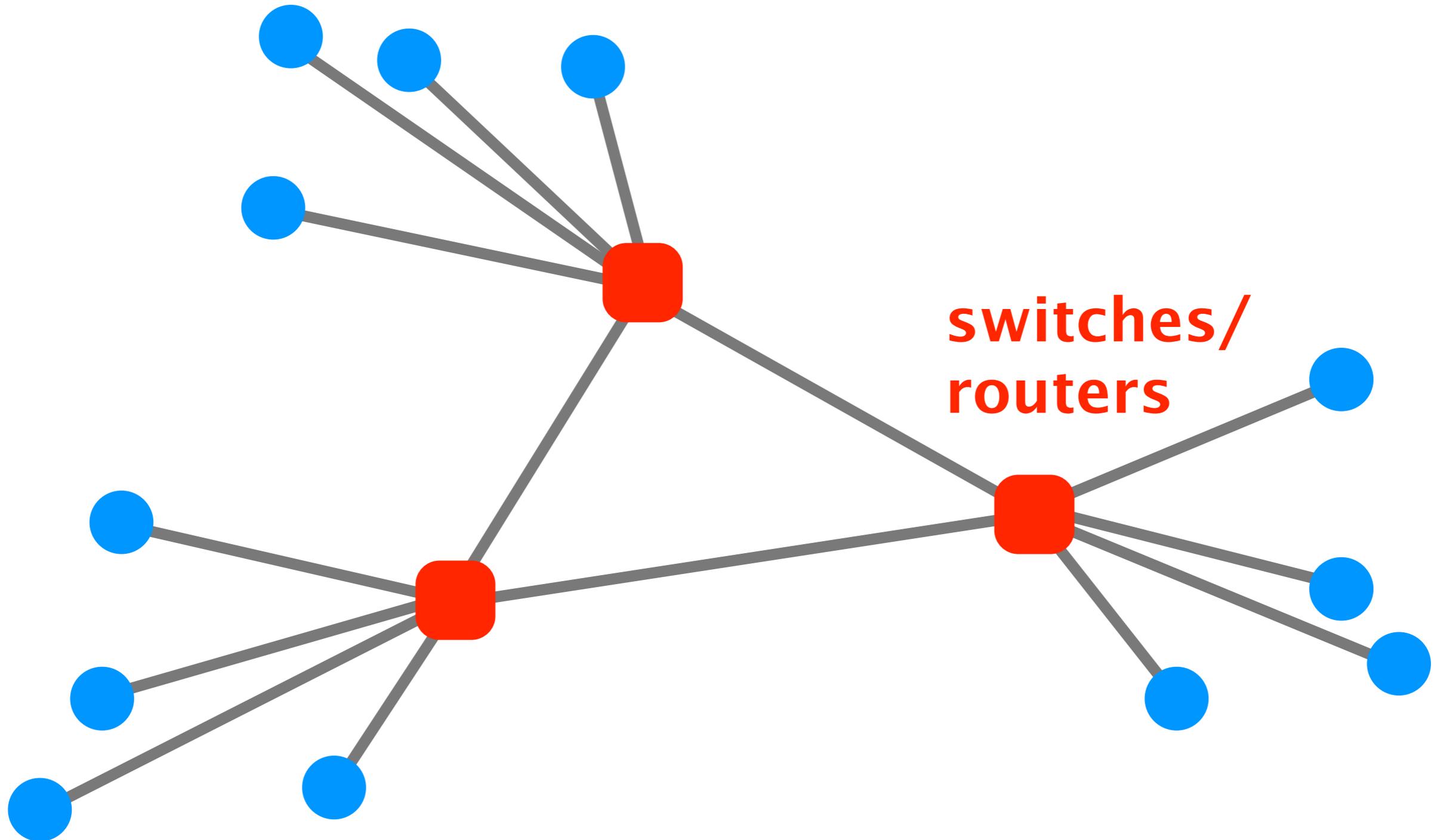
End-systems send & receive data



End-systems come in a wide-variety



Switches & routers forward data to the destination



# Routers vary in size and usage

Home  
router



~20 cm

0,5 kg

1 Gbps

Internet core  
router

>200cm

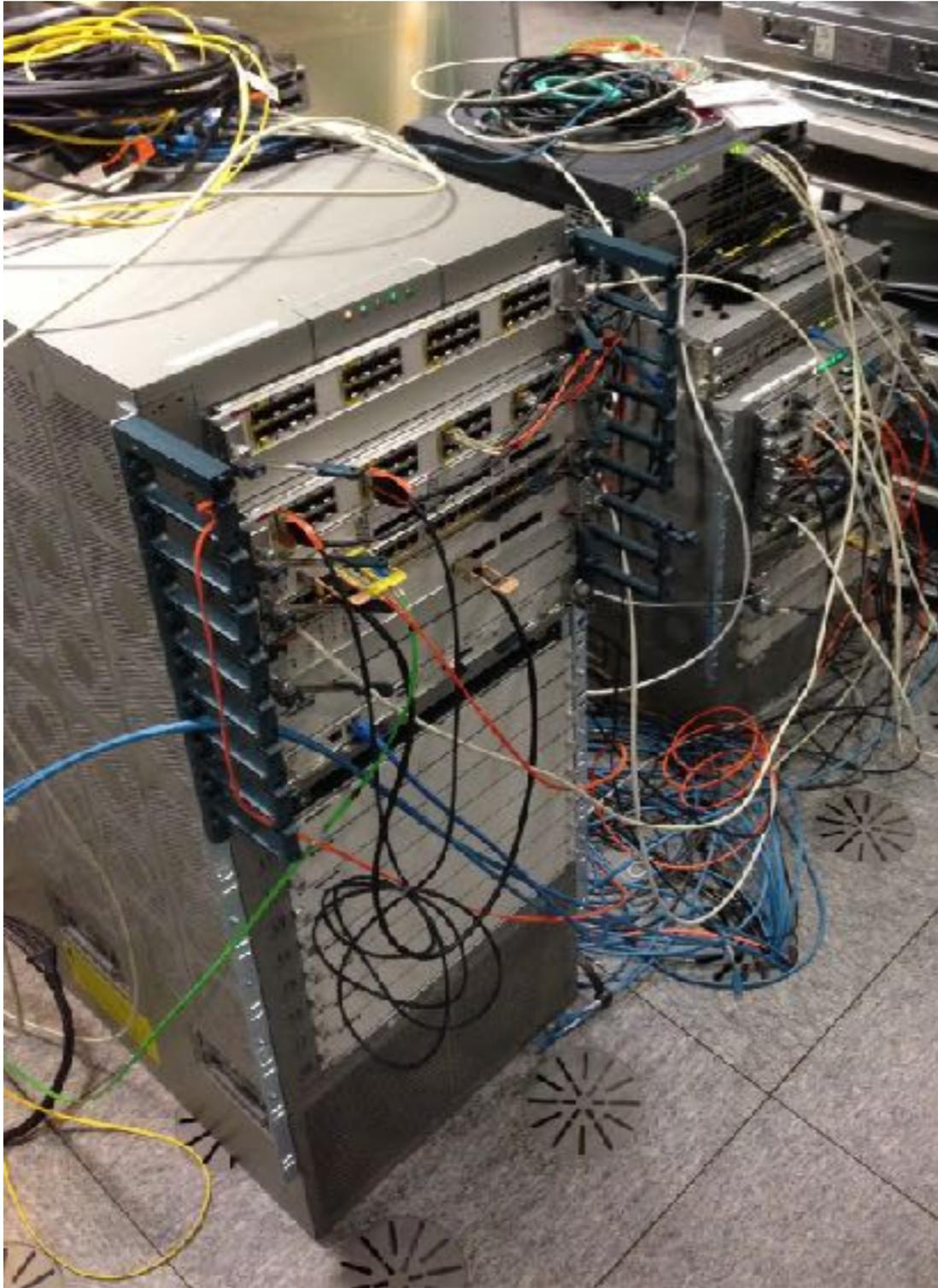
700kg

>12 Tbps

(>920 Tbps in  
multi-chassis\*)



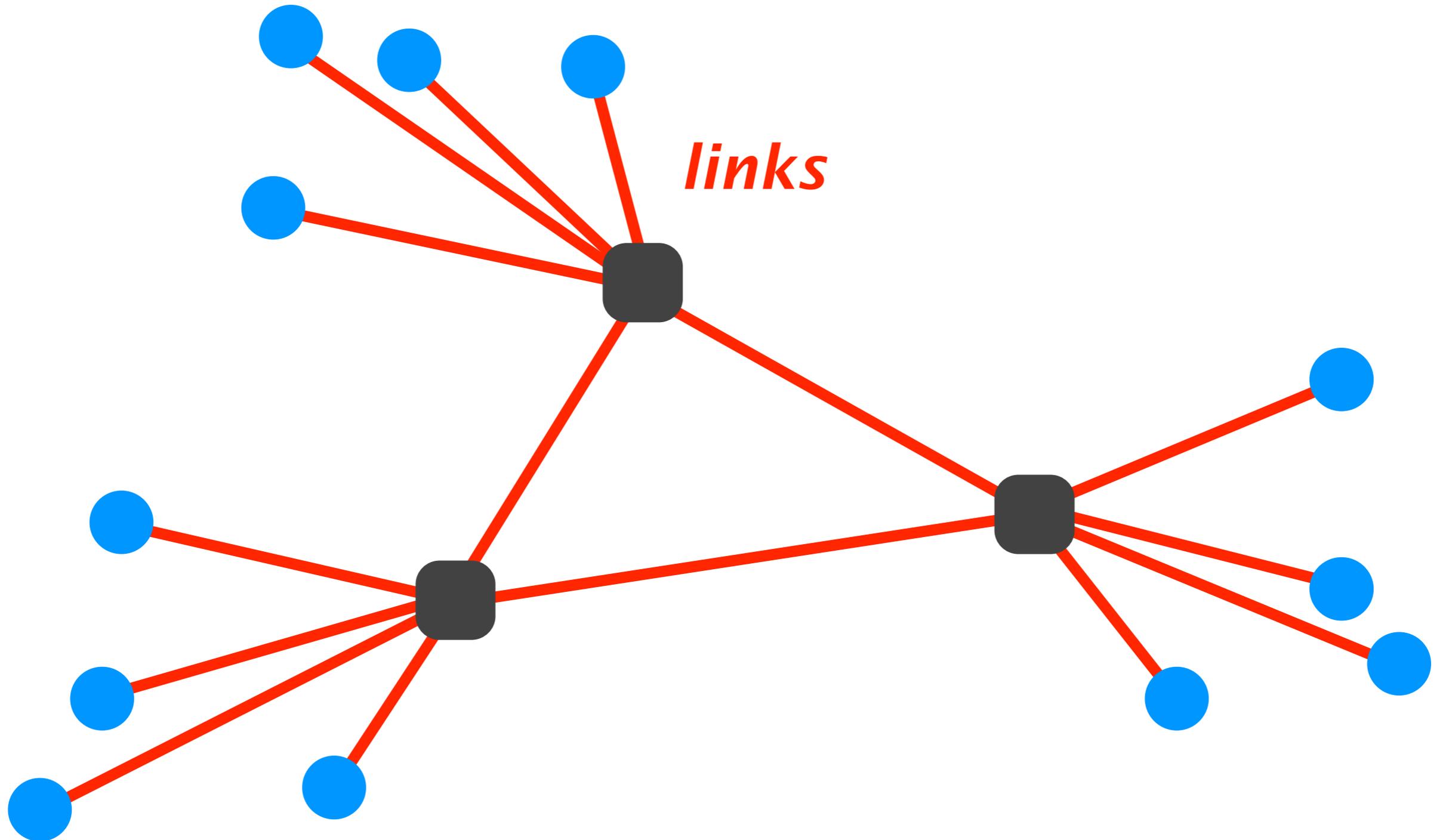
\*[https://www.cisco.com/c/en/us/products/collateral/routers/carrier-routing-system/data\\_sheet\\_c78-726136.html](https://www.cisco.com/c/en/us/products/collateral/routers/carrier-routing-system/data_sheet_c78-726136.html)



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,...



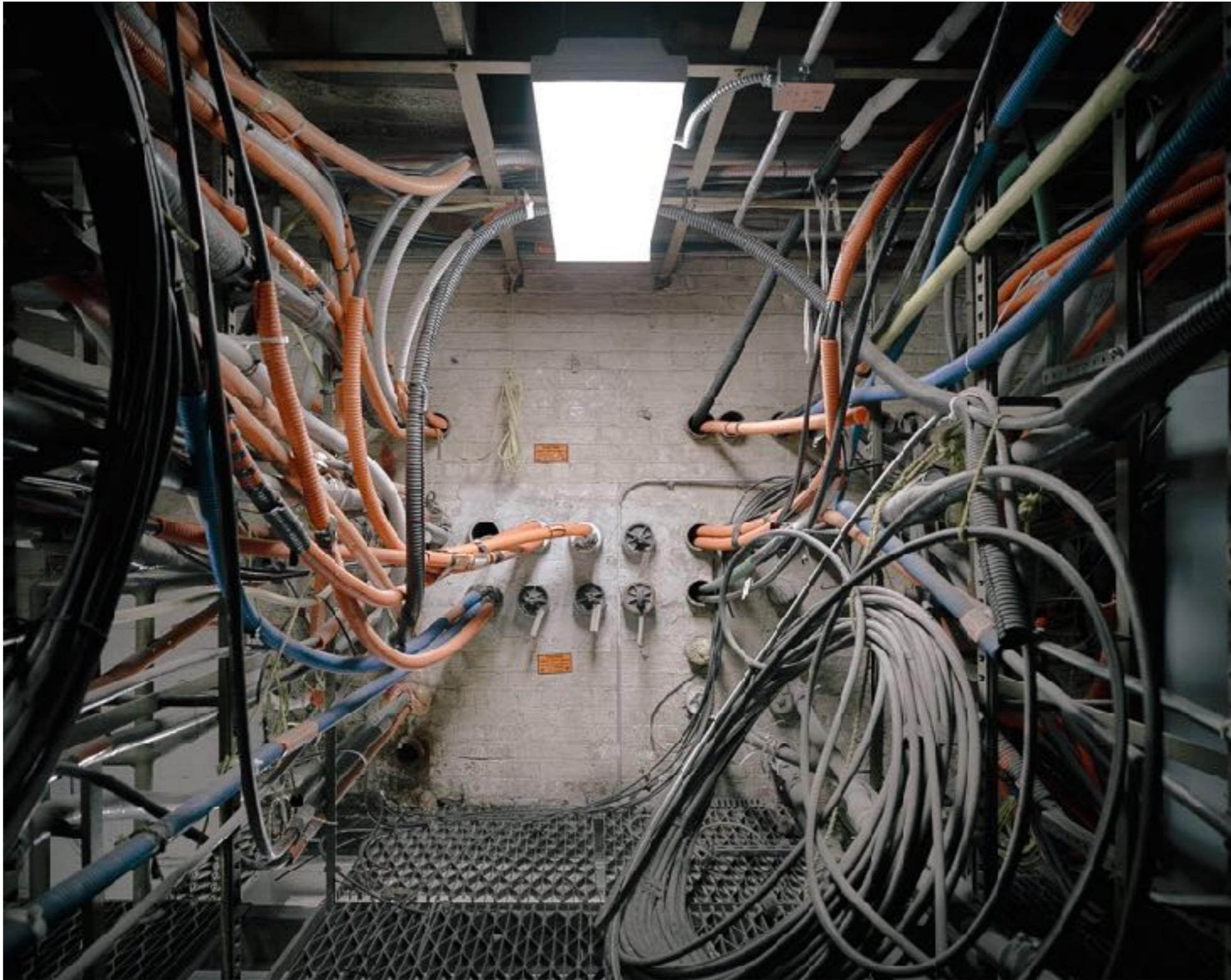
Optical fibers



Wireless link



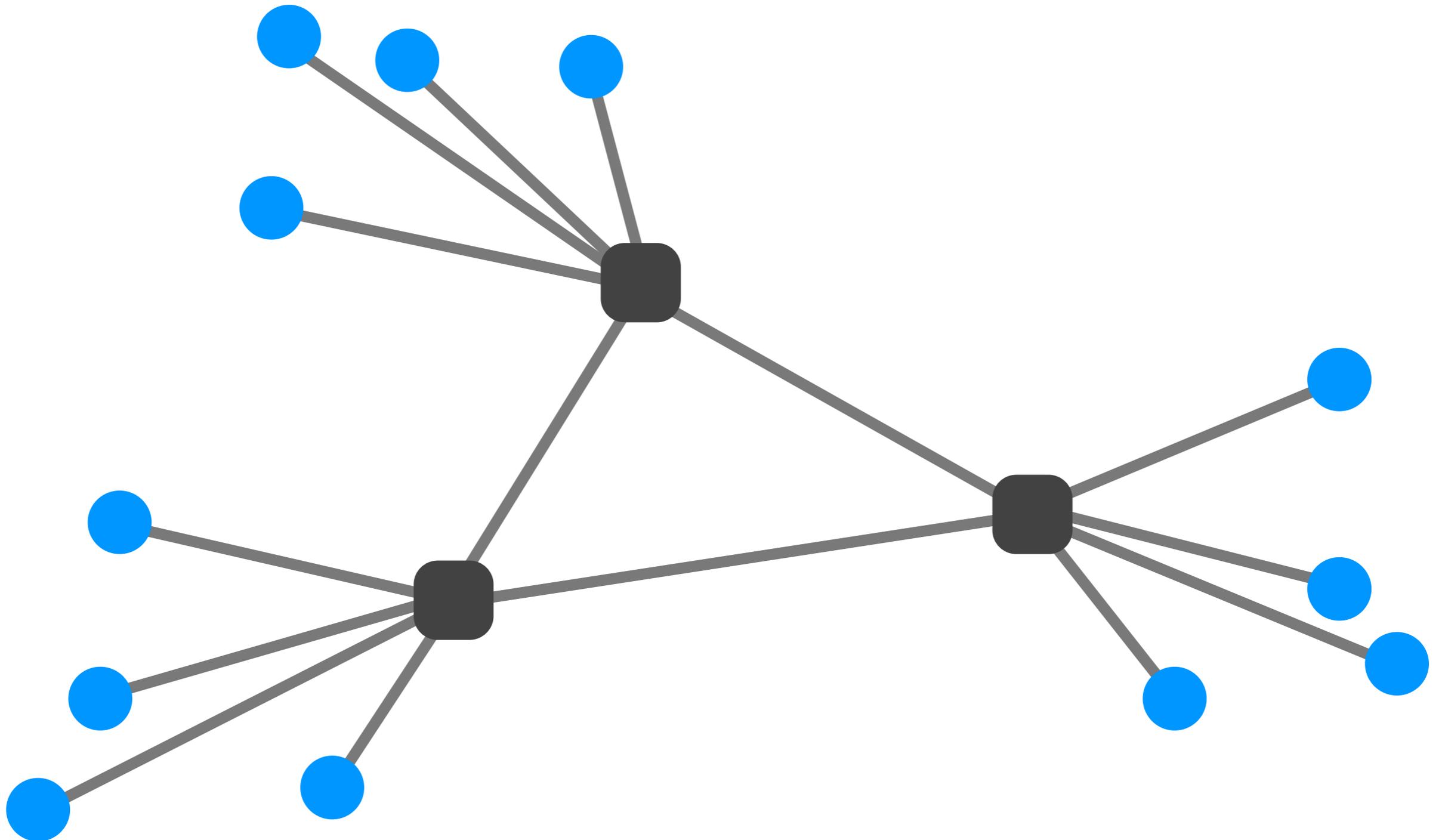




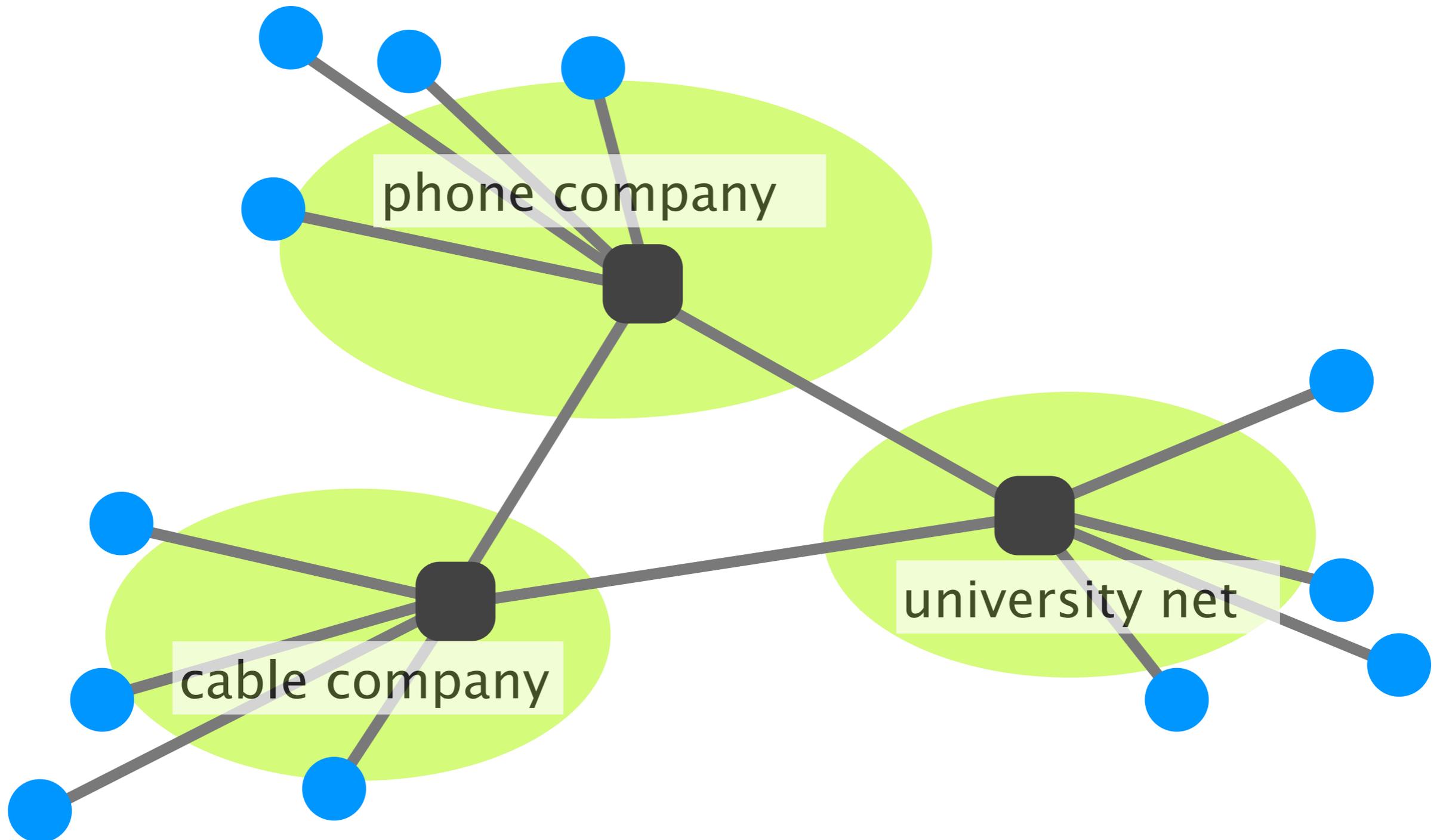
Somewhere in Manhattan...

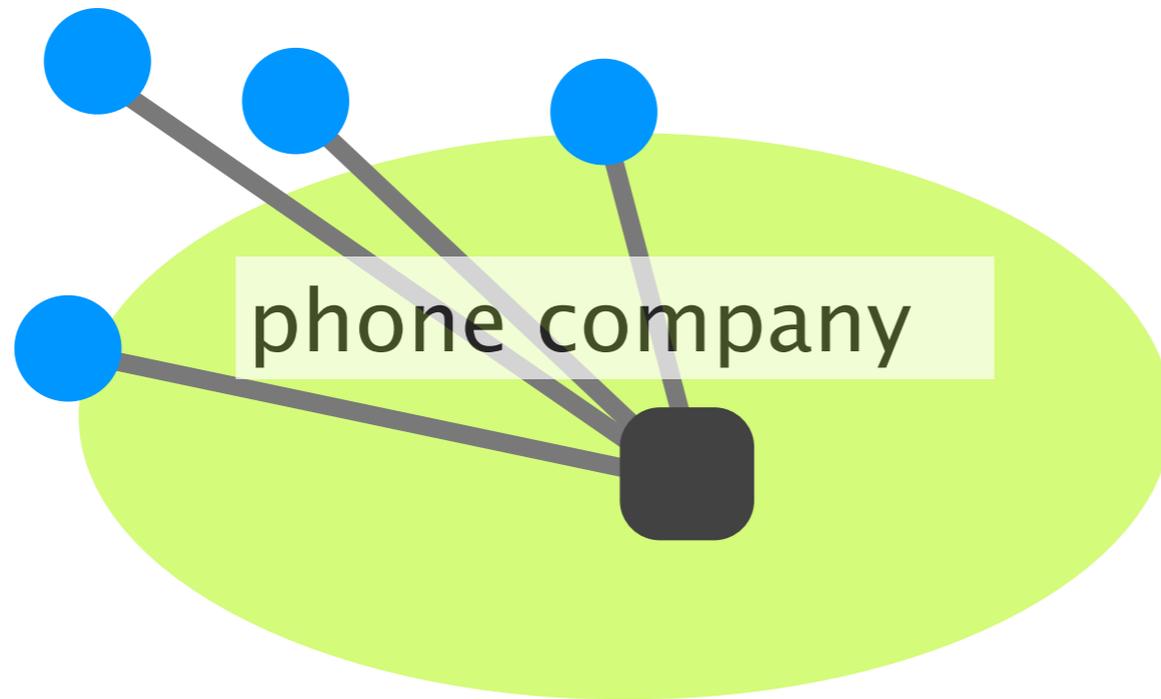
<http://www.petergarritano.com/the-internet.html>

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?**



DSL is composed of 3 channels:

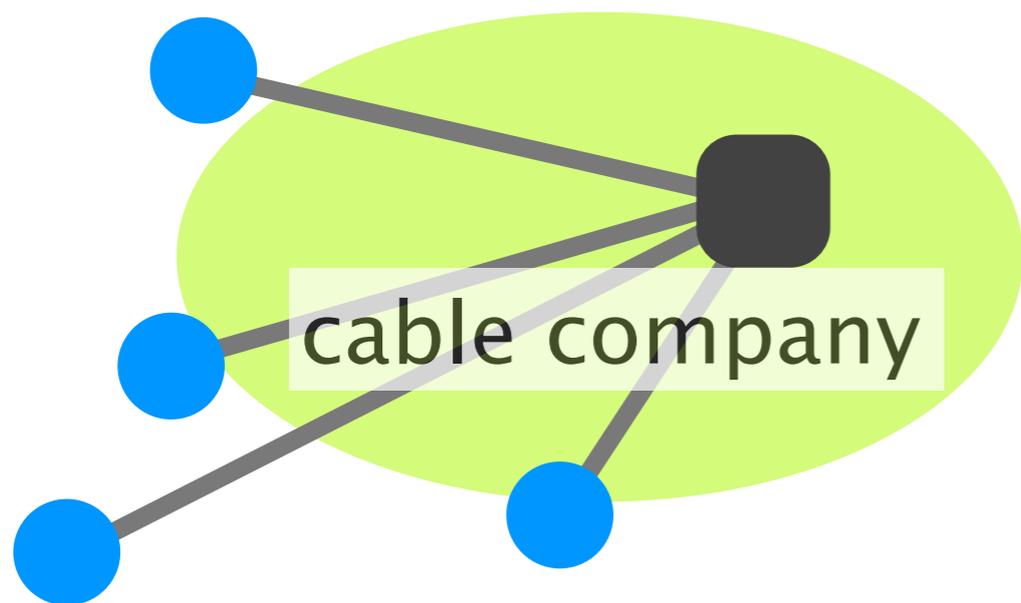
- downstream data channel
- upstream data channel
- 2-ways phone channel

**tens to few hundred Mbps**

**few Mbps to few tens Mbps**



**Why is there such an asymmetry?**



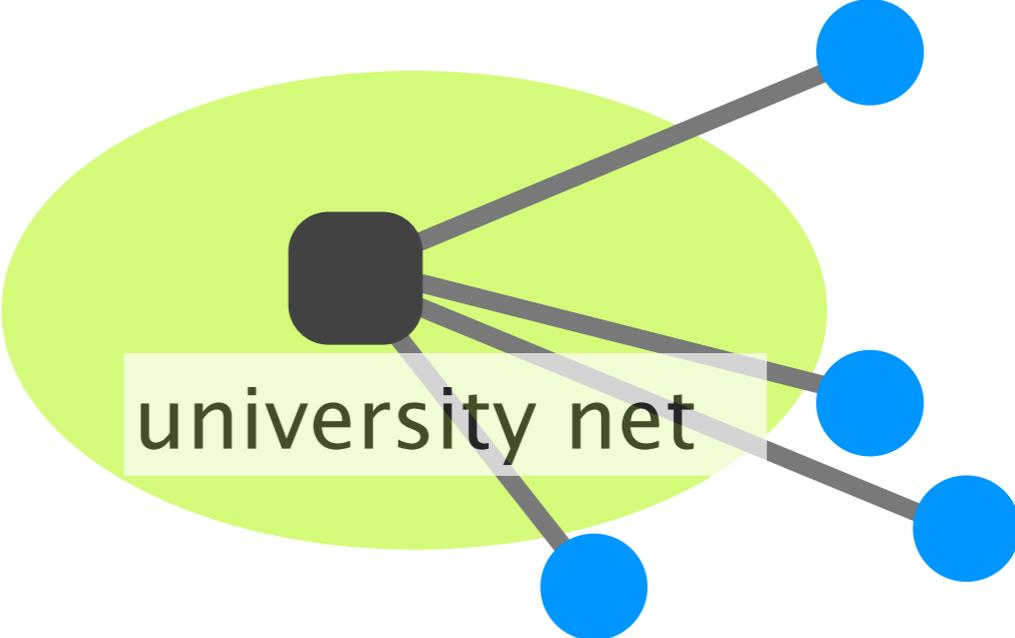
# Cable Access Technologies (CATV) brings high BW to the households via cable TV



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

1 Gbps, 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

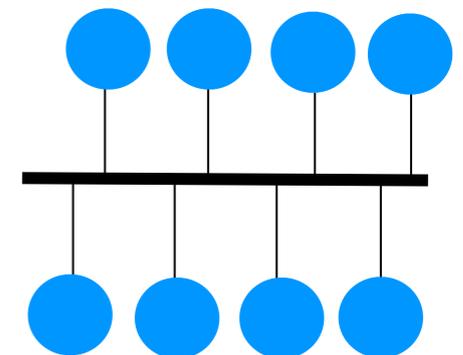
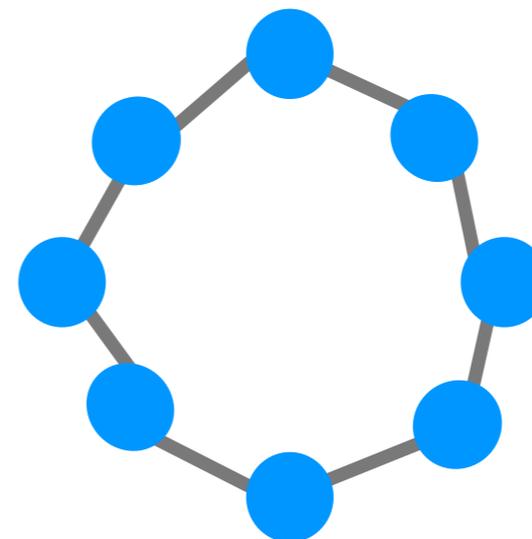
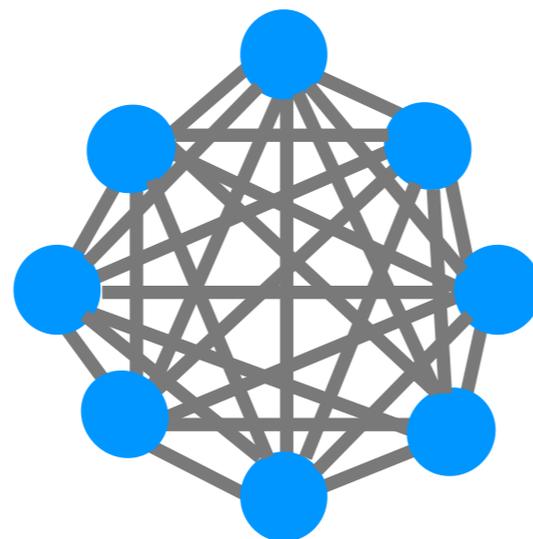
# Compare these three designs in terms of **sharing**, **resiliency**, and **per-node capacity**

design

full-mesh

chain

bus



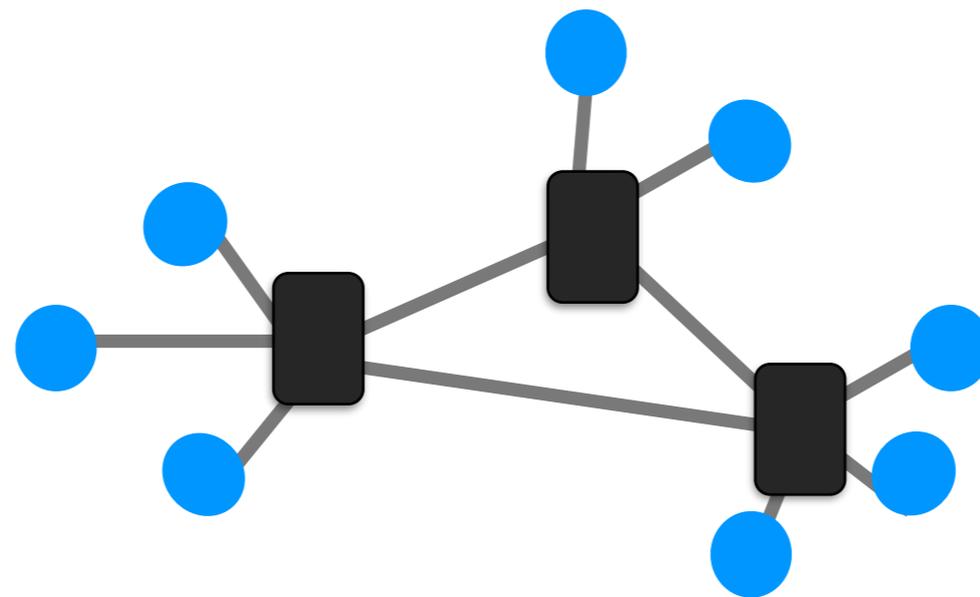
advantages

disadvantages

# Switched networks provide **reasonable** and **flexible** compromise

design

switched



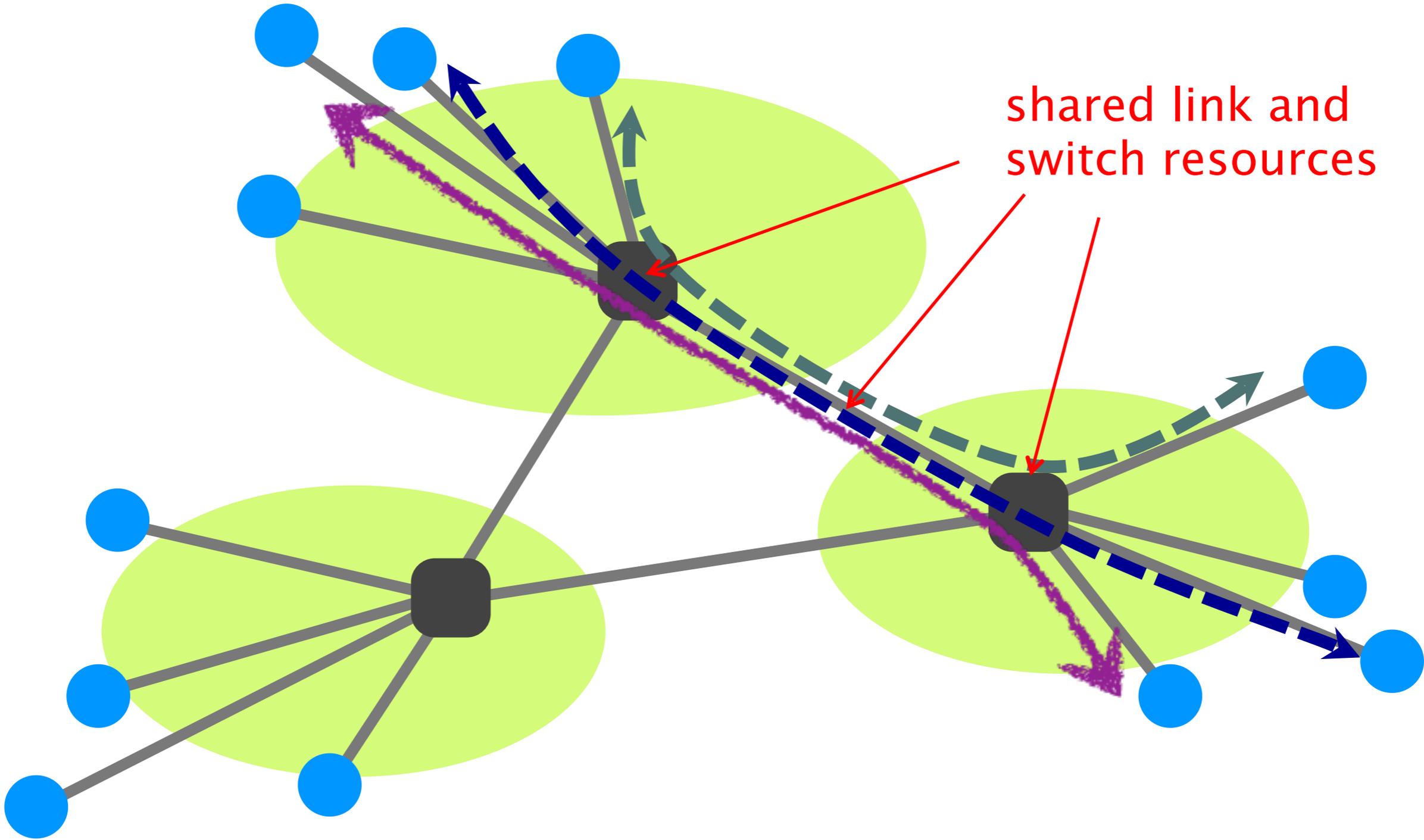
advantages

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

disadvantages

require smart devices to perform:  
forwarding, routing, **resource allocation**

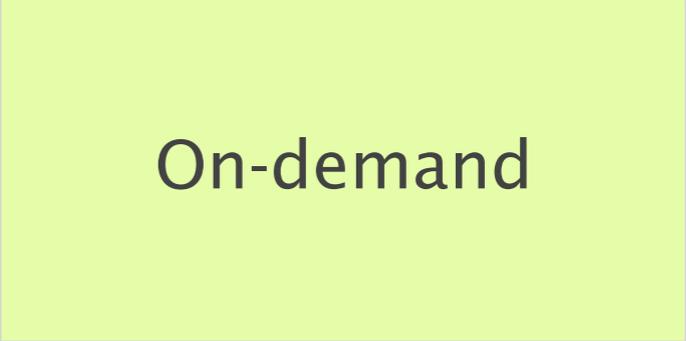
# Links and switches are shared between flows



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



Reservation



On-demand

principle

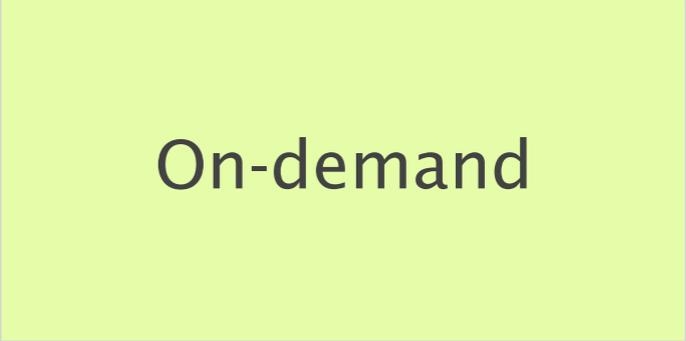
reserve the bandwidth  
you need in advance

send data when you need

Both are examples of **statistical multiplexing**



Reservation



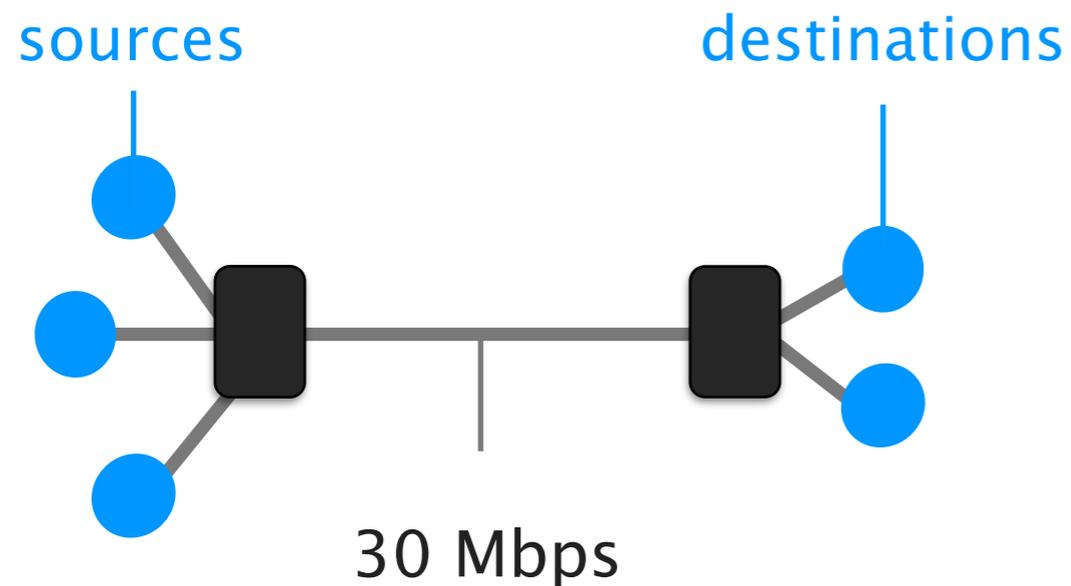
On-demand

multiplexing

**at the flow-level**

**at the packet-level**

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

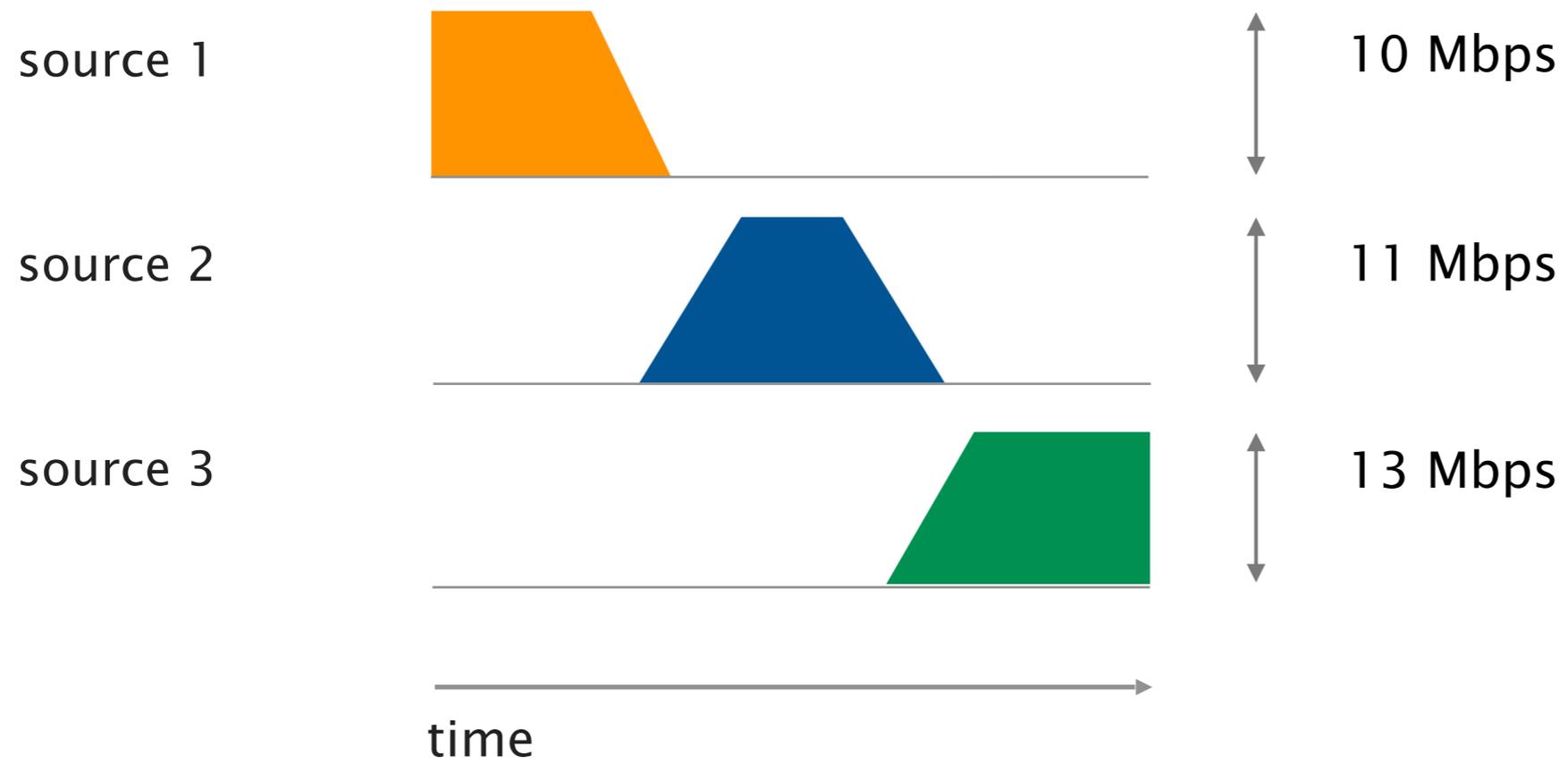


Consider that each source  
needs 10 Mbps

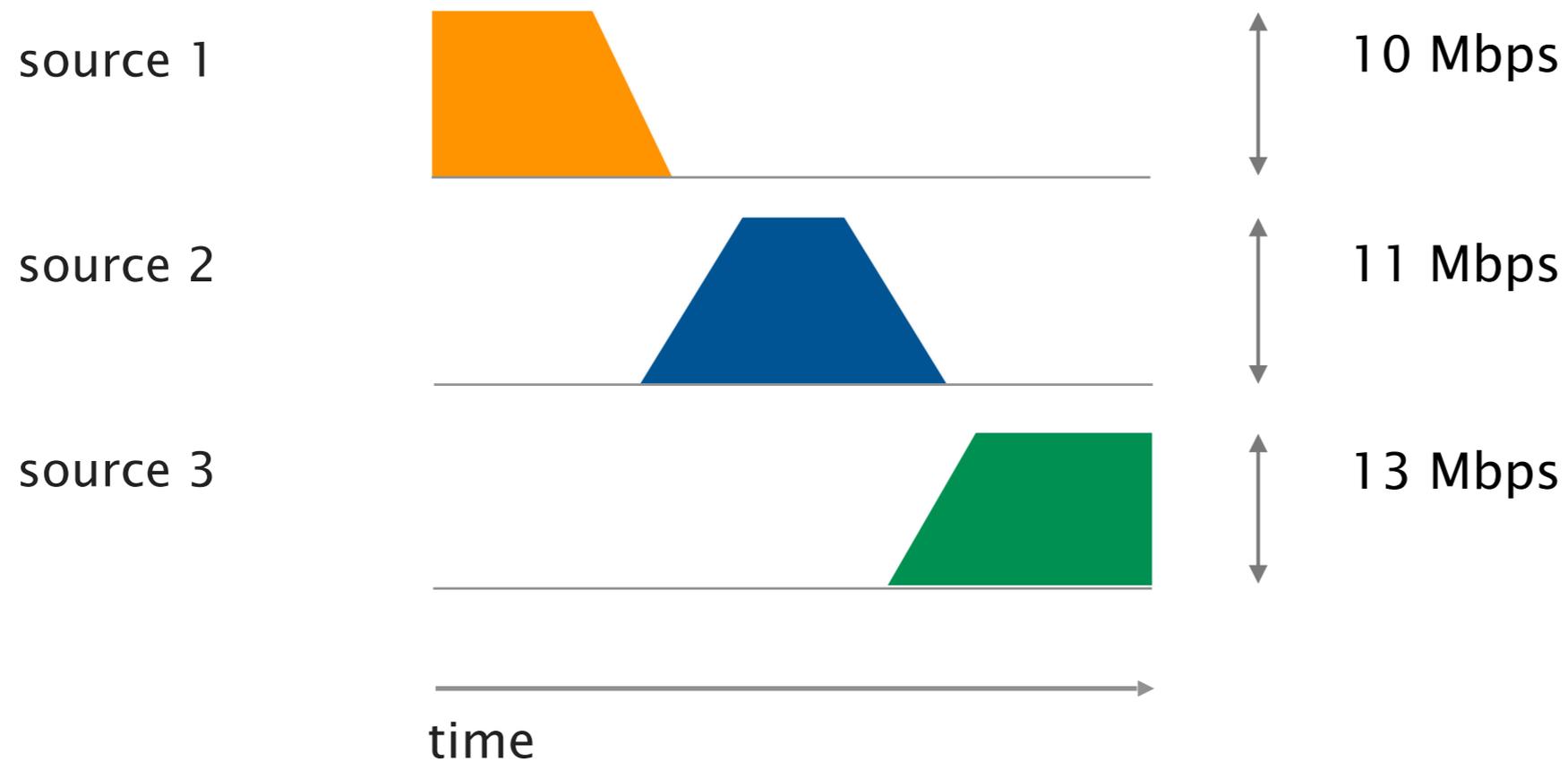
What do they get with:

- 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

Reservation **makes sense** when  $P/A$  is small

voice traffic has a ratio of 3 or so

Reservation **wastes capacity** when  $P/A$  is big

data applications are bursty, ratios  $>100$  are common

**That's why the phone network used reservations**

**... and why the Internet does not!**

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



Reservation



On-demand

implem.

circuit-switching

packet-switching

Reservation

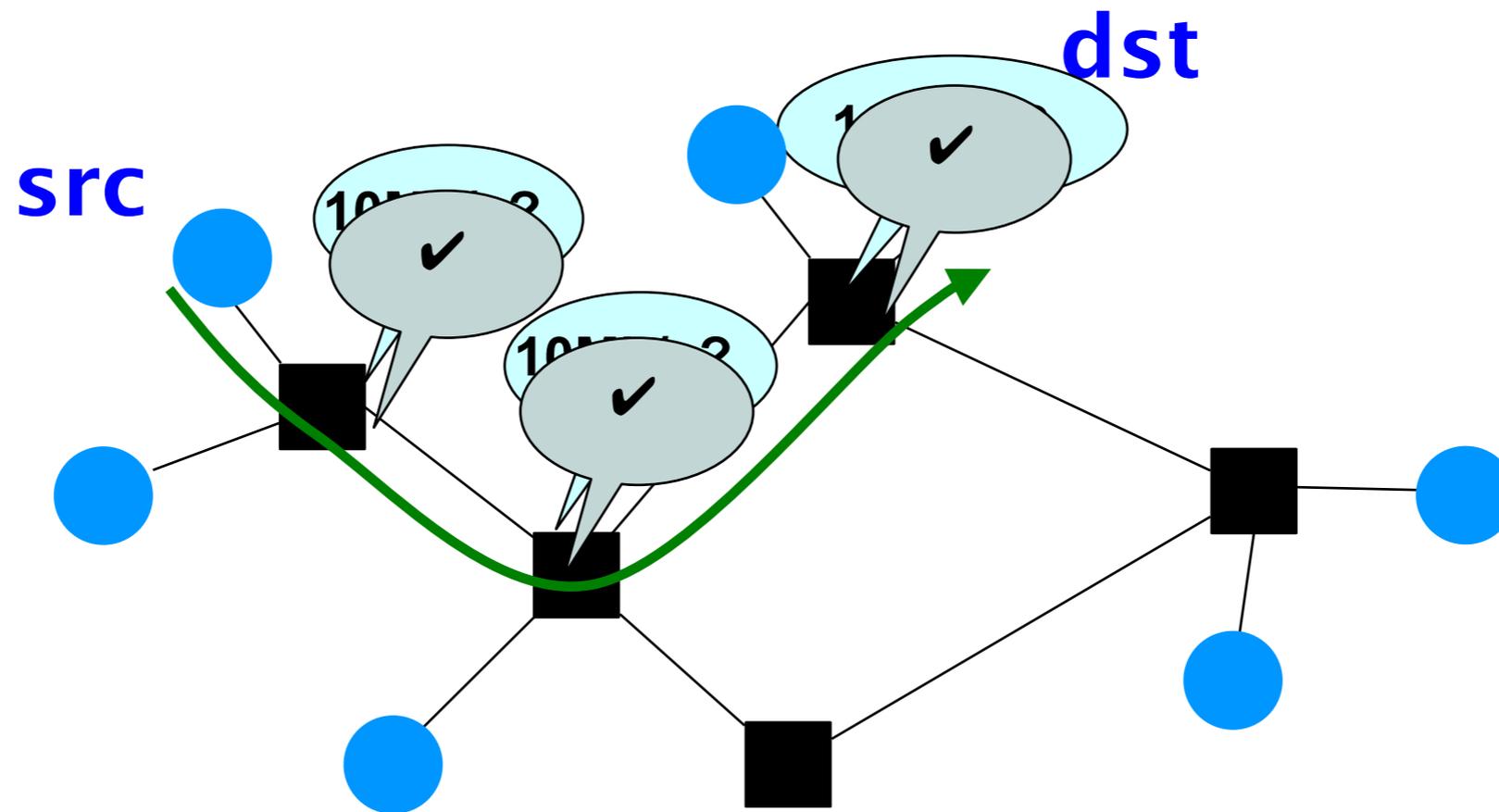
On-demand

implem.

circuit-switching

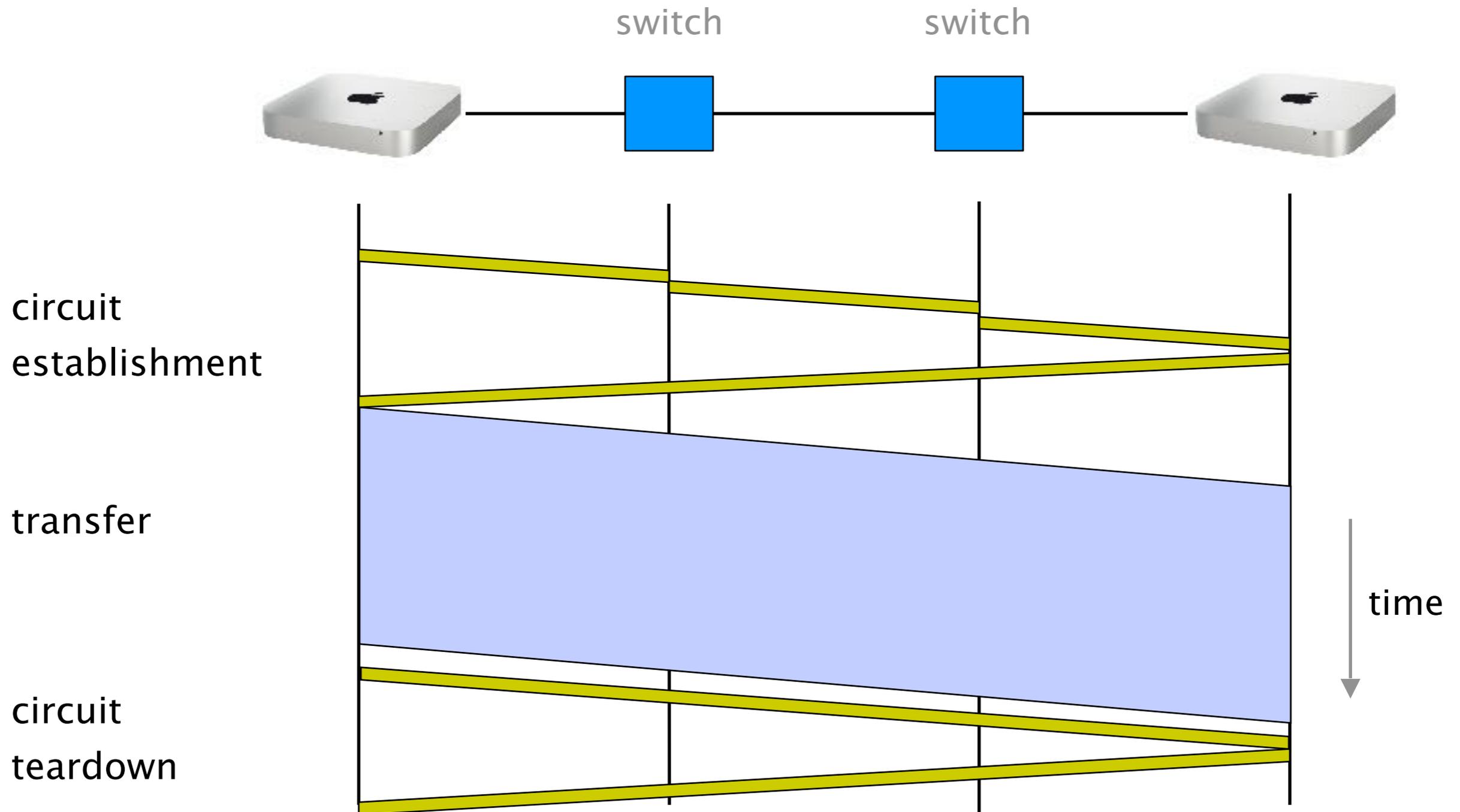
packet-switching

# 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

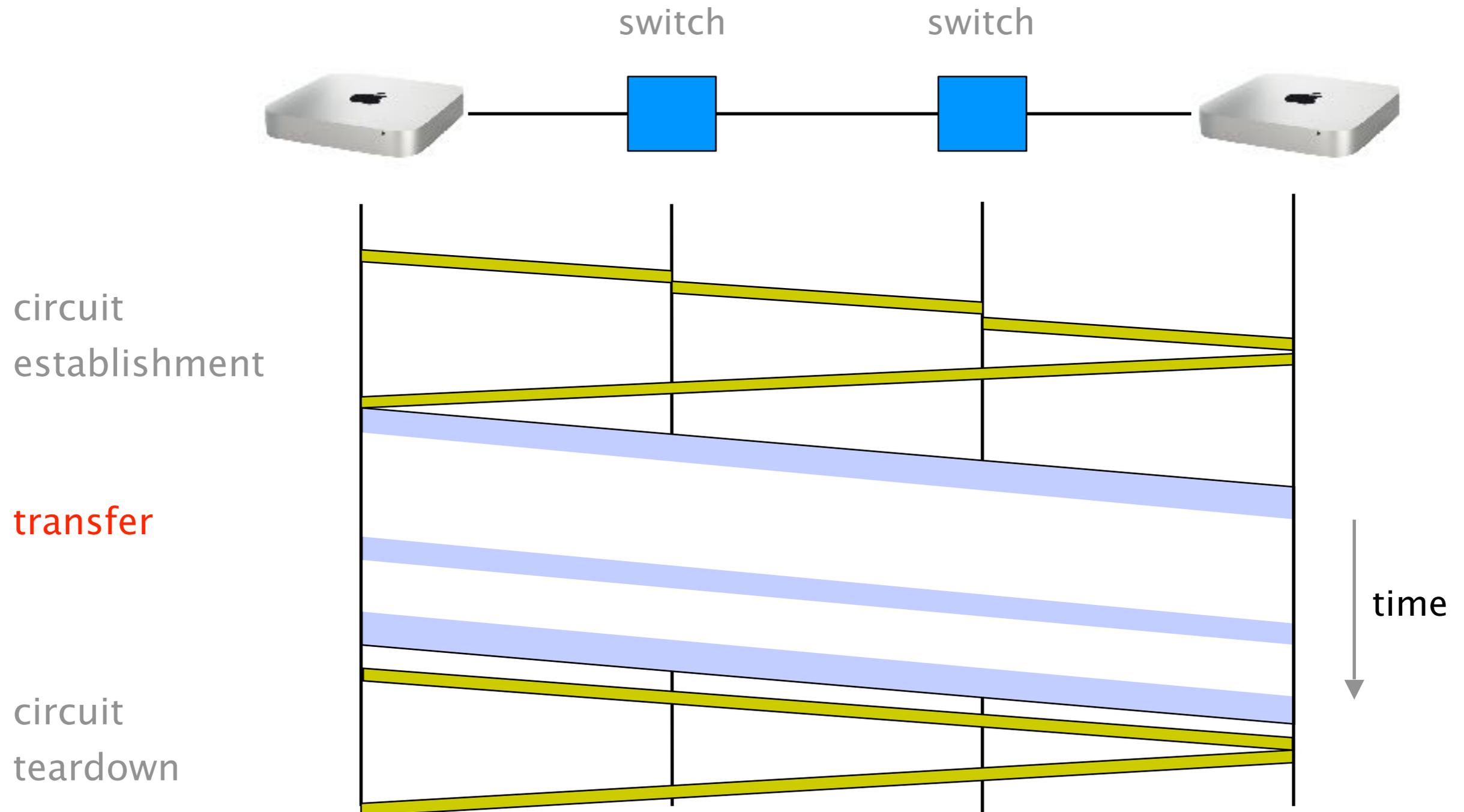
# Let's walk through example of data transfer using circuit switching



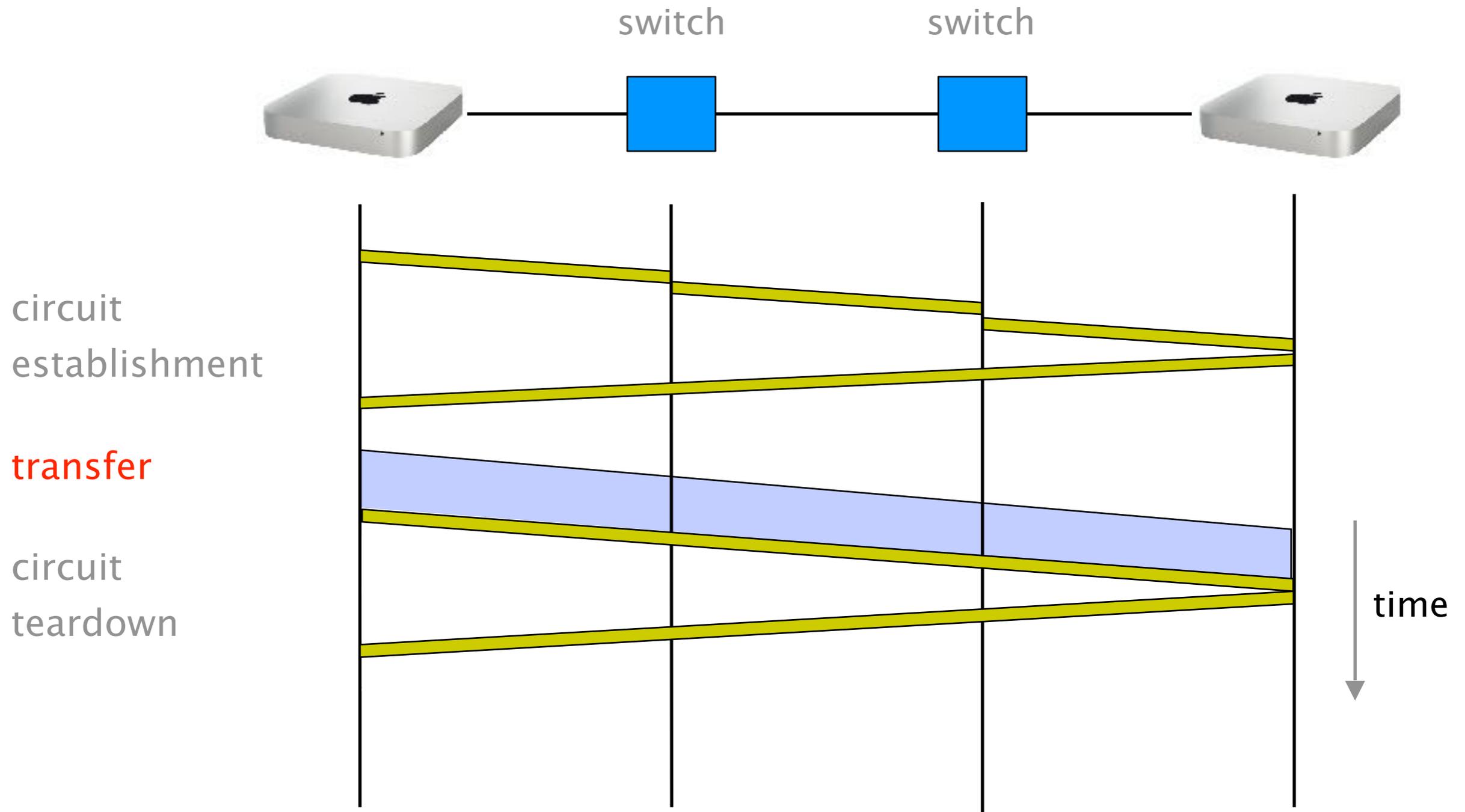
The efficiency of the transfer depends on how utilized the circuit is once established

This is an example of poor efficiency.

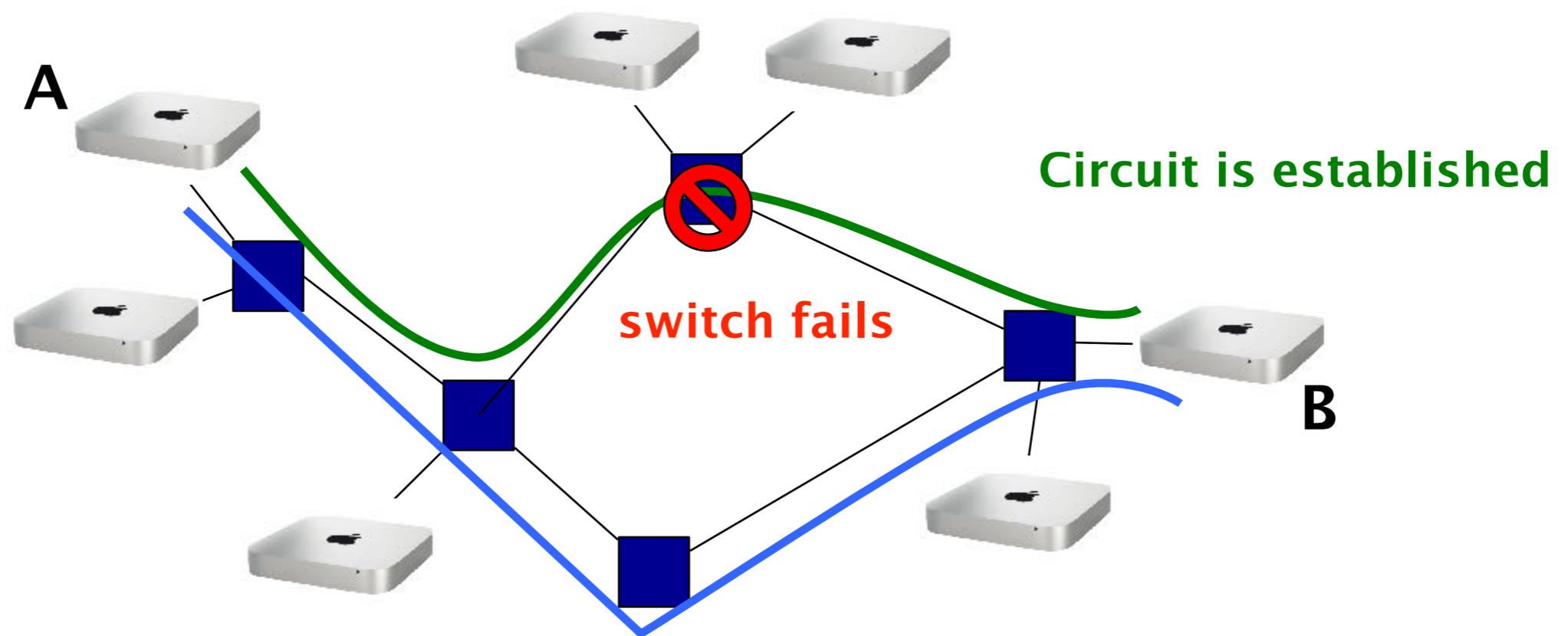
The circuit is mostly idle due to traffic bursts



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



A is forced to signal a new circuit to restore communication

# 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?

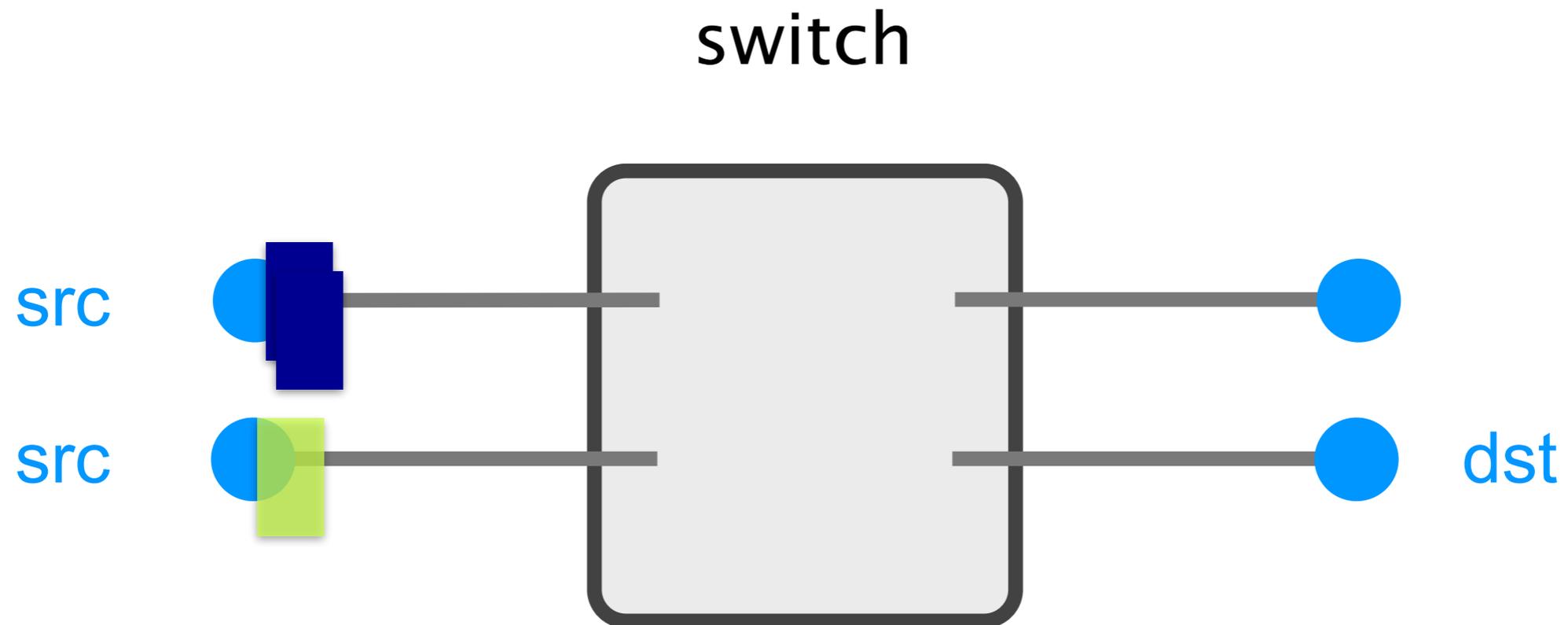
Reservation

circuit-switching

On-demand

packet-switching

In packet switching,  
data transfer is done using independent packets

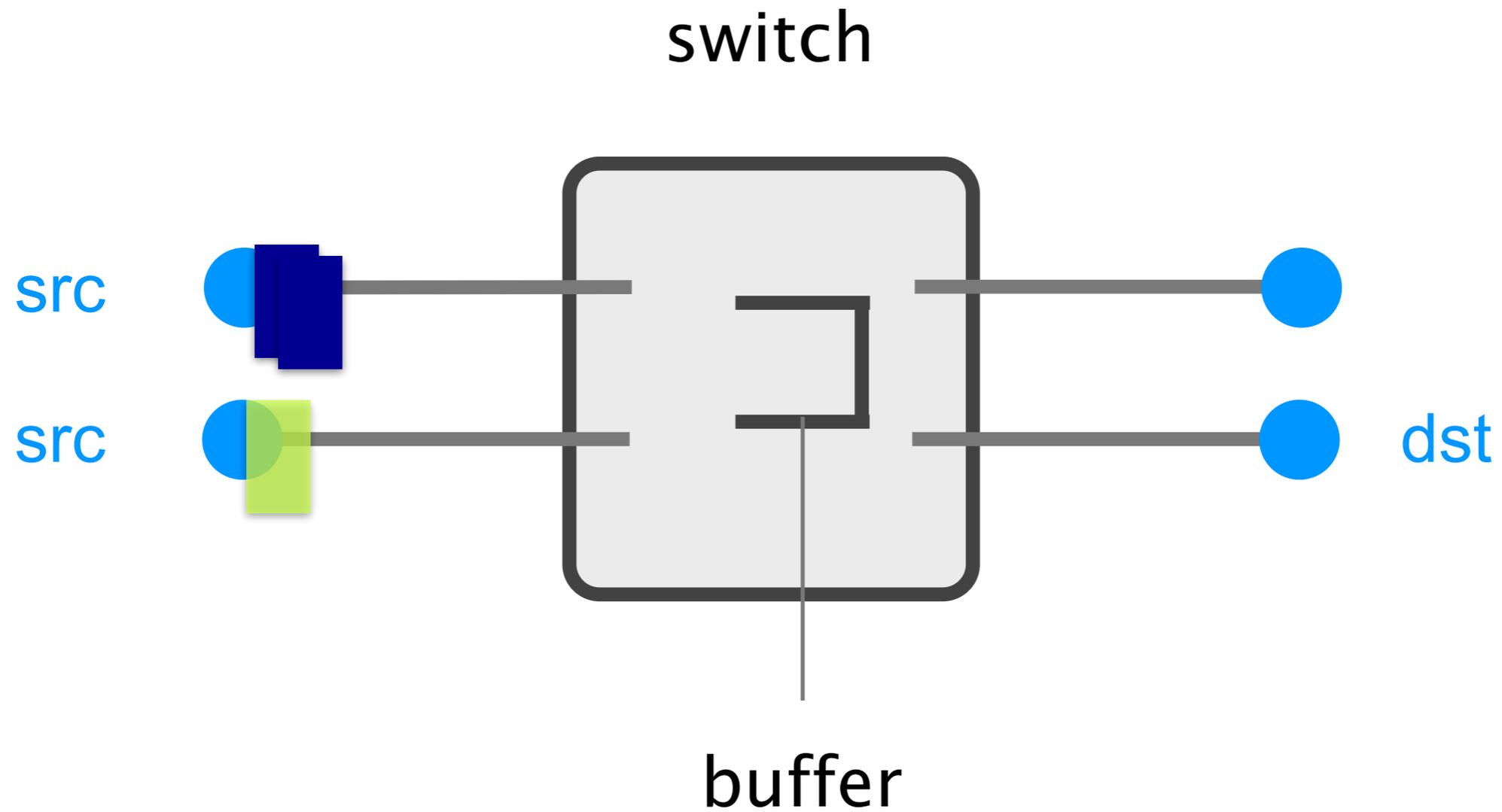


Each packet contains destination (**dst**)

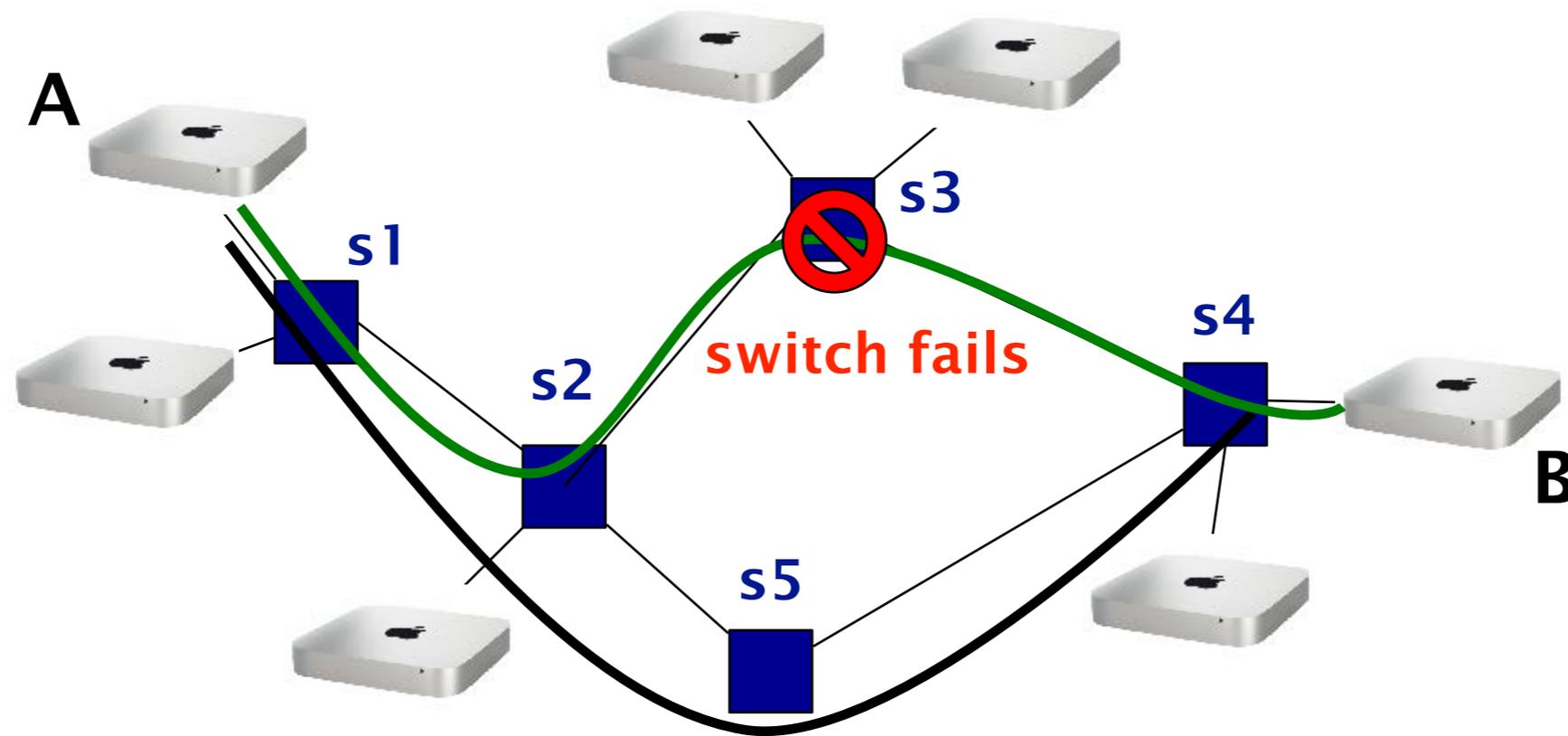
Since packets are sent without global coordination, they can “clash” with each other

To absorb transient overload,  
packet switching relies on buffers

To absorb transient overload,  
packet switching relies on buffers



# Packet switching routes around trouble



route recomputed  
on the fly by s2

# Pros and cons of packet switching

## advantages

efficient use of resources

simpler to implement

route around trouble

## disadvantages

unpredictable performance

requires buffer management and  
congestion control

Packet switching beats circuit switching  
with respect to *resiliency* and *efficiency*

Internet  packets

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

# Communication Networks

## Part 1: Overview



What is a network made of?

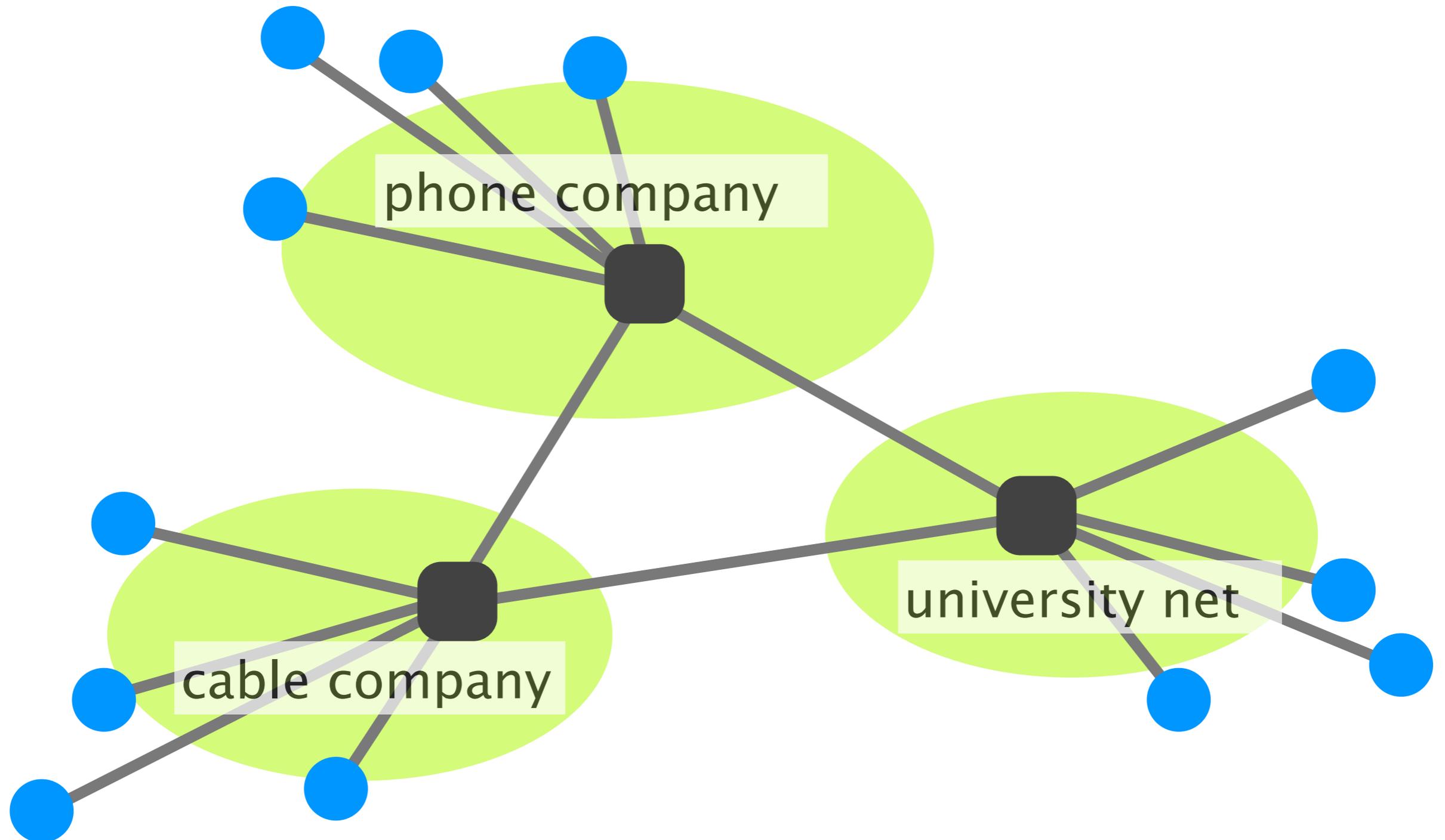
How is it shared?

**#3** **How is it organized?**

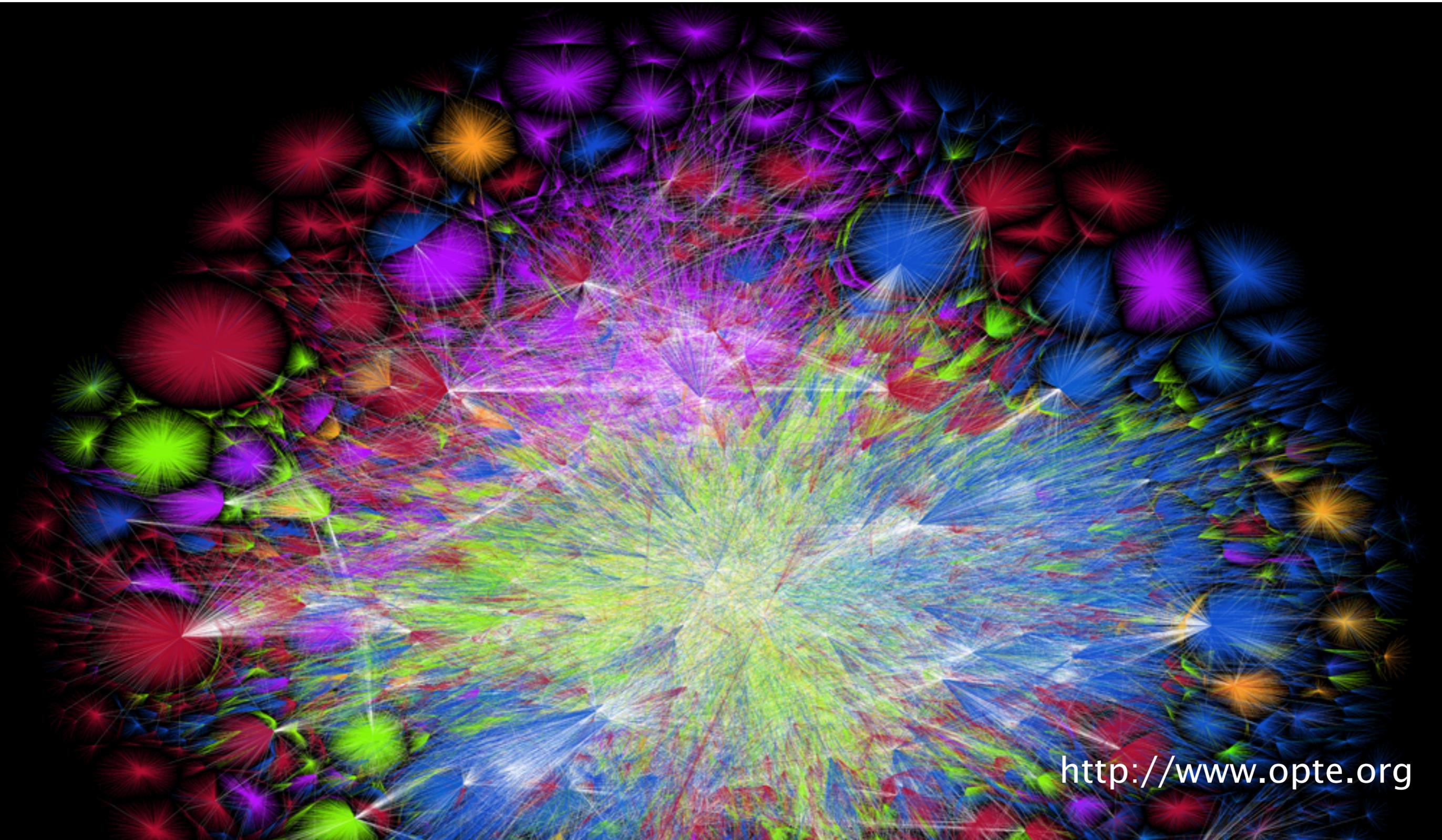
How does communication happen?

How do we characterize it?

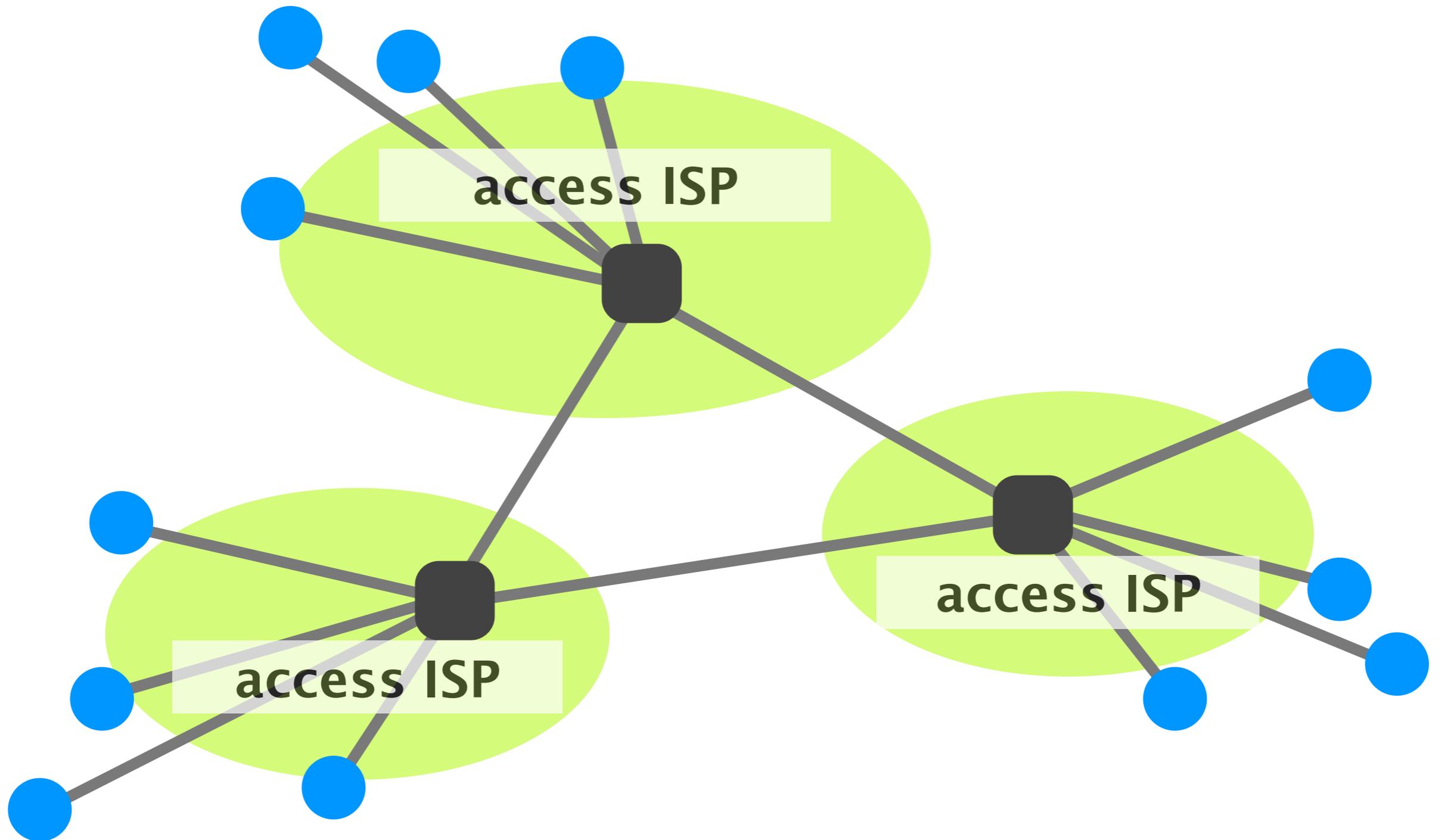
So far, this is our vision of the Internet...

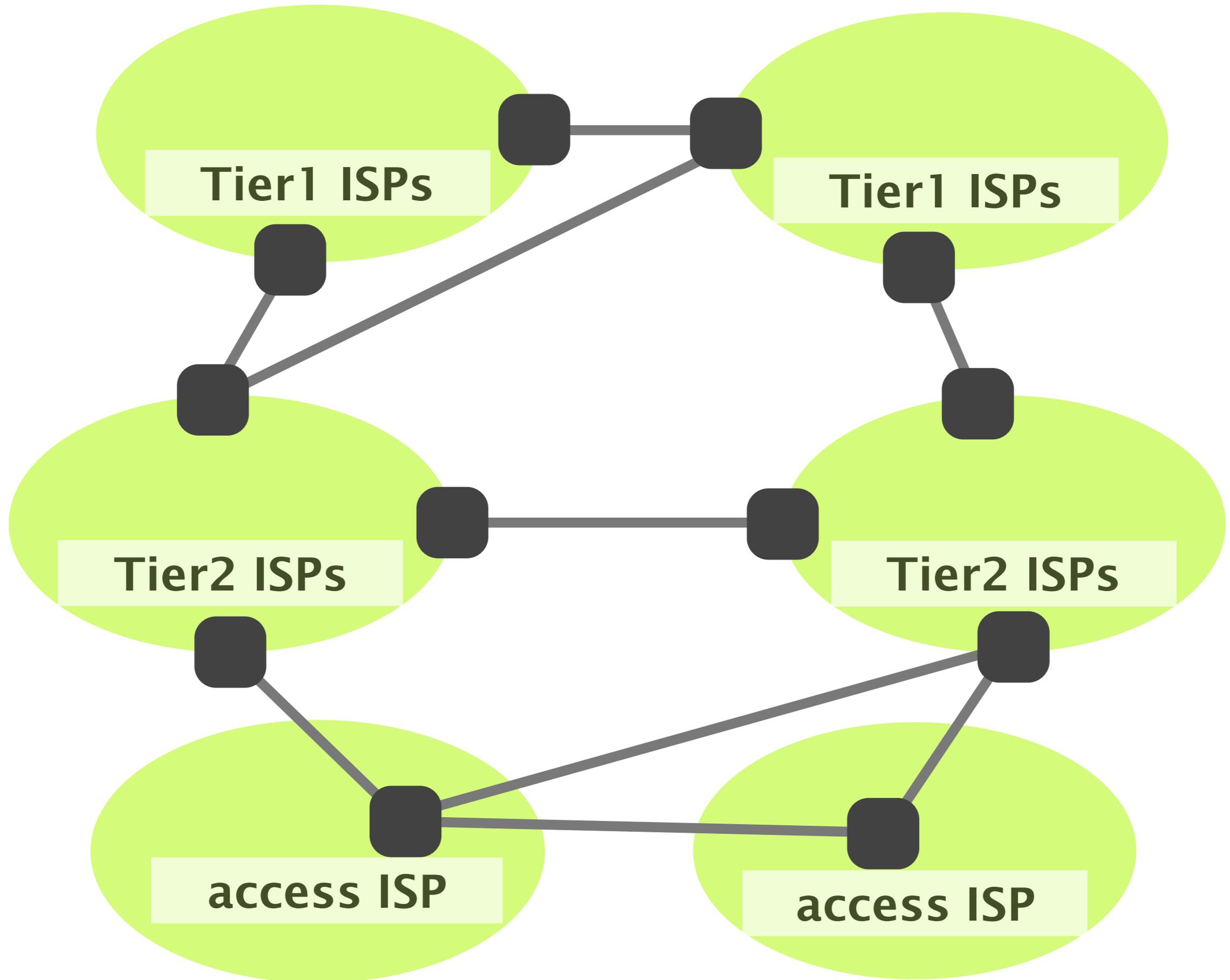


The real Internet is a “tad” more complex



<http://www.opte.org>





# The Internet has a hierarchical structure

Tier-1

international

have no provider

Tier-2

national

provide transit to Tier-3s

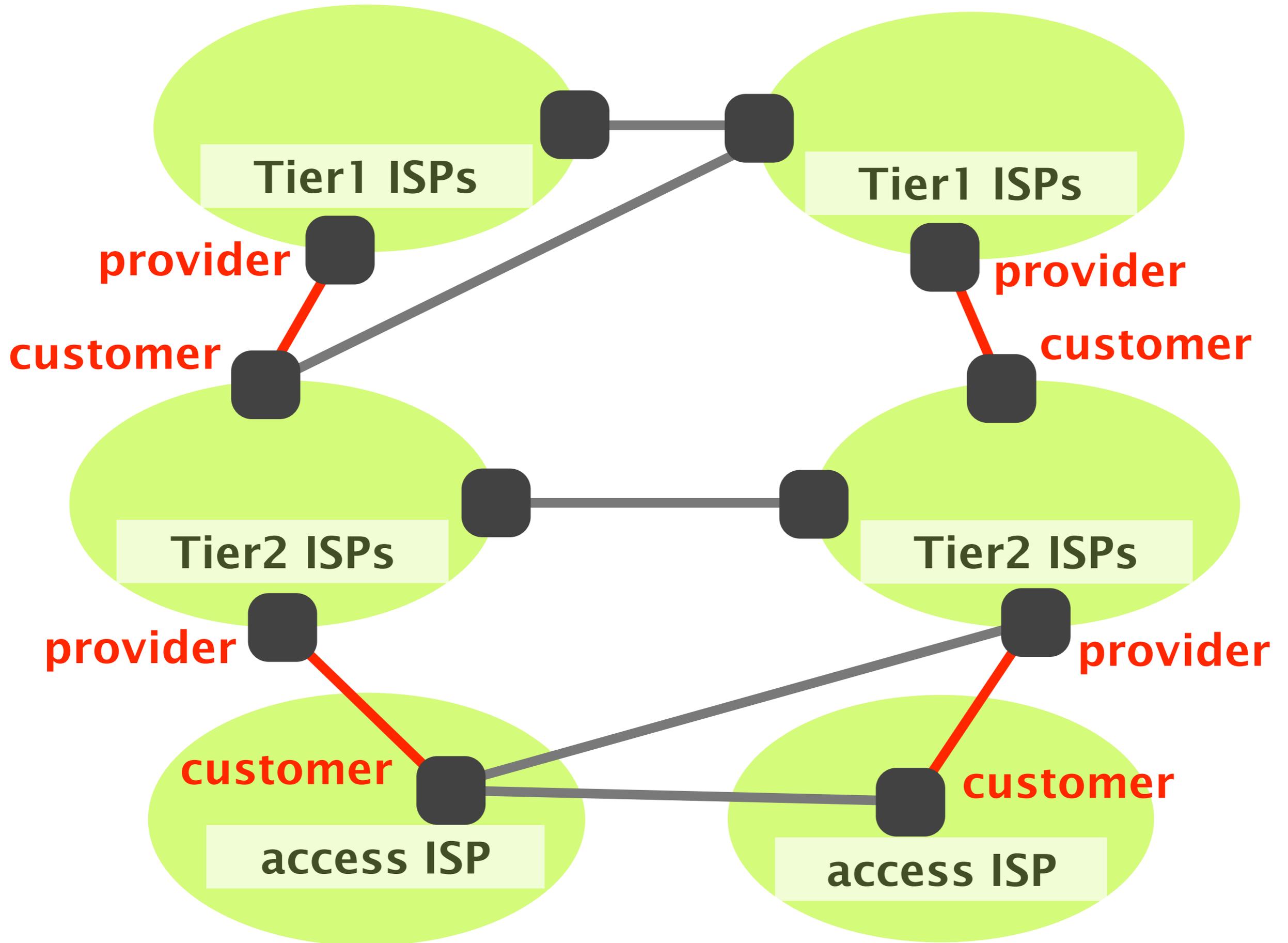
have at least one provider

Tier-3

local

do not provide any transit

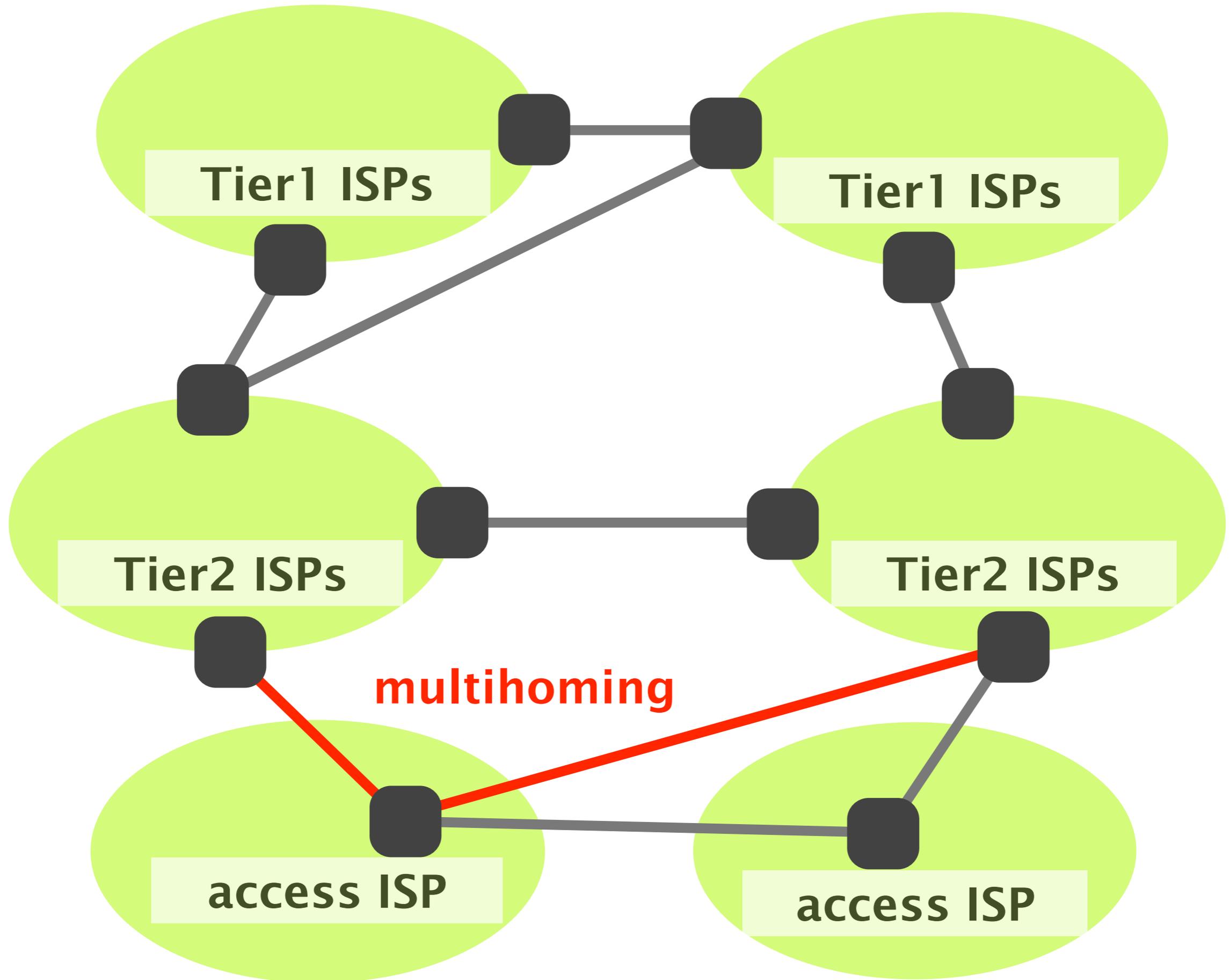
have at least one provider



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

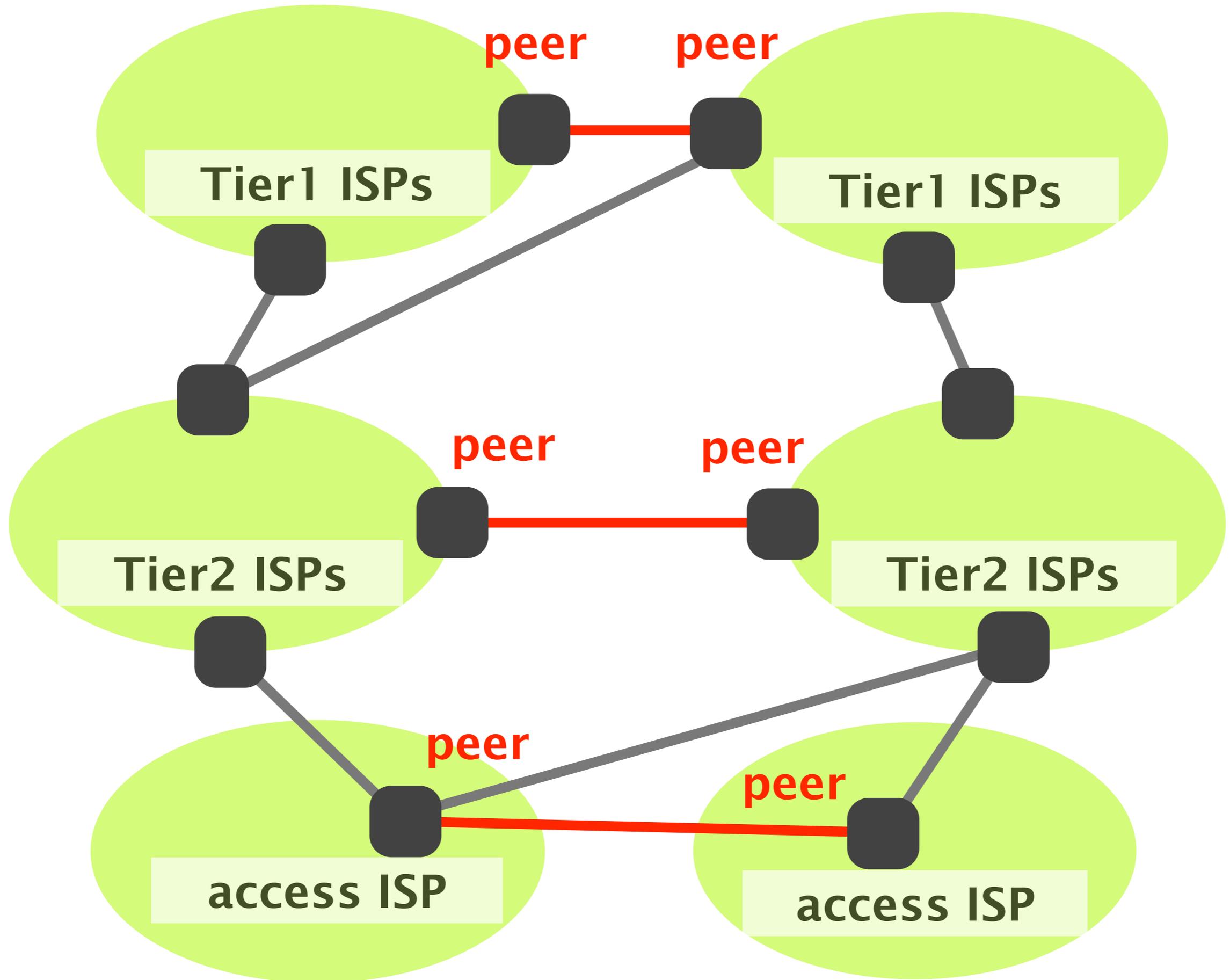
total ~50,000 networks

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

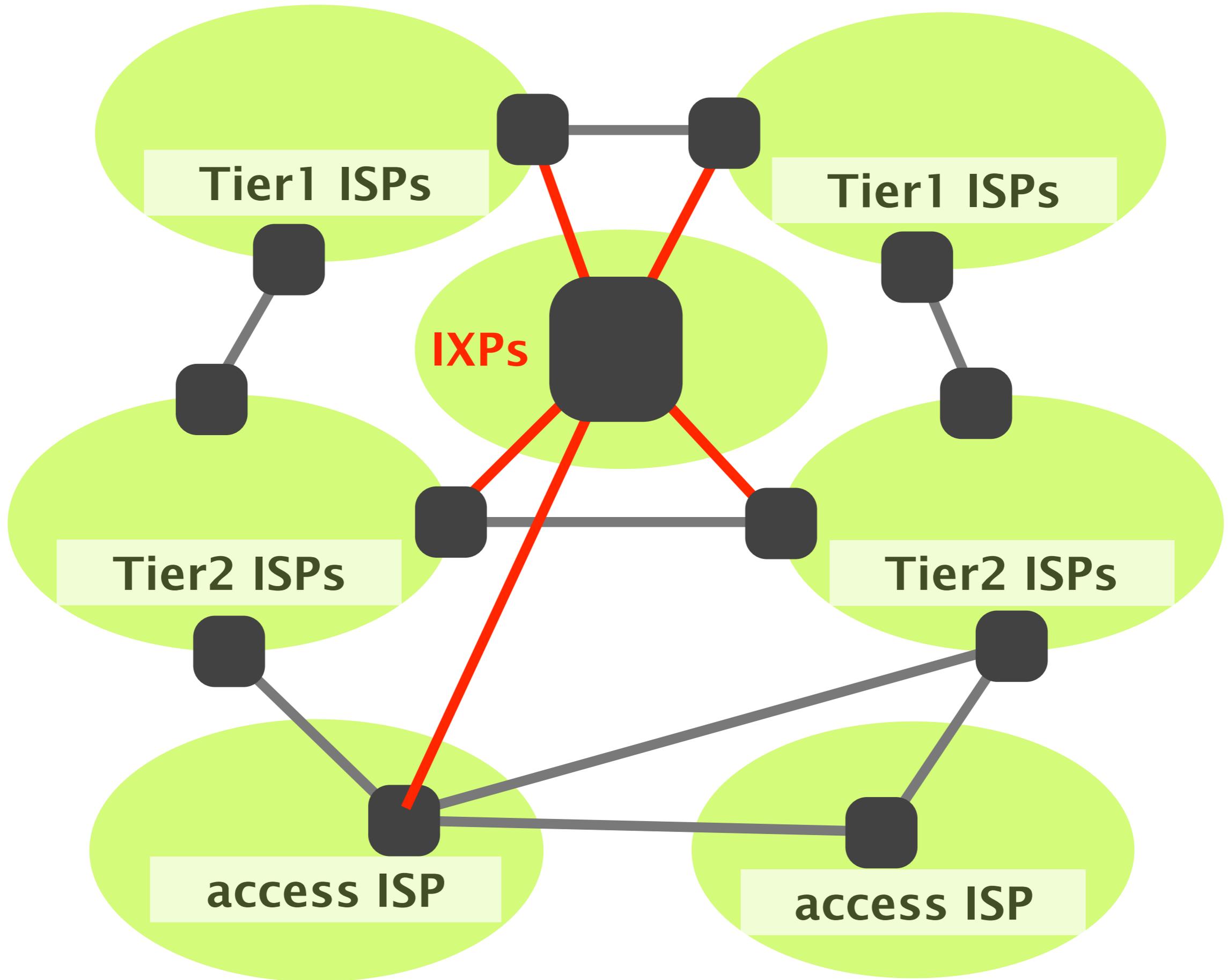
## Bandwidth costs

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

How can we design a **more resilient** network?

RAND

lead to the invention of packet switching

Len Kleinrock

How can we design a **more efficient** network?

UCLA

(also) lead to the invention of packet switching

Bob Kahn

How can we **connect** all these networks together?

DARPA

lead to the invention of the Internet as we know it

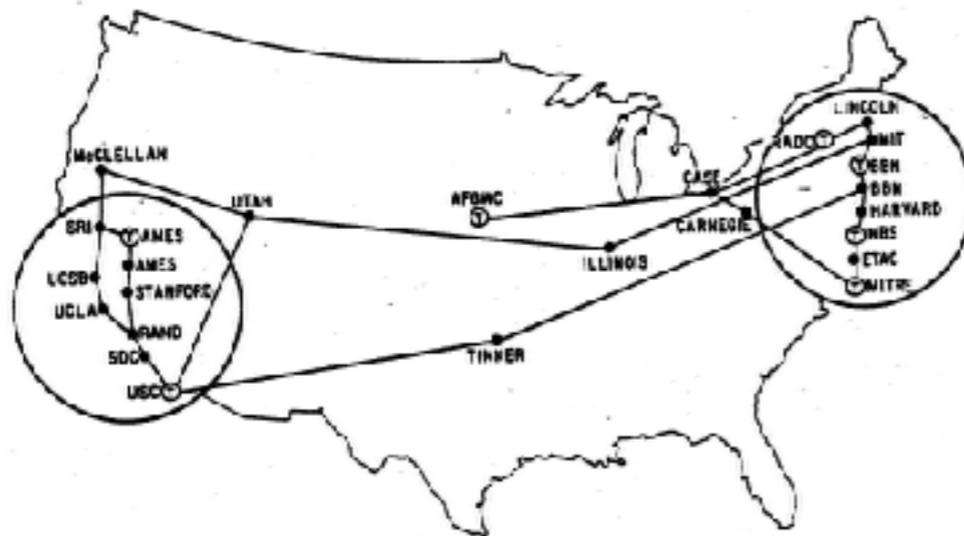
# The 60s saw the creation of packet switching and the **A**dvanced **R**esearch **P**rojects **A**gency **N**etwork



Dezember 1969



Juni 1970



März 1972



--- SATELLITE CIRCUIT  
○ ARPANET  
□ TSP  
△ FLEXIBLE ARPANET  
NOTE: THIS MAP DOES NOT SHOW ARPANET EXPERIMENTAL SATELLITE CONNECTIONS!  
NAMES: CIRCLES ARE HOST NAMES, NOT NECESSARILY HOST NAMES

Juli 1977

# 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**

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

1971	<b>Network Control Program</b> predecessor of TCP/IP
1972	<b>Email &amp; Telnet</b>
1973	<b>Ethernet</b>
1974	<b>TCP/IP</b> 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

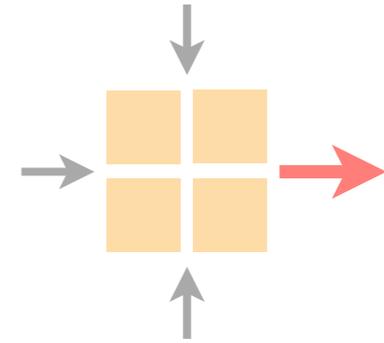
1993 Search engines invented (Excite)

1995 NSFNet is decommissioned

1998 Google reinvents search

# Communication Networks

## Part 1: Overview



- #1           What is a network made of?
- #2           How is it shared?
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