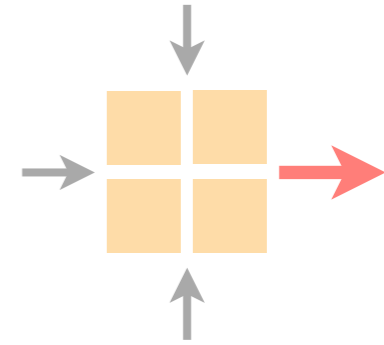


# Communication Networks

Spring 2022



Laurent Vanbever

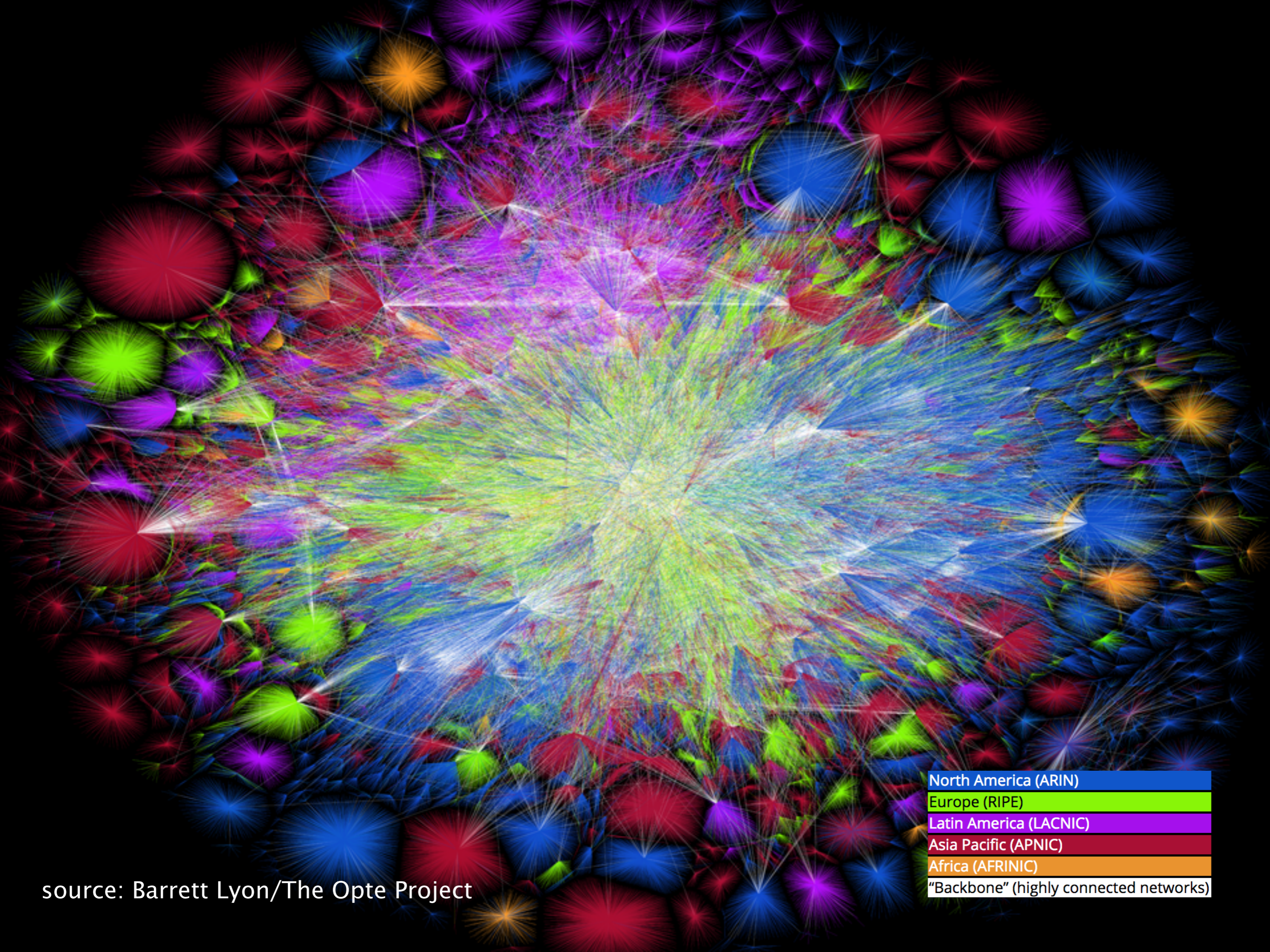
[nsg.ee.ethz.ch](mailto:nsg.ee.ethz.ch)

21 February 2022

D-ITET

Materials inspired from Scott Shenker & Jennifer Rexford





North America (ARIN)  
Europe (RIPE)  
Latin America (LACNIC)  
Asia Pacific (APNIC)  
Africa (AFRINIC)  
"Backbone" (highly connected networks)

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





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



~4 exabytes

estimated\* **daily** global IP traffic  
in 2017

\* Cisco Visual Networking Index 2017—2022

~13 exabytes

estimated\* **daily** global IP traffic  
in **2022**

\* Cisco Visual Networking Index 2017—2022



~75% of all Internet traffic

estimated\* percentage of **video traffic**  
in 2017

\* Cisco Visual Networking Index 2017—2022

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%




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

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

~**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**

# NEWS

Home | Coronavirus | Video | World | UK | Business | Tech | Science | Stories | Entertainment & Arts | Health

Asia | China | India

## Myanmar coup: How the military disrupted the internet

By Christopher Giles  
BBC Reality Check

🕒 4 February



Reality Check



<https://www.bbc.com/news/world-asia-55889565>





LILY HAY NEWMAN

SECURITY 08.10.2020 06:13 PM

# Belarus Has Shut Down the Internet Amid a Controversial Election

Human rights organizations have blamed the Belarusian government for widespread outages.



<https://www.wired.com/story/belarus-internet-outage-election/>

News > World > Africa

# Algeria and Iraq shut down internet nationwide to stop students cheating in exams

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

Chris Baynes | Thursday 21 June 2018 22:25 | 180 shares |



Like Click to follow The Independent

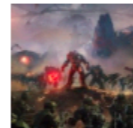






Nintendo Switch isn't just a console, it's a 127-year saga that began with a deck of cards

Nintendo | 1 hour ago



Halo Wars 2 review: a solidly Spartan sequel to the real-time strategy classic

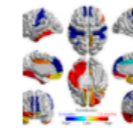
8/10

Halo | 56 minutes ago



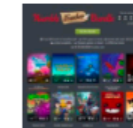
Apple's WWDC 2017 will return to San Jose in June

WWDC | 1 hour ago



This algorithm can spot signs of autism in children a year before they're diagnosed

Autism | 2 hours ago

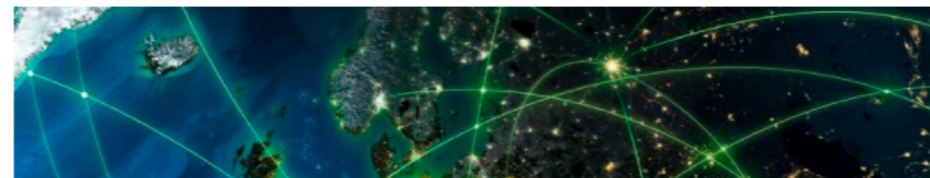


Humble collection migration

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

Tuesday 3 January 2017



Internet communications get congested  
for **economical reasons**





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/2015/03/13/technology/fcc-releases-net-neutrality-rules.html>. The page features the New York Times logo and navigation links like 'HOME', 'SEARCH', 'SUBSCRIBE NOW', and 'LOG IN'. A horizontal menu of related articles is visible at the top, including 'Snap Aims for Valuation of More Than \$20 Billion in I.P.O.', 'Facebook's Zuckerberg, Bucking Tide, Takes Public Stand Against Isolationism', 'Tech We're Using: Why I Still Love TiVo and How a Sous Vide Gadget Rescued Me', 'Airlines Phasing Out Screens Because You Are All on Your Devices', 'Social Q's: Family Planning ... for Your Phones', and 'Tech Tip: Adding Facebook's Birthday List to a Calendar Program'. The main article is titled 'F.C.C. Sets Net Neutrality Rules' by Rebecca R. Ruiz, dated March 12, 2015. It includes a video player with the title 'The New Net Neutrality Rules' and 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'. The article text begins with '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.'

TECHNOLOGY

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

By REBECCA R. RUIZ MARCH 12, 2015

The New Net Neutrality Rules  
By NATALIA V. OSIPOVA and CAITLIN PRENTKE

RELATED COVERAGE

- F.C.C. Approves Net Neutrality Rules, Classifying Broadband Internet Service as a Utility FEB. 26, 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 screenshot shows a web browser window displaying a New York Times article. The browser's address bar shows the URL: <https://www.nytimes.com/2017/12/14/technology/net-neutrality-repeal-vote.html>. The page header includes the New York Times logo, navigation links for 'SECTIONS', 'HOME', and 'SEARCH', and buttons for 'SUBSCRIBE NOW' and 'LOG IN'. The article is categorized under 'TECHNOLOGY' and has the title '*F.C.C. Repeals Net Neutrality Rules*'. The author is listed as 'By CECILIA KANG' and the date is 'DEC. 14, 2017'. Social media sharing icons for Facebook, Twitter, Email, and Print are visible, along with a bookmark icon and a comment count of '1950'. The main image shows a television set on a stand displaying a man in a suit, with a clock on the wall behind it. To the right, a 'RELATED COVERAGE' section lists five related articles with their titles and dates. At the bottom of the browser window, a status bar shows 'Connecting...' and a partial caption: 'Ajit Pai, the F.C.C. chairman, said the rollback of the net neutrality rules would eventually help consumers'.

F.C.C. Repeals Net Neutrality Rules

By CECILIA KANG DEC. 14, 2017

TECHNOLOGY

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. 8, 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... Ajit Pai, the F.C.C. chairman, said the rollback of the net neutrality rules would eventually help consumers

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




**Netflix US** 

@netflix

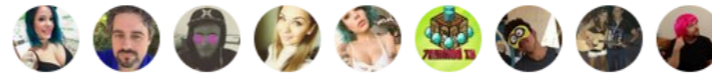
Follow



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

... but might restore soon

**Forbes**

Jan 26, 2021, 08:00am EST | 1,001 views

# Net Neutrality Likely To Return With New FCC Chair



**Wayne Rash** Contributor ⓘ

Consumer Tech

*Wayne Rash is a technology and science writer based in Washington.*



<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<sup>41</sup> Offenes Internet**

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

<sup>2</sup> 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.

<sup>3</sup> 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.

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

---

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

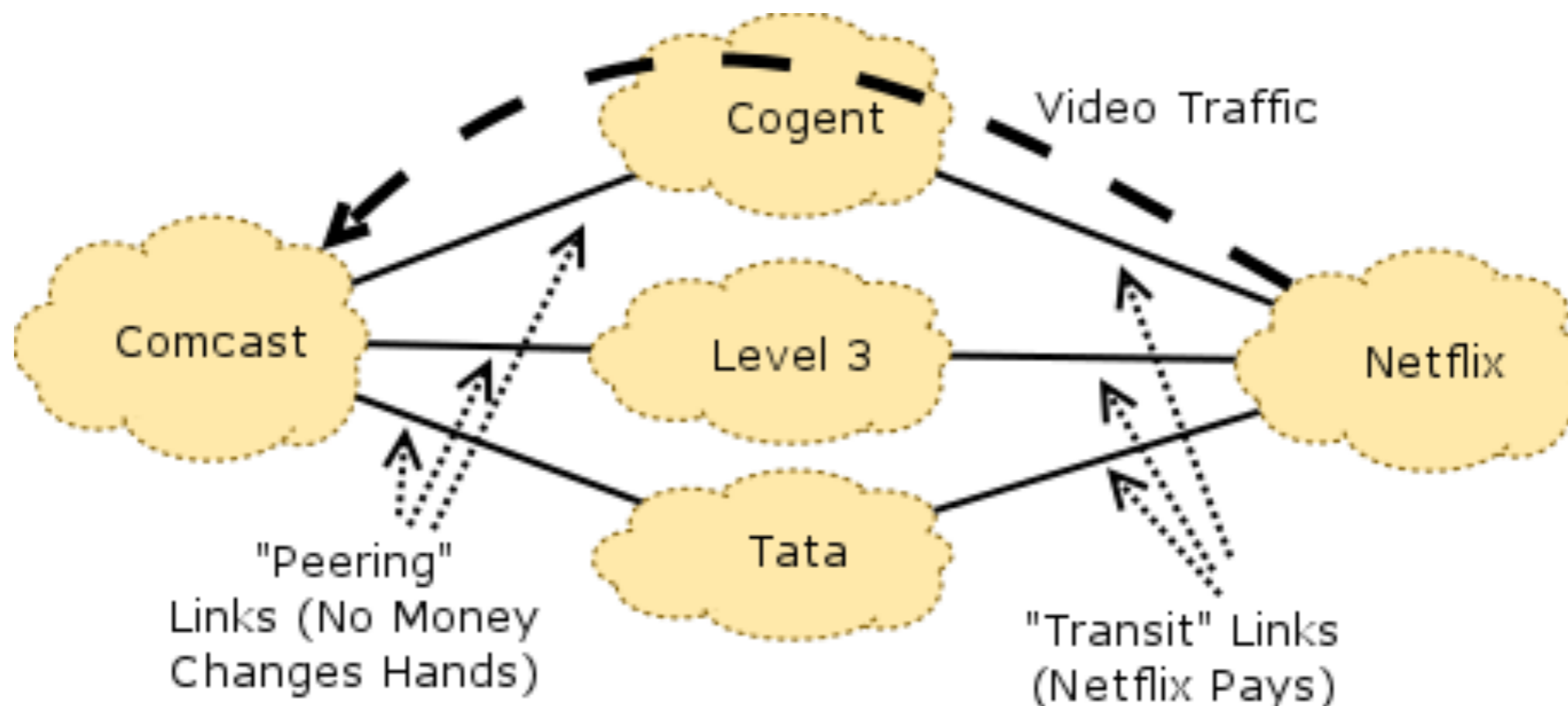
Some Internet communications  
are interfered against or heavily congested



Who should pay the other for Internet connectivity?

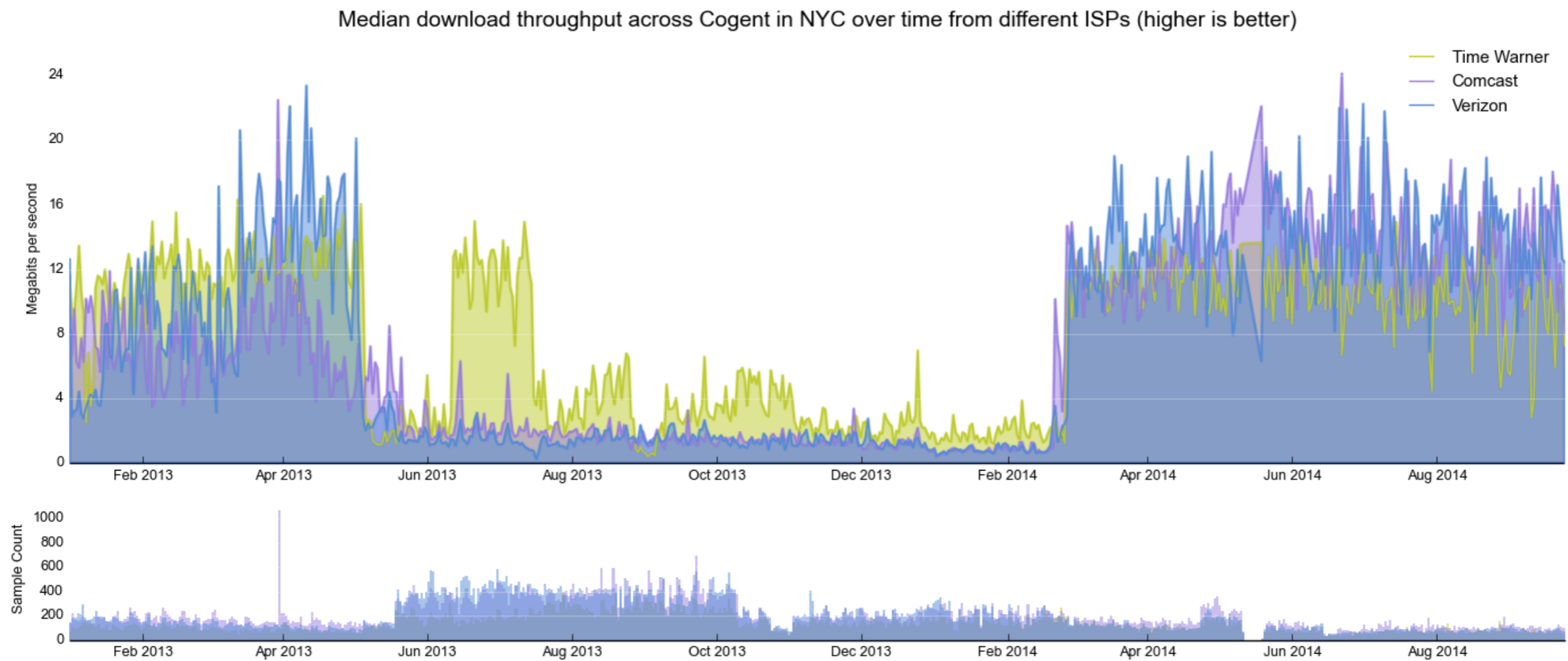


# A primer on the conflict between Netflix and Comcast



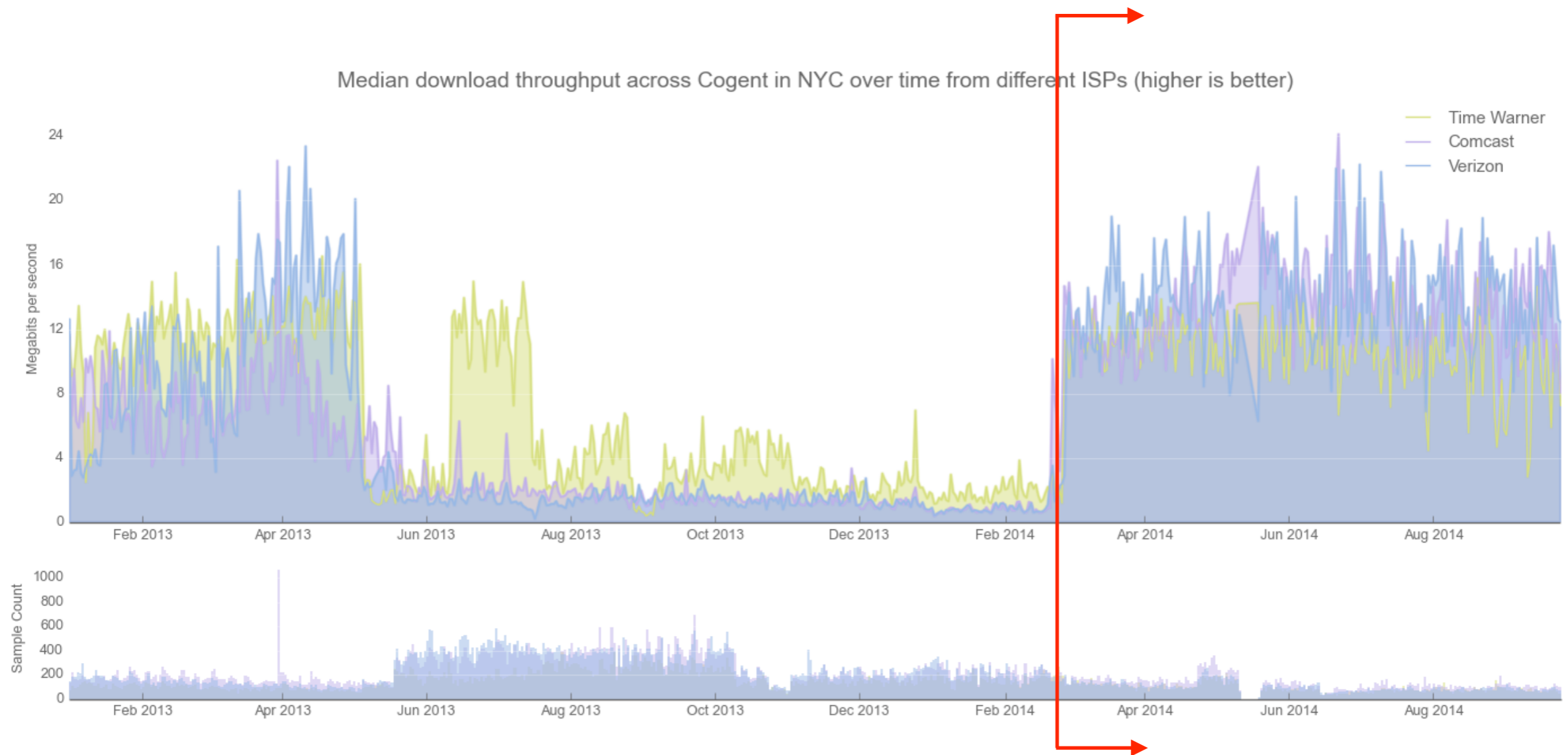
<https://freedom-to-tinker.com/blog/feamster/why-your-netflix-traffic-is-slow-and-why-the-open-internet-order-wont-necessarily-make-it-faster/>

# 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**

# 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', 'Abonnemente', 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. Below the text is a photograph of a person holding a tablet displaying the Netflix logo. To the right of the main article, there is a 'MEISTGELESEN IM RESSORT' section with two featured articles: 'Huawei- und OnePlus-Smartphones strahlen am meisten' by Jochen Siegle (14.2.2018) and '«Wir befinden uns im finsternen Mittelalter»' by Henning Steier (18.9.2014). The bottom of the page features social media sharing icons for Facebook, Twitter, LinkedIn, and Email, along with 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

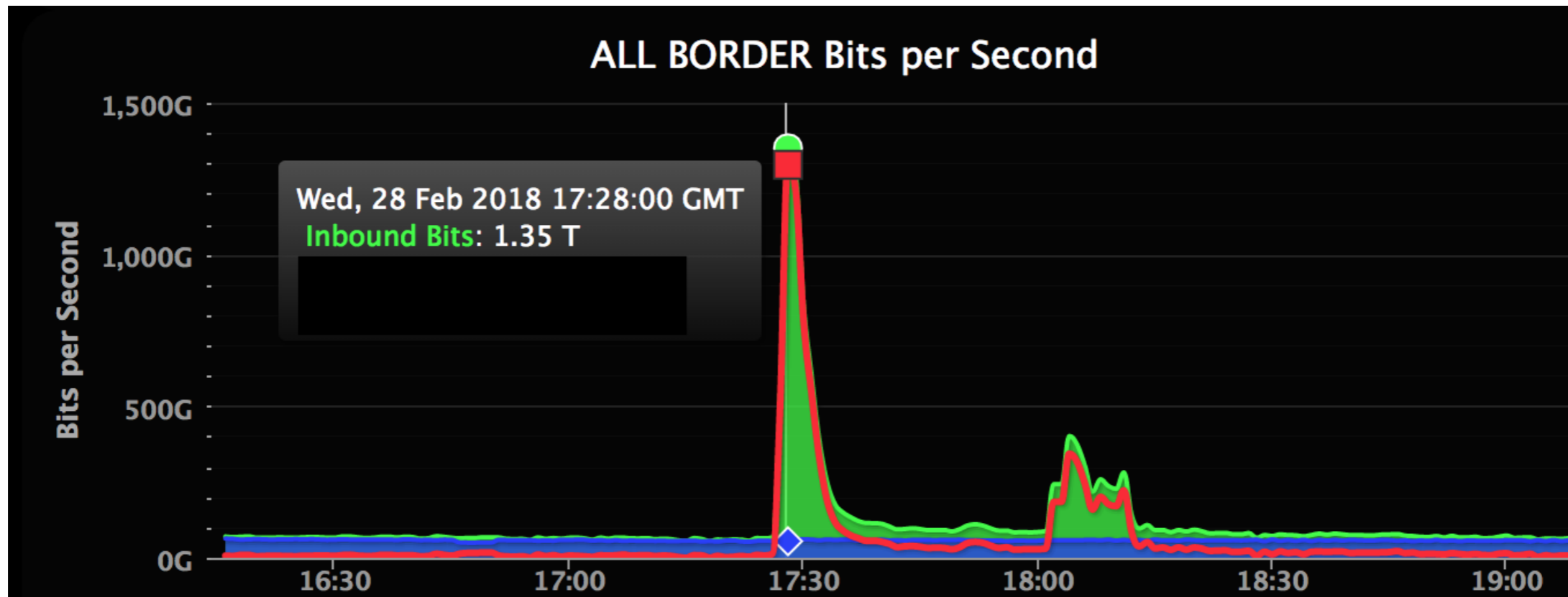
**Huawei- und OnePlus-Smartphones strahlen am meisten**  
Jochen Siegle / 14.2.2018, 14:30 Uhr

**«Wir befinden uns im finsternen Mittelalter»**  
Henning Steier / 18.9.2014, 10:40 Uhr

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

Internet infrastructures are regularly targeted  
by large-scale attacks

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**



In June 2020, Amazon was targeted by a **2.30 Tbps** DDoS attack



The image is a screenshot of a BBC News article. At the top, the BBC logo is on the left, and navigation links for 'Sign in', 'Home', 'News', 'Sport', 'Reel', 'Worklife', and 'Travel' are on the right. Below this is a red banner with the word 'NEWS' in white. Underneath the banner is another red bar with navigation links: 'Home', 'Coronavirus', 'Video', 'World', 'UK', 'Business', 'Tech', 'Science', 'Stories', 'Entertainment & Arts', and 'Health'. The 'Tech' link is underlined. Below the navigation is the article title 'Amazon 'thwarts largest ever DDoS cyber-attack'' in a large, bold, black font. Under the title is the date '18 June 2020' with a clock icon. Below the date is a red square with a white share icon.



# In August 2021, Microsoft was targeted by a **2.40 Tbps** DDoS attack

The screenshot shows a web browser window displaying the Azure blog post. The browser's address bar shows the URL: [azure.microsoft.com/en-us/blog/business-as-usual-for-azure-customers-despite-24-tbps-ddos-attack/](https://azure.microsoft.com/en-us/blog/business-as-usual-for-azure-customers-despite-24-tbps-ddos-attack/). The page header includes the Azure logo, navigation links (Explore, Products, Solutions, Pricing, Partners, Resources), a 'Free account' button, a search bar, and links for Docs, Support, Contact Sales, and Sign in. The main content area features the article title, a 'Subscribe' button, social media icons for Facebook, Twitter, and LinkedIn, and the author's name: Amir Dahan, Senior Program Manager, Azure Networking. The article text discusses a 2.4 Tbps DDoS attack in August 2021, comparing it to a 2020 attack and providing a bar chart of maximum attack bandwidth.

Blog / Security

## Business as usual for Azure customers despite 2.4 Tbps DDoS attack

Posted on October 11, 2021

[Amir Dahan](#), Senior Program Manager, Azure Networking

*This blog post was co-authored by Alethea Toh, Program Manager and Syed Pasha, Principal Network Engineer, Azure Networking.*

In early August, we shared [Azure's Distributed Denial-of-Service \(DDoS\) attack trends](#) for the first half of 2021. We reported a 25 percent increase in the number of attacks compared to Q4 of 2020, albeit a decline in maximum attack throughput, from one terabit per second (Tbps) in Q3 of 2020 to 625 Mbps in the first half of 2021.

The last week of August, we observed a 2.4 Tbps DDoS attack targeting an Azure customer in Europe. This is 140 percent higher than [2020's 1 Tbps attack](#) and higher than any network volumetric event previously detected on Azure.

### Maximum attack bandwidth (Tbps)

Time Period	Maximum attack bandwidth (Tbps)
Q3 of 2020	1.0
First half of 2021	0.625
Last week of August 2021	2.4

**Subscribe**

### Explore

See where we're heading. Check out upcoming changes to Azure products

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Let us know if you have any additional questions about Azure

[Ask questions](#)

### Topics

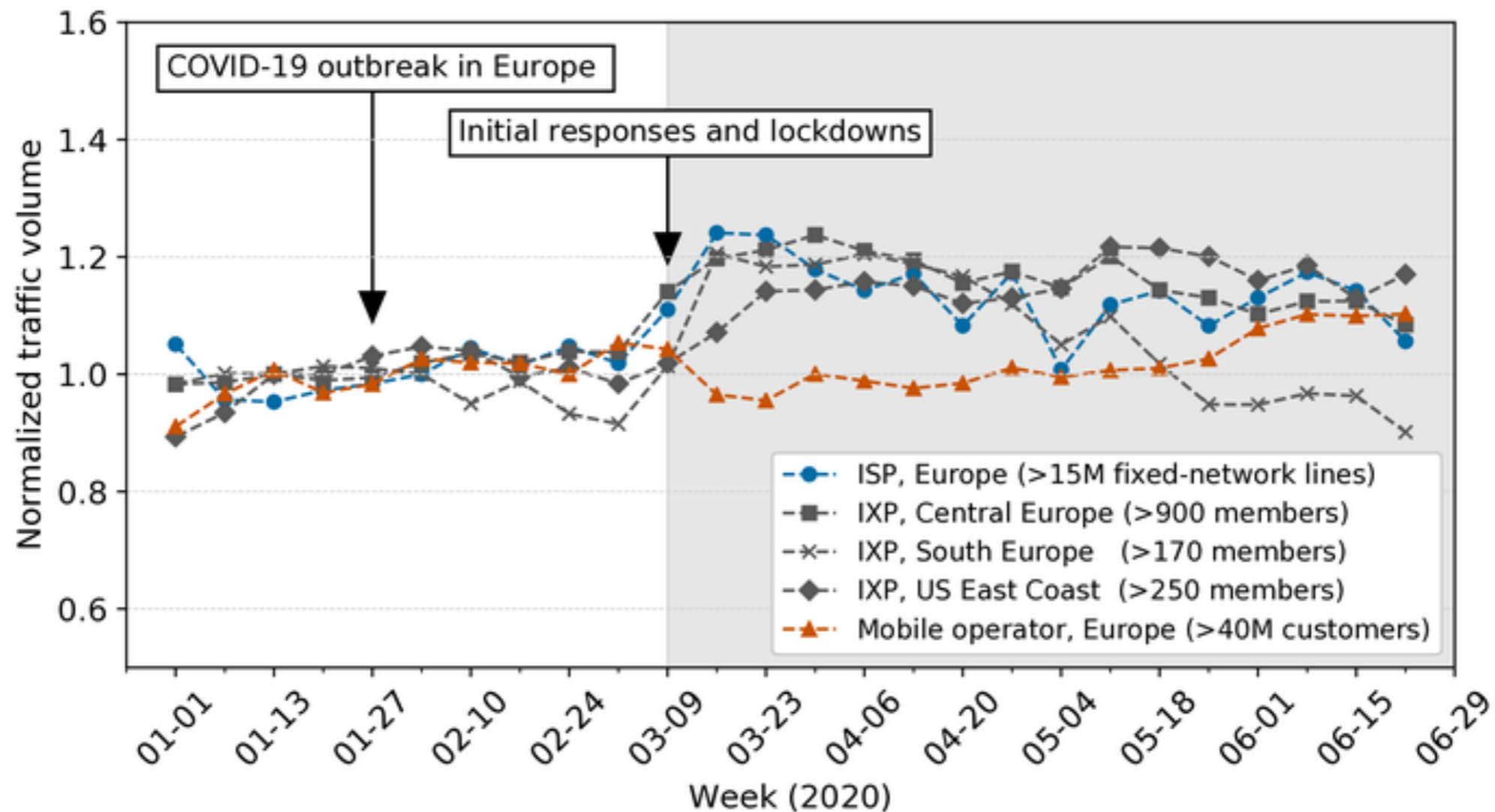
- [Announcements](#) (2338)
- [API Management](#) (41)
- [Artificial Intelligence](#) (255)
- [Azure Maps](#) (32)
- [Azure Marketplace](#) (150)
- [Azure Stream Analytics](#) (37)
- [Big Data](#) (655)
- [Blockchain](#) (89)

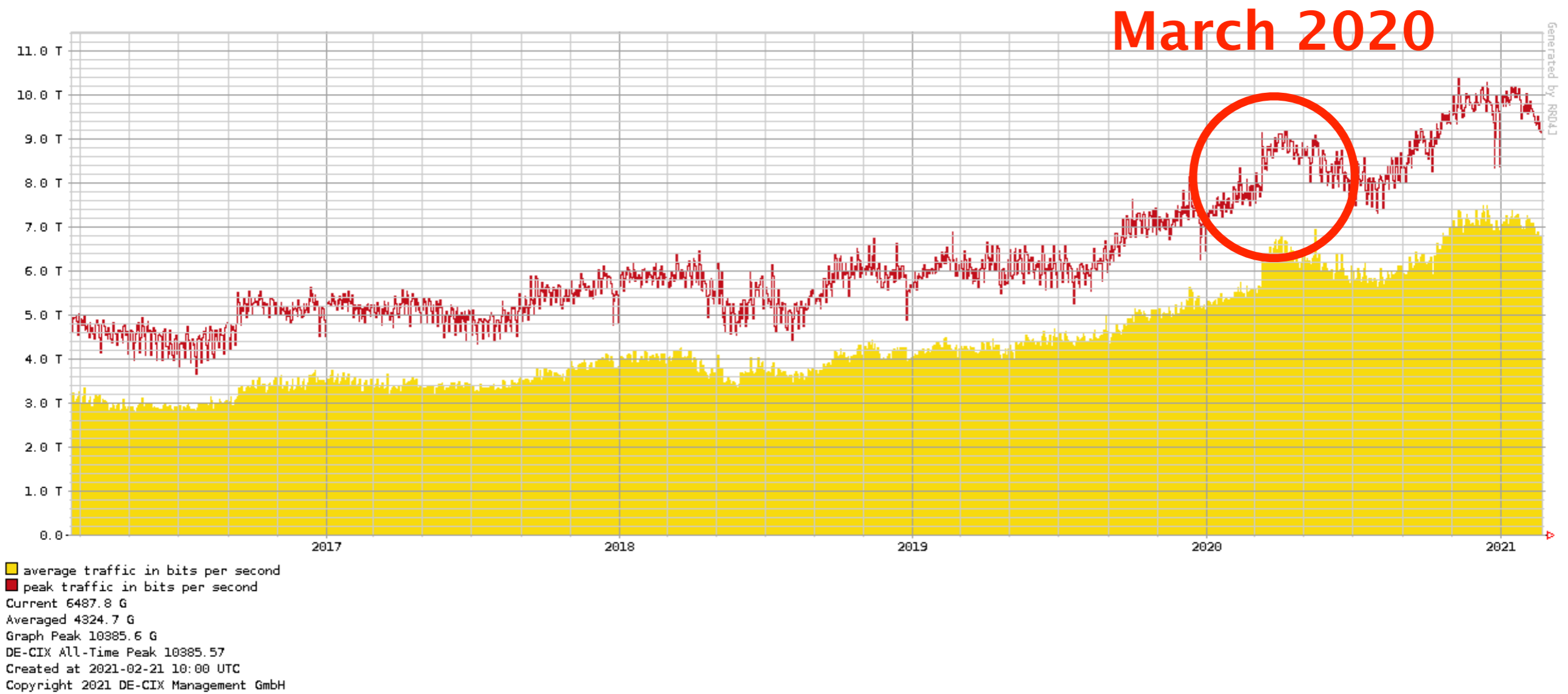
The Internet

*A vital* place during a pandemic



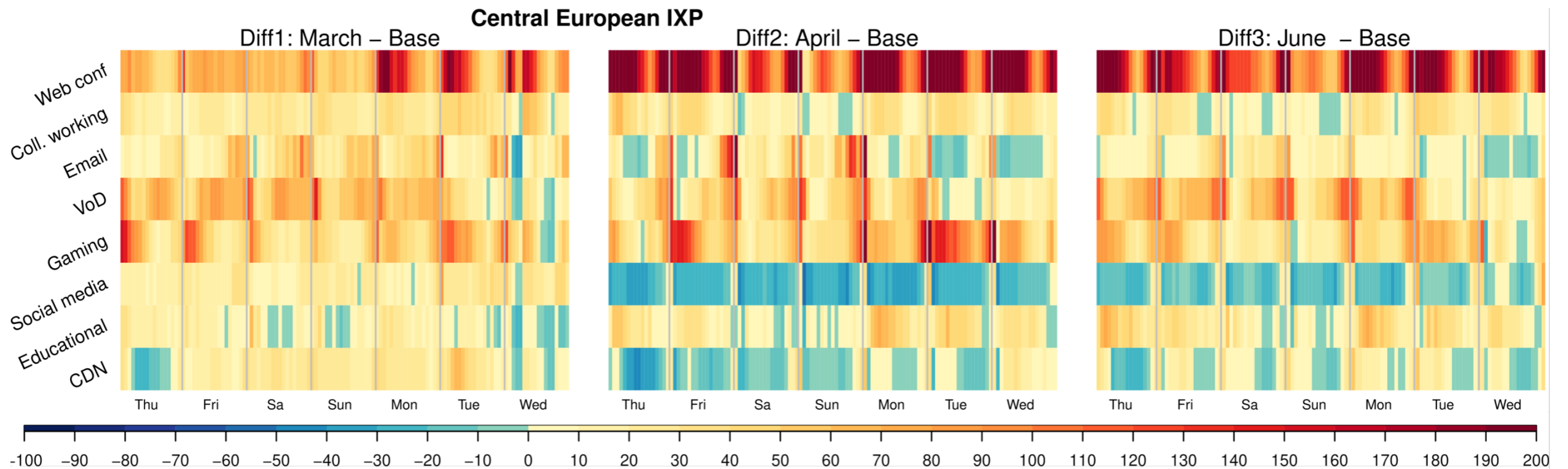
Following the lockdown in March 2020,  
(wired) networks saw traffic increasing by 15–20%





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

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



# All in all the Internet performed very well in these unprecedented 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.

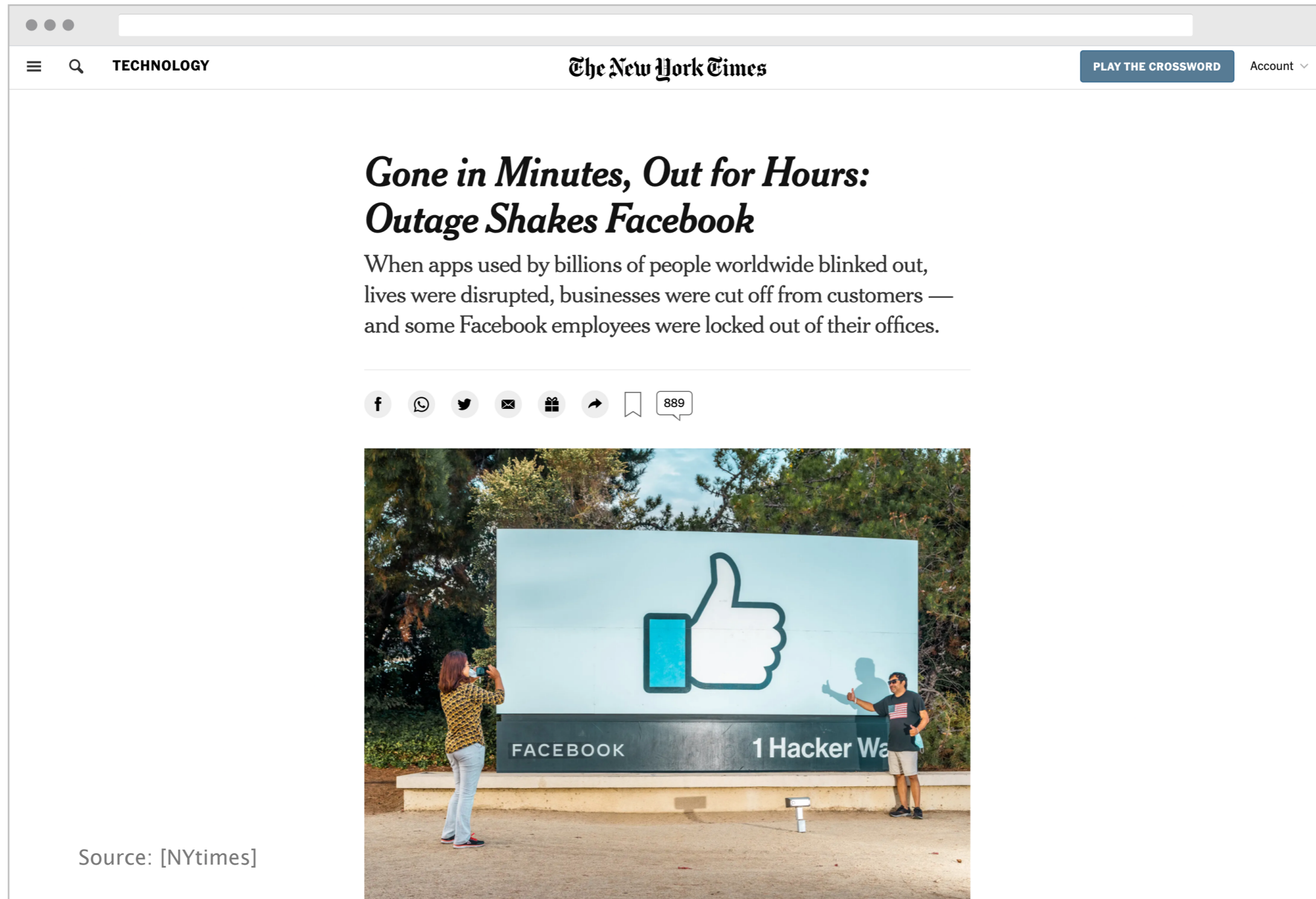
[source]



The Internet

*A fragile place*

Despite being absolutely critical,  
the Internet infrastructure is inherently fragile



The screenshot shows a web browser window displaying a New York Times article. The browser's address bar is empty. The page header includes a hamburger menu, a search icon, the word "TECHNOLOGY", the New York Times logo, a "PLAY THE CROSSWORD" button, and an "Account" dropdown. The article title is "Gone in Minutes, Out for Hours: Outage Shakes Facebook". The lead paragraph reads: "When apps used by billions of people worldwide blinked out, lives were disrupted, businesses were cut off from customers — and some Facebook employees were locked out of their offices." Below the text are social media sharing icons for Facebook, WhatsApp, Twitter, Email, Print, and a share icon, along with a comment count of 889. The main image shows a large outdoor sign with the Facebook logo and the text "FACEBOOK" and "1 Hacker Wa". A woman is taking a photo of the sign, and a man is standing next to it, pointing at the logo.

Source: [NYtimes]

Our engineering teams have learned that **configuration changes on the backbone routers** that coordinate network traffic between our data centers caused issues that interrupted this communication.

This disruption to network traffic had a cascading effect on the way our data centers communicate, **bringing our services to a halt.**

Source: [fb.com]

 **Sheera Frenkel** ✓  
@sheeraf

Was just on phone with someone who works for FB who described employees unable to enter buildings this morning to begin to evaluate extent of outage because their badges weren't working to access doors.

8:51 PM · Oct 4, 2021 · Twitter for iPhone

---

**19.1K** Retweets   **9,929** Quote Tweets   **83.3K** Likes

 **Steve Gibson** ✓  
@SGgrc

Someone on the Facebook recovery effort has explained that a routine BGP update went wrong, which in turn locked out those with remote access who could reverse the mistake. Those who do have physical access do not have authorization on the servers. Catch-22.

9:59 PM · Oct 4, 2021 · TweetDeck

---

**746** Retweets   **247** Quote Tweets   **2,028** Likes

 "Alex" and 3 others follow

 **Tabletop Scenarios**  
@badthingsdaily

The networking gear involved in an outage is access controlled by locks that are dependent on the network gear that is involved in the outage that is access controlled by locks that are dependent on network gear that is involved in the outage that is access controlled by the...

11:17 PM · Oct 4, 2021 · TweetDeck

---

**106** Retweets   **10** Quote Tweets   **391** Likes



# August 2017

Google routing blunder sent J: x

Secure | https://www.theregister.co.uk/2017/08/27/google\_routing\_blunder\_sent\_japans\_internet\_dark/

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Data Centre ► **Networks**

## Google routing blunder sent Japan's Internet dark on Friday

### Another big BGP blunder

By [Richard Chirgwin](#) 27 Aug 2017 at 22:35 40 SHARE ▼

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

The trouble began when The Chocolate Factory "leaked" a big route table to Verizon, the result of which was traffic from Japanese giants like NTT and KDDI was sent to Google on the expectation it would be treated as transit.

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

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

BGP Mon dissects [what went wrong here](#), reporting that more than

### Most read

- Helicopter crashes after manoeuvres to 'avoid... DJI Phantom drone'
- That terrifying 'unfixable' Microsoft Skype security flaw: THE TRUTH
- Stephen Elop and the fall of Nokia revisited
- BBC presenter loses appeal, must pay £420k in IR35 crackdown
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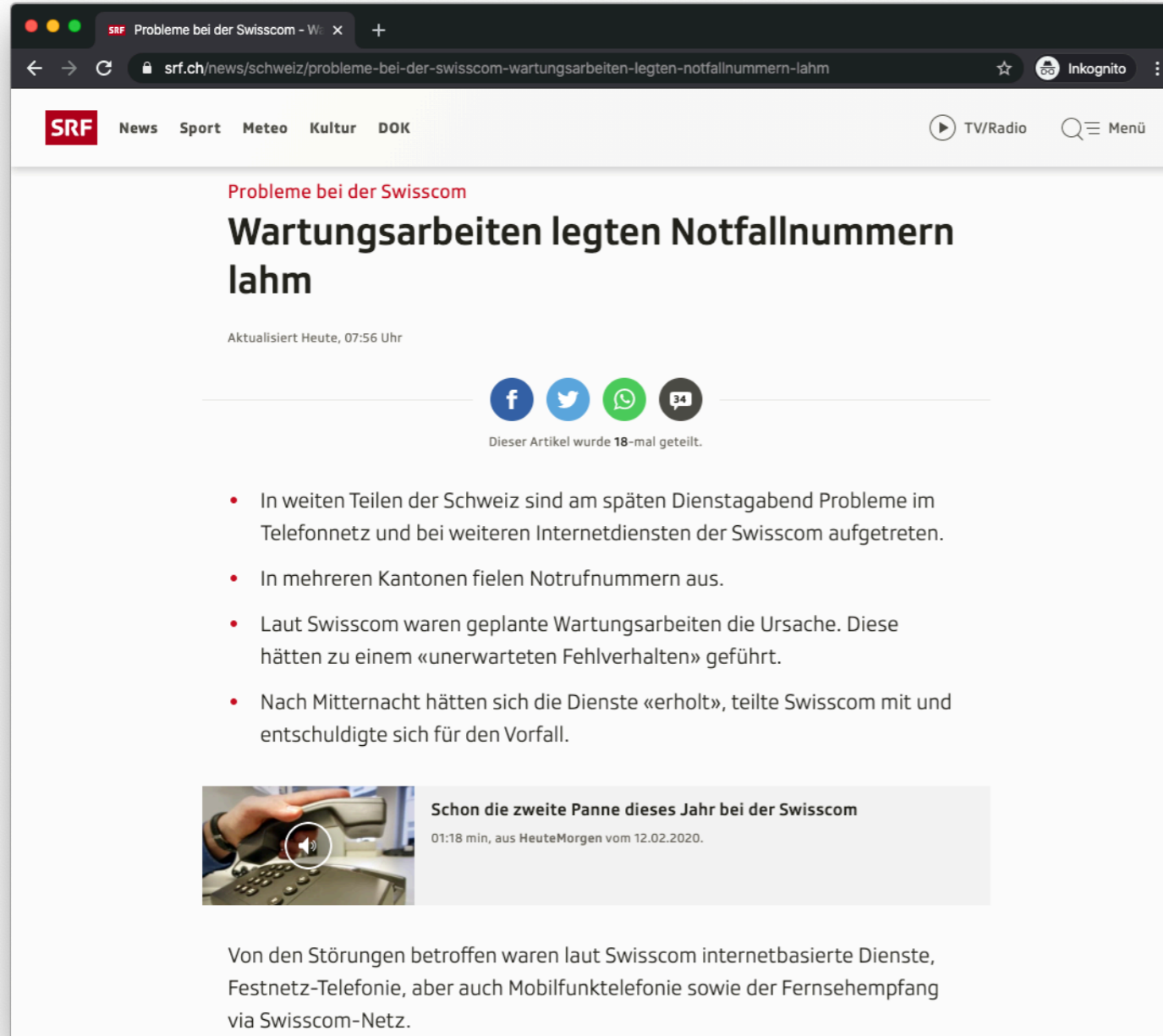
[https://www.theregister.co.uk/2017/08/27/google\\_routing\\_blunder\\_sent\\_japans\\_internet\\_dark/](https://www.theregister.co.uk/2017/08/27/google_routing_blunder_sent_japans_internet_dark/)

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.

# In February 2020, a planned maintenance work in Swisscom's network shuts down emergency numbers



The screenshot shows a web browser window displaying a news article from SRF. The browser's address bar shows the URL: [srf.ch/news/schweiz/probleme-bei-der-swisscom-wartungsarbeiten-legten-notfallnummern-lahm](https://www.srf.ch/news/schweiz/probleme-bei-der-swisscom-wartungsarbeiten-legten-notfallnummern-lahm). The article title is "Wartungsarbeiten legten Notfallnummern lahm" (Maintenance work paralyzes emergency numbers). The article is dated "Aktualisiert Heute, 07:56 Uhr". Below the title are social media sharing icons for Facebook, Twitter, WhatsApp, and a share icon with the number 34. A note states "Dieser Artikel wurde 18-mal geteilt." (This article was shared 18 times). The main content consists of a bulleted list of details about the outage. At the bottom, there is a video player thumbnail with the title "Schon die zweite Panne dieses Jahr bei der Swisscom" (Already the second outage of this year at Swisscom) and a duration of 01:18 min, dated 12.02.2020. Below the video player, a short paragraph summarizes the affected services.

**Probleme bei der Swisscom**  
**Wartungsarbeiten legten Notfallnummern lahm**

Aktualisiert Heute, 07:56 Uhr

Dieser Artikel wurde 18-mal geteilt.

- In weiten Teilen der Schweiz sind am späten Dienstagabend Probleme im Telefonnetz und bei weiteren Internetdiensten der Swisscom aufgetreten.
- In mehreren Kantonen fielen Notrufnummern aus.
- Laut Swisscom waren geplante Wartungsarbeiten die Ursache. Diese hätten zu einem «unerwarteten Fehlverhalten» geführt.
- Nach Mitternacht hätten sich die Dienste «erholt», teilte Swisscom mit und entschuldigte sich für den Vorfall.

**Schon die zweite Panne dieses Jahr bei der Swisscom**  
01:18 min, aus HeuteMorgen vom 12.02.2020.

Von den Störungen betroffen waren laut Swisscom internetbasierte Dienste, Festnetz-Telefonie, aber auch Mobilfunktelefonie sowie der Fernsehempfang via Swisscom-Netz.

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

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

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

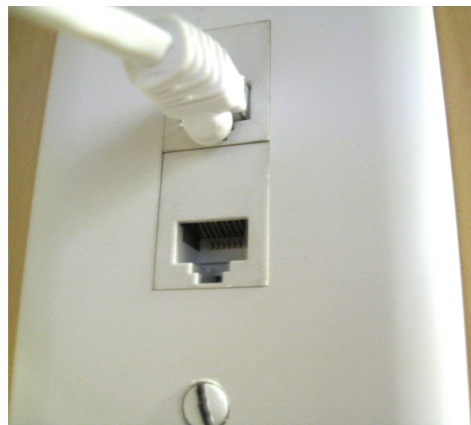


# Communication Networks

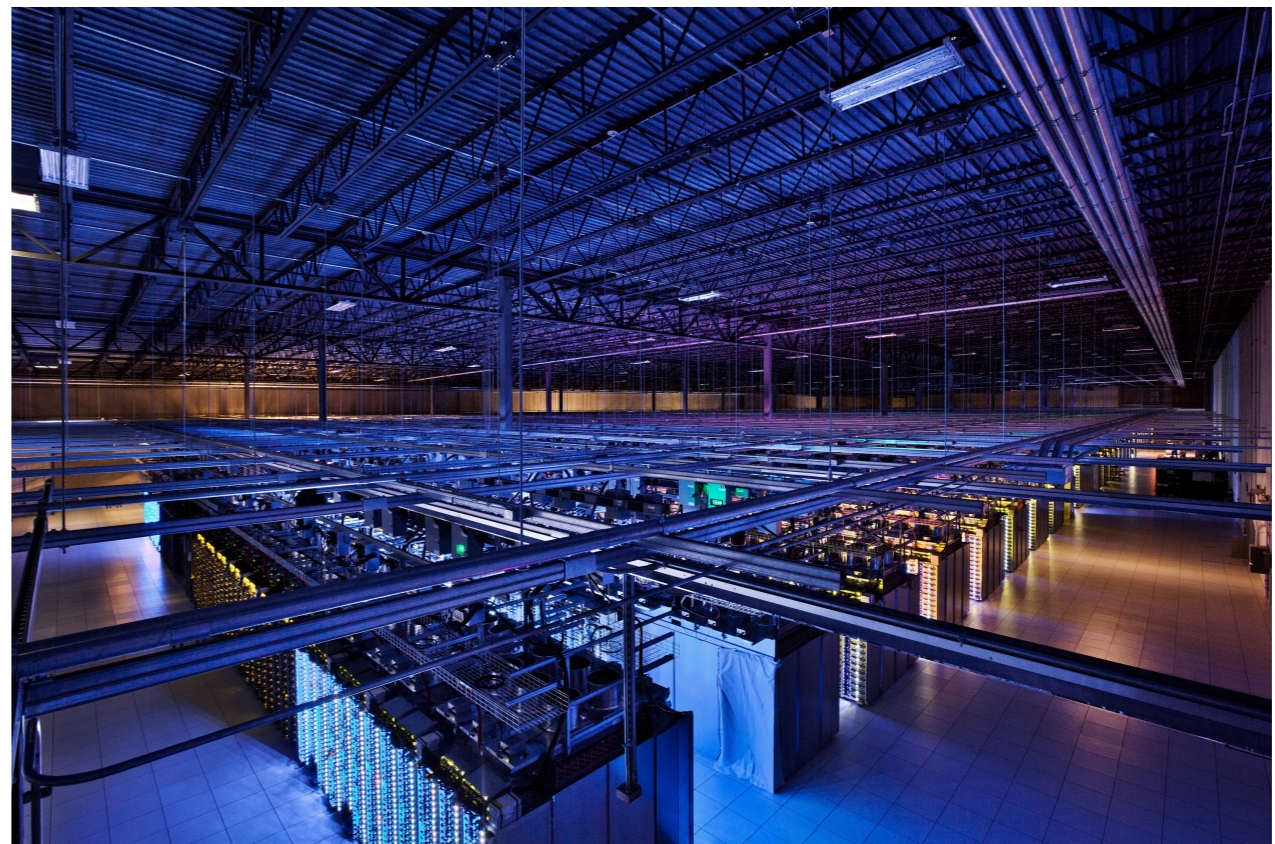
## **Course goals**

# 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

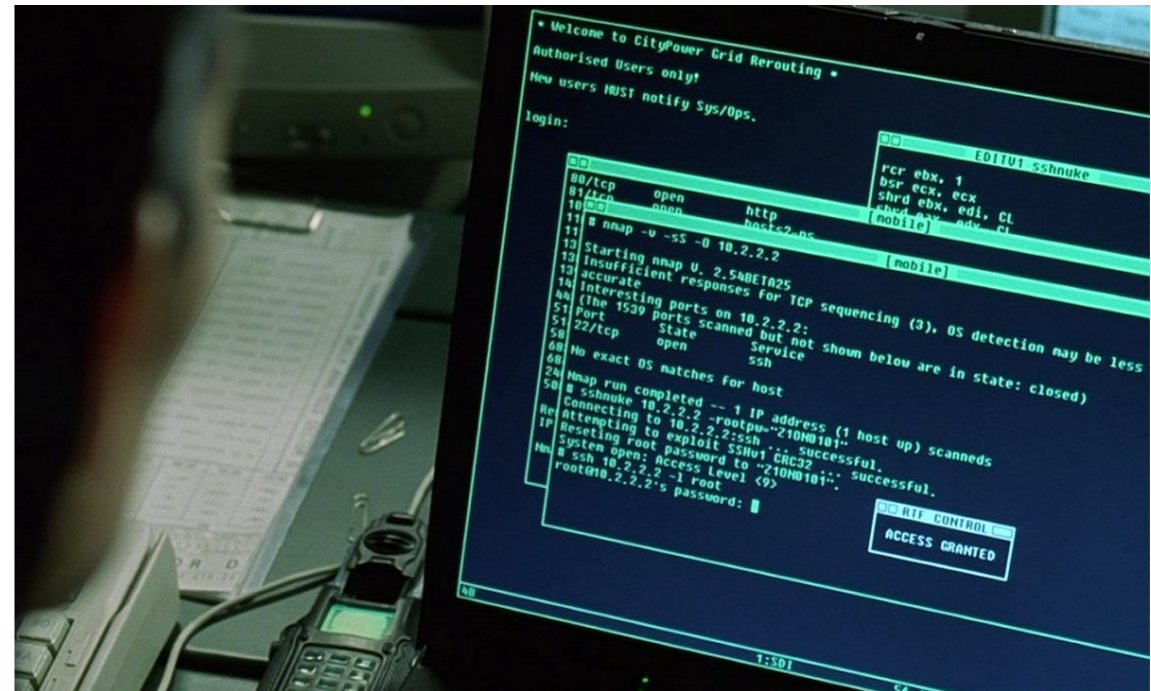
How do you **communicate reliably using unreliable mediums?**

Naming    Layering    Routing    Reliability    **Sharing**

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

# Skills

Build, operate and configure networks

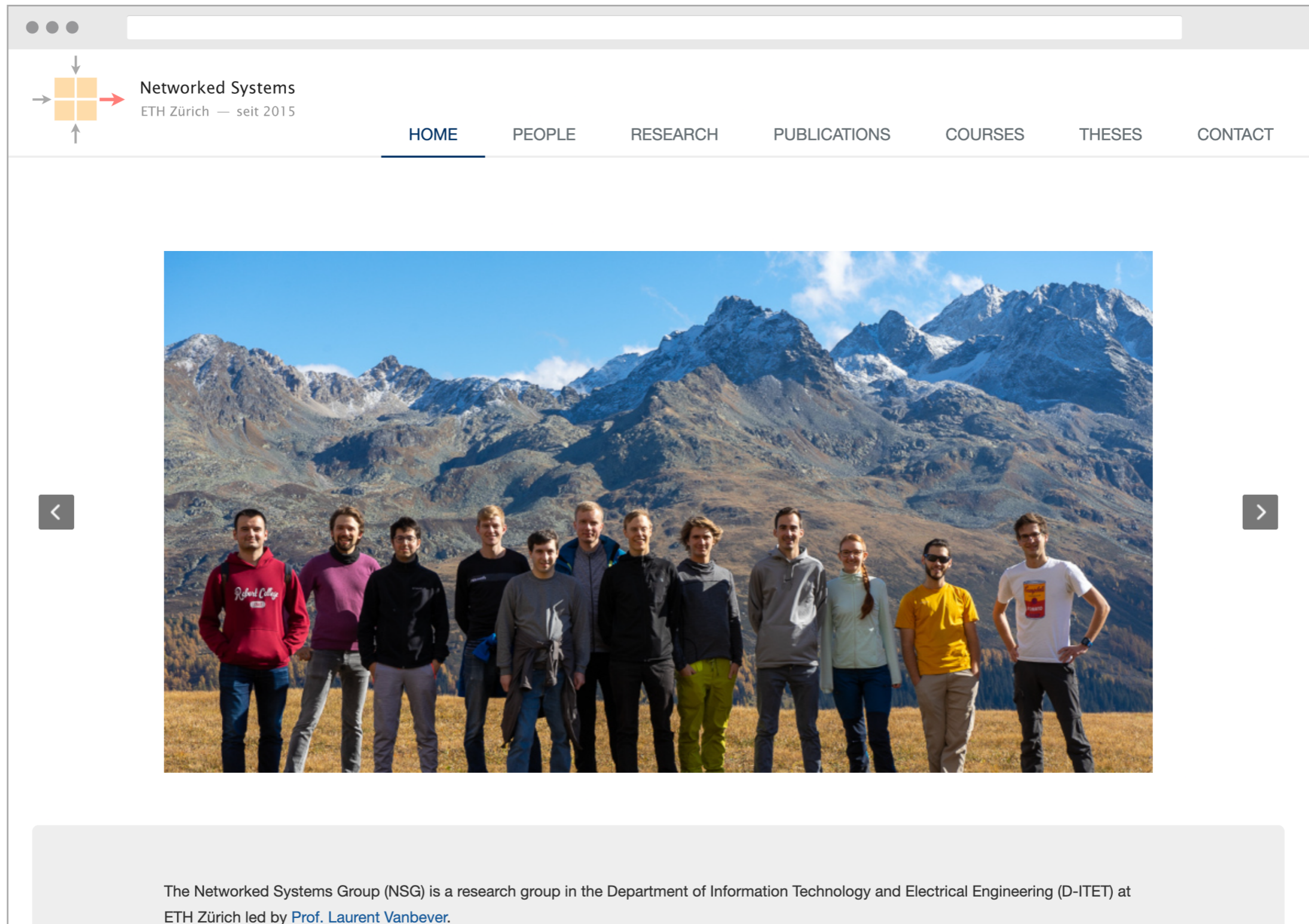


Trinity using a port scanner (nmap) in Matrix Reloaded™



# Insights

## Learn about some of our current research



The screenshot shows the homepage of the Networked Systems group at ETH Zürich. The header includes the group's logo (a 2x2 grid of orange squares with arrows pointing inwards) and the text "Networked Systems" and "ETH Zürich — seit 2015". A navigation menu contains the following items: HOME (underlined), PEOPLE, RESEARCH, PUBLICATIONS, COURSES, THESES, and CONTACT. The main content area features a large photograph of a group of eleven people standing in a field with snow-capped mountains in the background. The photo is flanked by left and right navigation arrows. Below the photo, a grey box contains the following text:

The Networked Systems Group (NSG) is a research group in the Department of Information Technology and Electrical Engineering (D-ITET) at ETH Zürich led by [Prof. Laurent Vanbever](#).

Communication Networks

**Course organization**

# Your dream team for the semester



Tobias



Coralie



Alexander



Tibor



Thomas

+ Martin and Nasib who followed the lecture in previous years

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

The screenshot shows a web browser window displaying the 'Communication Networks' website for Spring 2022. The page features a navigation bar with the course title and a 'Spring 2022' badge. A logo for 'Networked Systems' is visible in the top right. The main content area includes a 'News' section with a post from Jan 19 about the website going live, and a 'Timeline' section showing the semester progress with markers for Lectures, Exercises, and Projects. The 'Contact' and 'Location & time' sections provide details about the instructor, research group, and lecture/exercise sessions.

**Communication Networks** Spring 2022

Networked Systems  
ETH Zürich — seit 2015

**News**

Jan 19 Website for 2022 goes live!  
Stay tuned for more content

**Timeline**

	Feb 20	Feb 27	Mar 6	Mar 13	Mar 20	Mar 27	Apr 3	Apr 10	Apr 17	Apr 24	May 1	May 8	May 15	May 22	May 29
Semester progress															
Lectures										East...					
Exercises															
Projects										Internet Routing					Reliable Transport

**Contact**  
Instructor: [Prof. Laurent Vanbever](#)  
Research group: [Networked Systems Group](#)  
Contact: [comm-net@ethz.ch](mailto:comm-net@ethz.ch)

**Location & time**  
Lecture: Monday 10 am–12 pm in [HG E 1.2](#)  
Exercise sessions: Thursday 10 am–12 pm in [HG E 1.2](#)

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

# The course will be split in three parts

Part 1

Overview

~1.5 lectures

Part 2

Concepts

~1.5 lectures

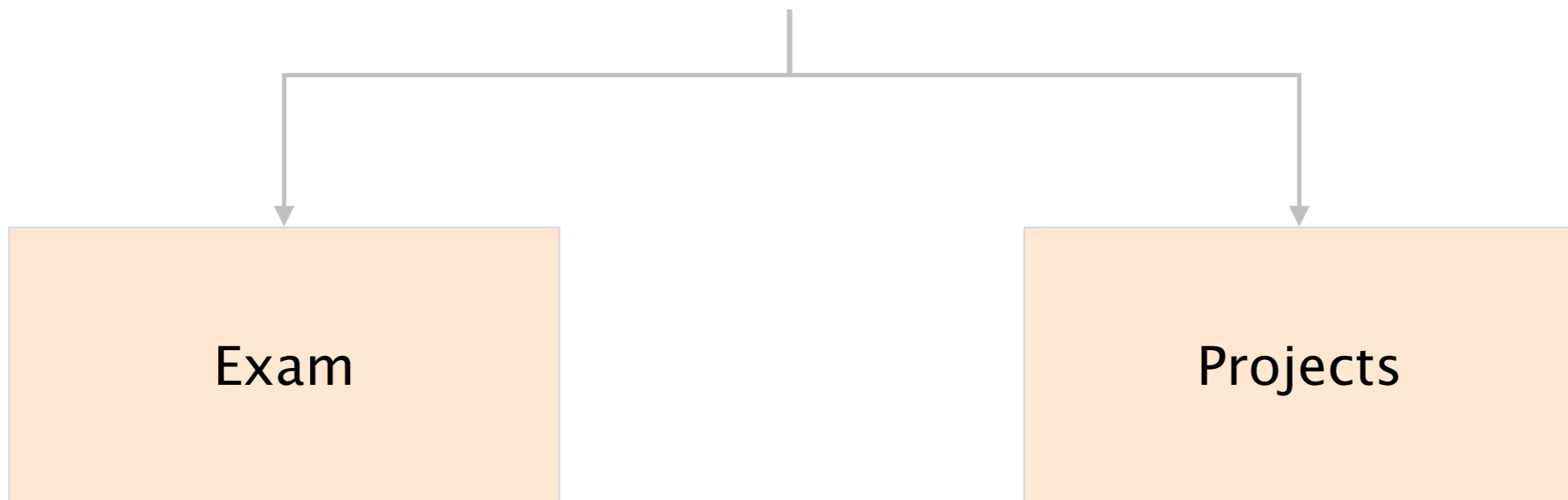
Part 3

Today's Internet

~10 lectures



# Your final grade



Exam

Projects

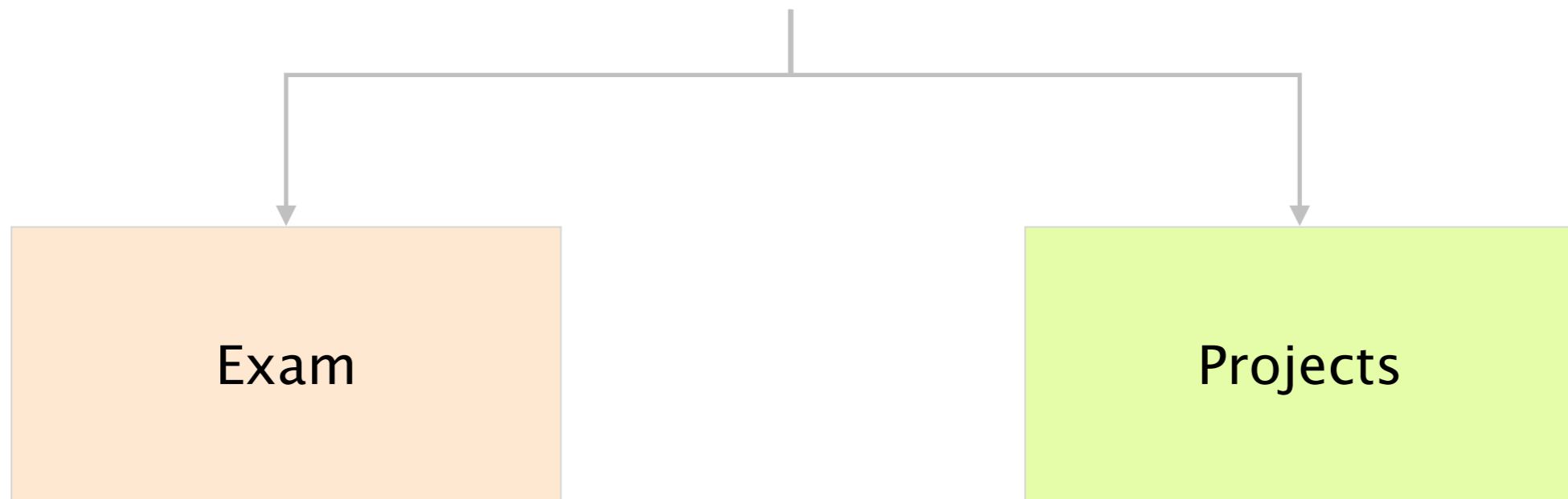
70%

30%

written, open book

continuous  
performance assessments

# Your final grade



Exam

Projects

70%

30%

written, open book

continuous  
performance assessments

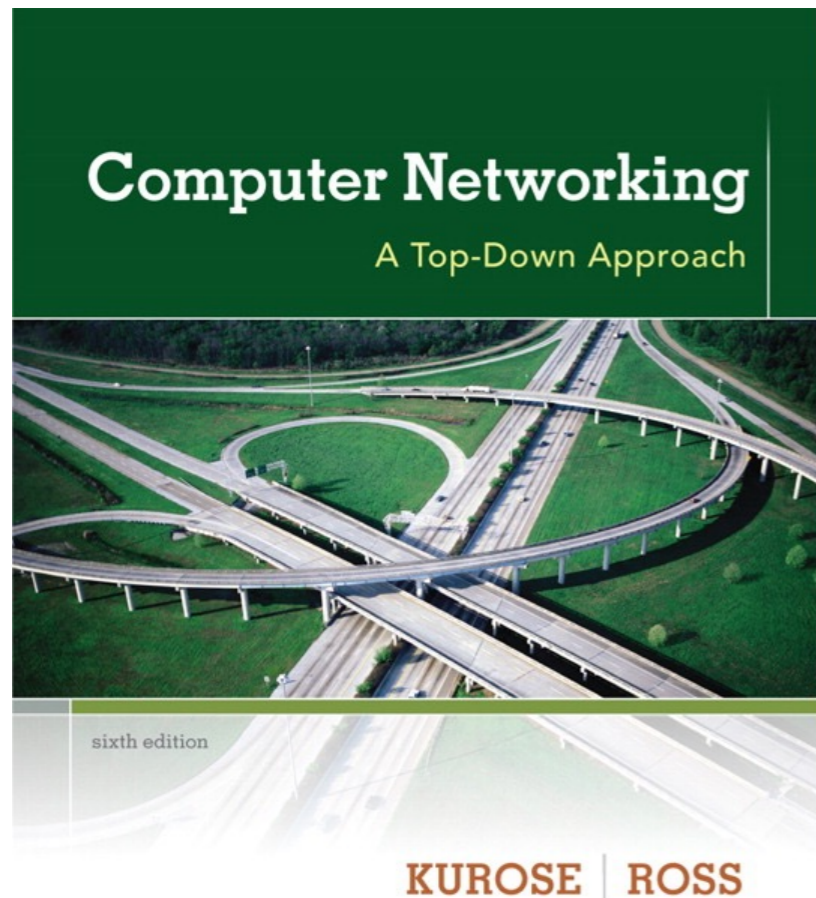
There will be two practical projects,  
to be done in group of maximum three students

- #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**

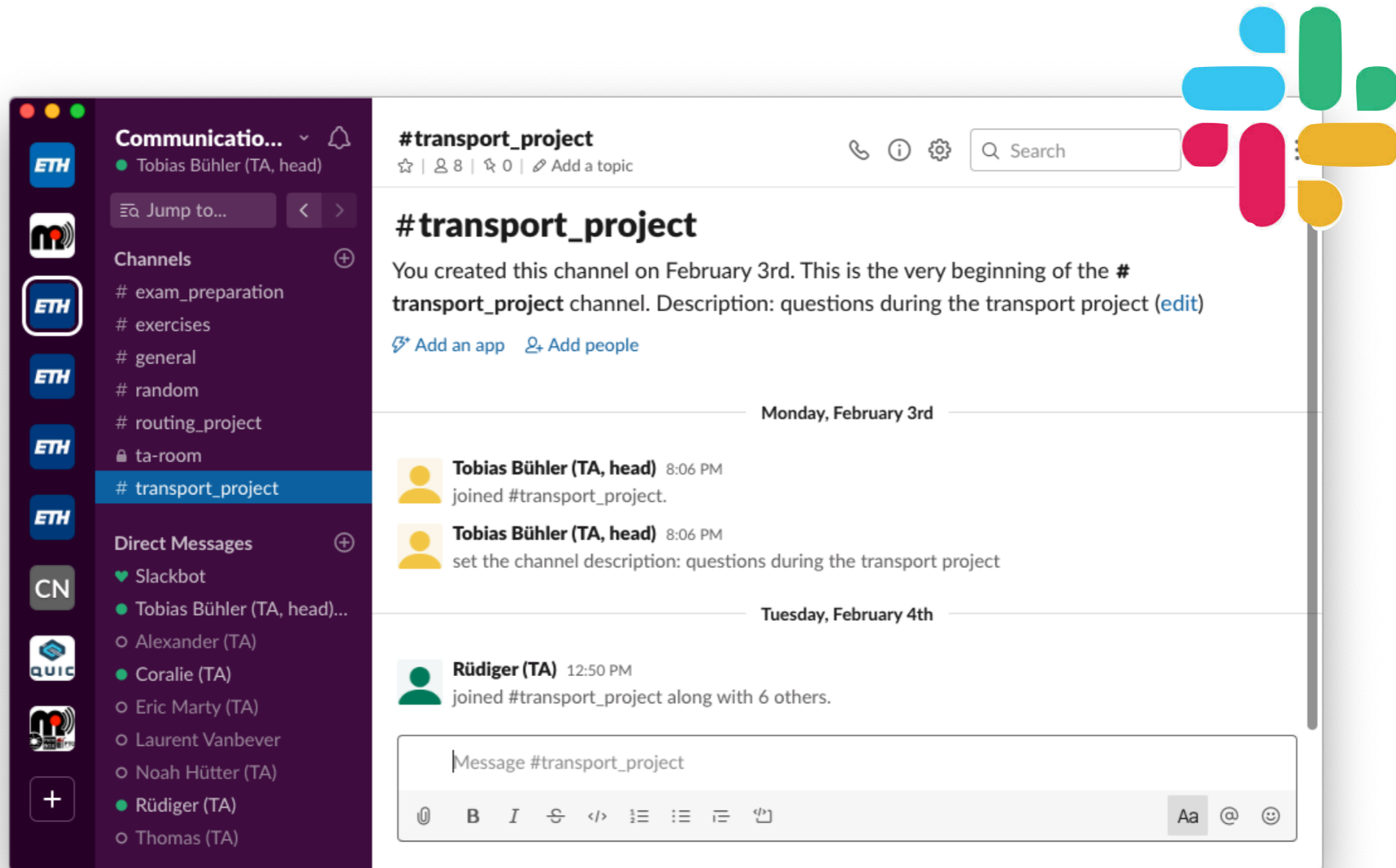


6th edition

using another edition is okay  
but numbering might vary

see sections indicated  
on [comm-net.ethz.ch](http://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://join.slack.com/t/comm-net22/signup>

Register with your @ethz.ch email

Ping us if you prefer using another one

Use your real name

It greatly facilitates our organization

We never publish sensitive data on Slack

e.g. your grades



# 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 cables and conduits running across it. The floor is a light-colored, polished tile. The overall atmosphere is one of a highly organized and technologically advanced environment.



# Communication Networks

## Part 1: Overview



- #1           What is a network made of?
- #2           How is it shared?
- #3           How is it organized?
- #4           How does communication happen?
- #5           How do we characterize it?

# Communication Networks

## Part 1: Overview



#1

**What is a network made of?**

How is it shared?

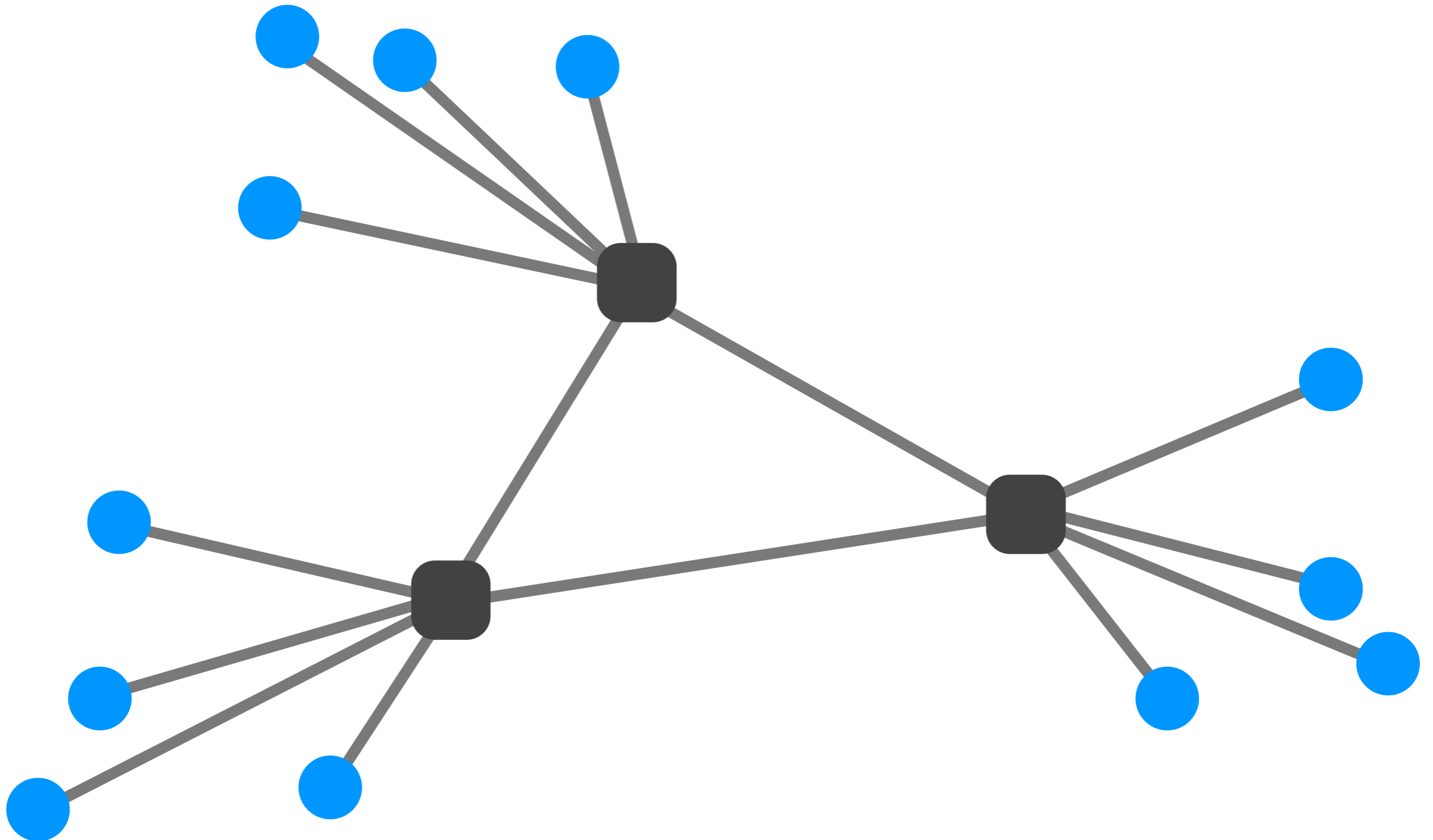
How is it organized?

How does communication happen?

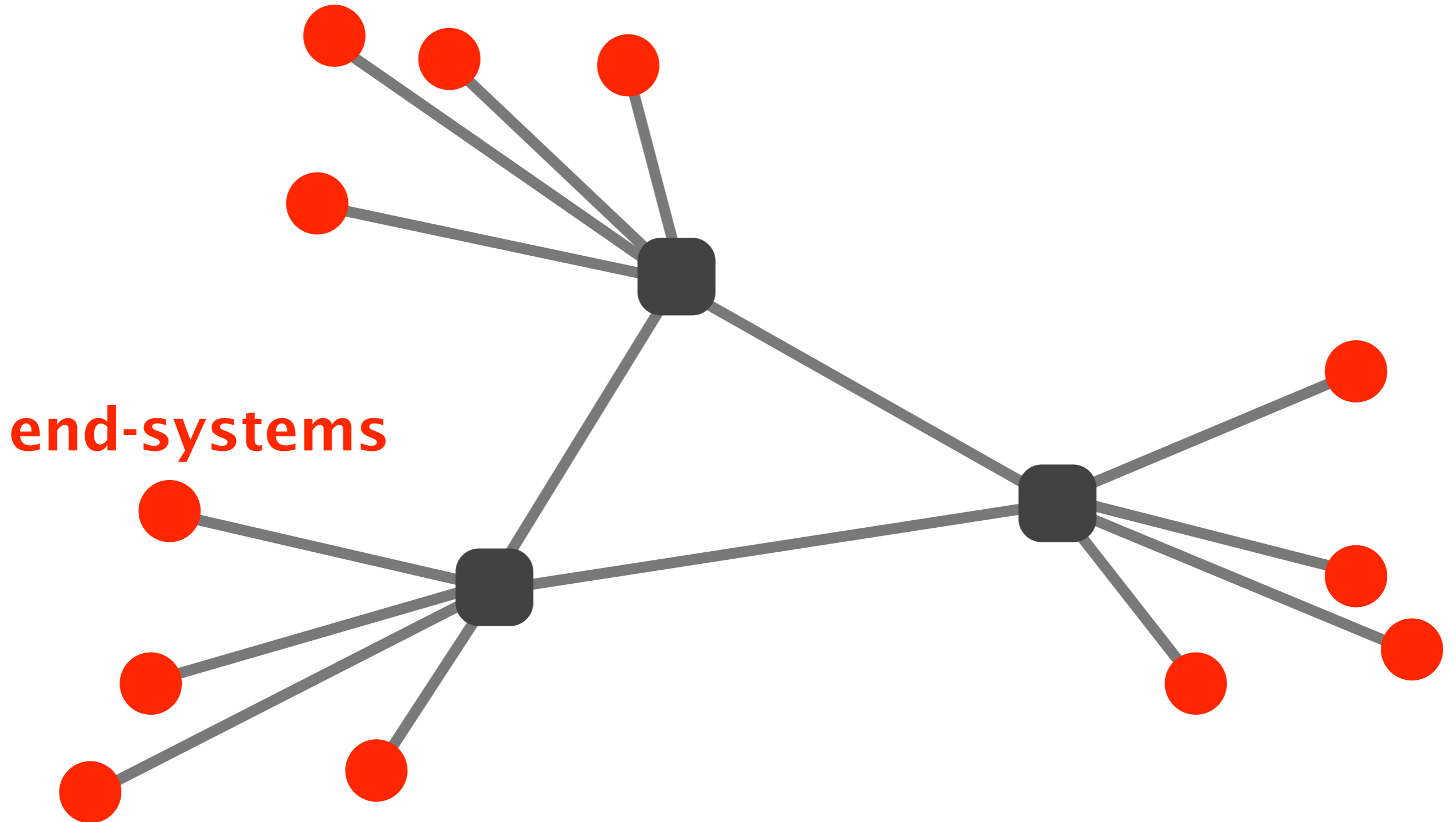
How do we characterize it?



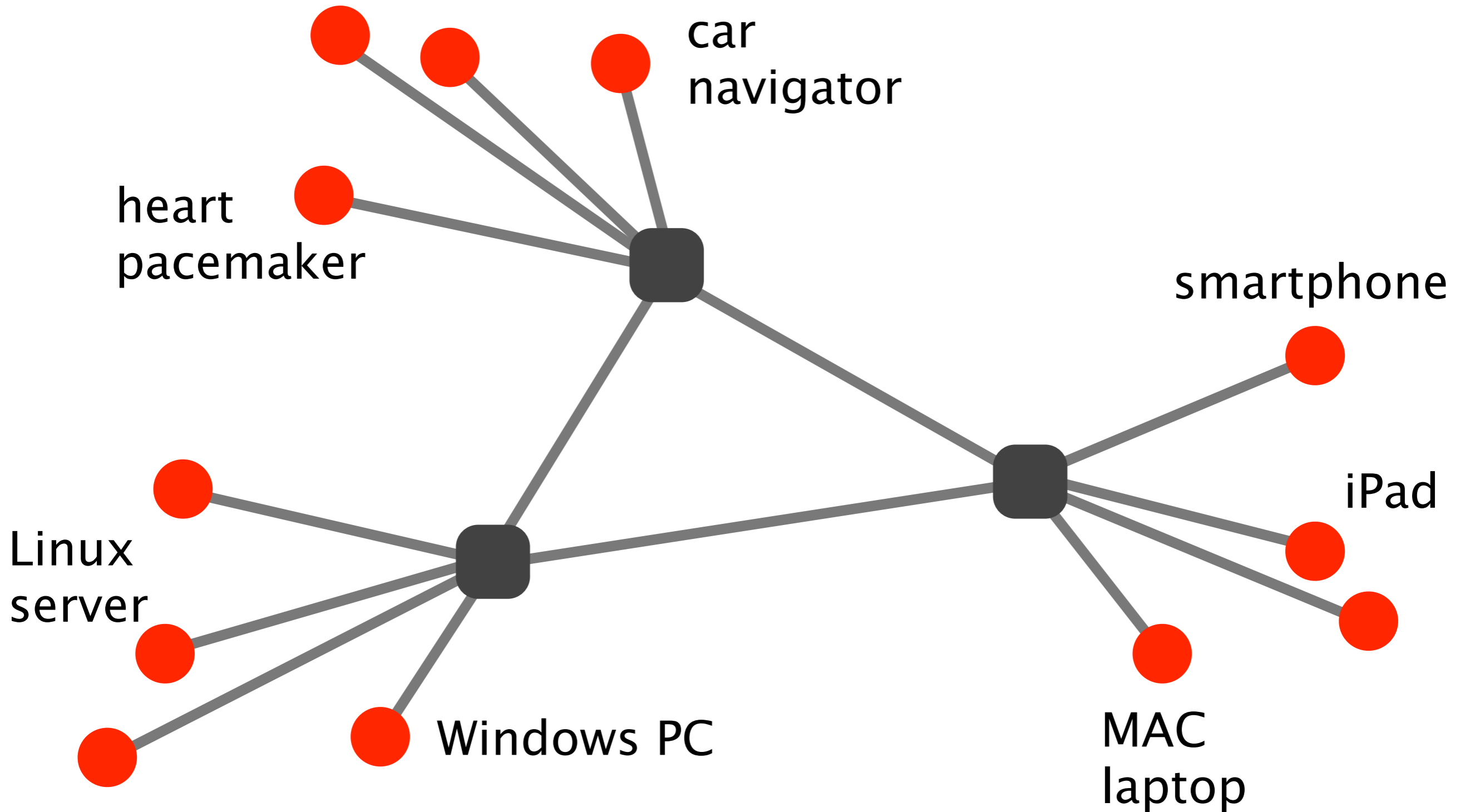
Networks are composed of three basic components



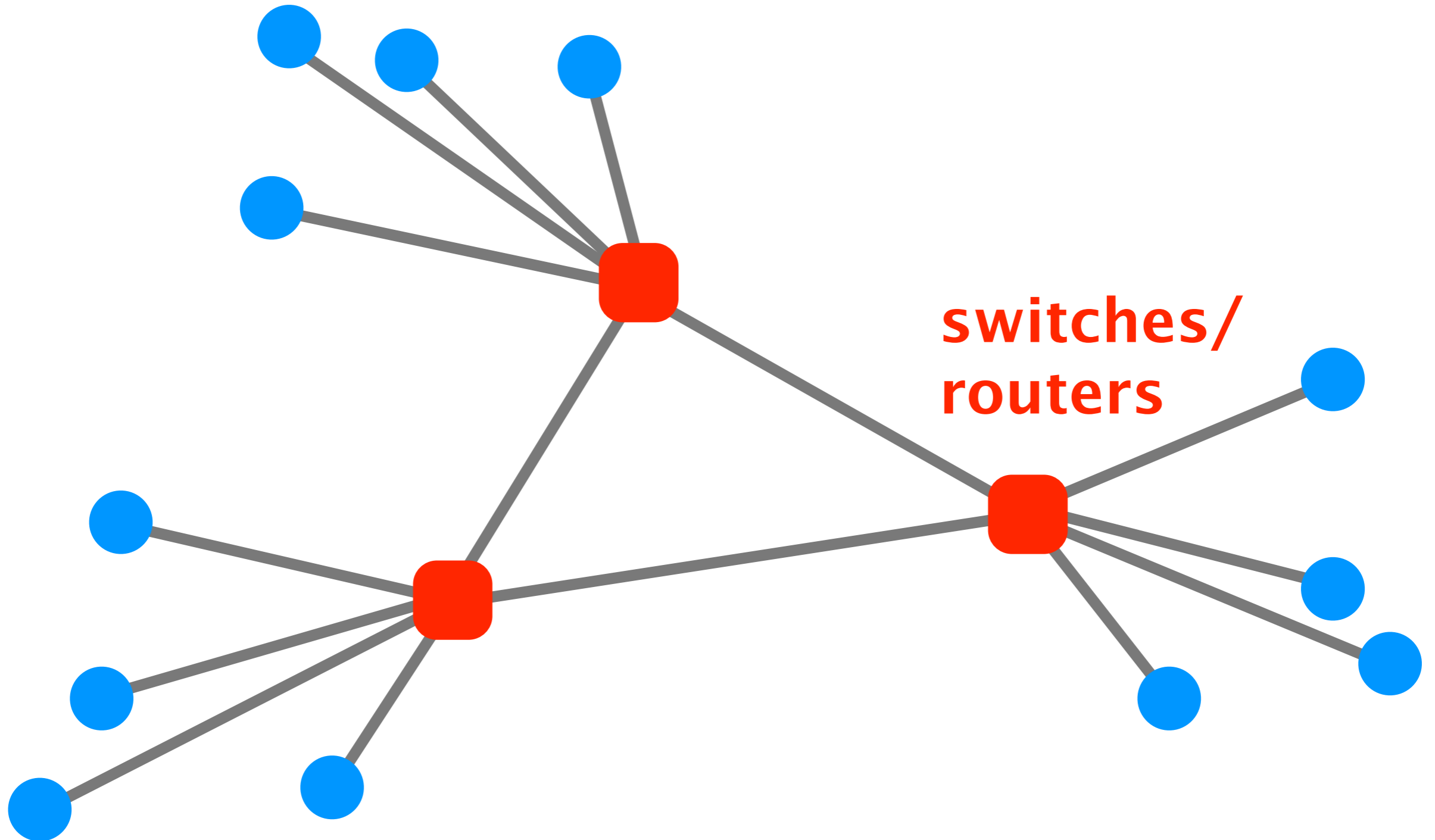
End-systems send & receive data



End-systems come in a wide-variety



Switches & routers forward data to the destination



# Routers/switches vary in size and usage

Home  
router



~20 cm

0,5 kg

1 Gbps

Internet core  
router

>200cm

700kg

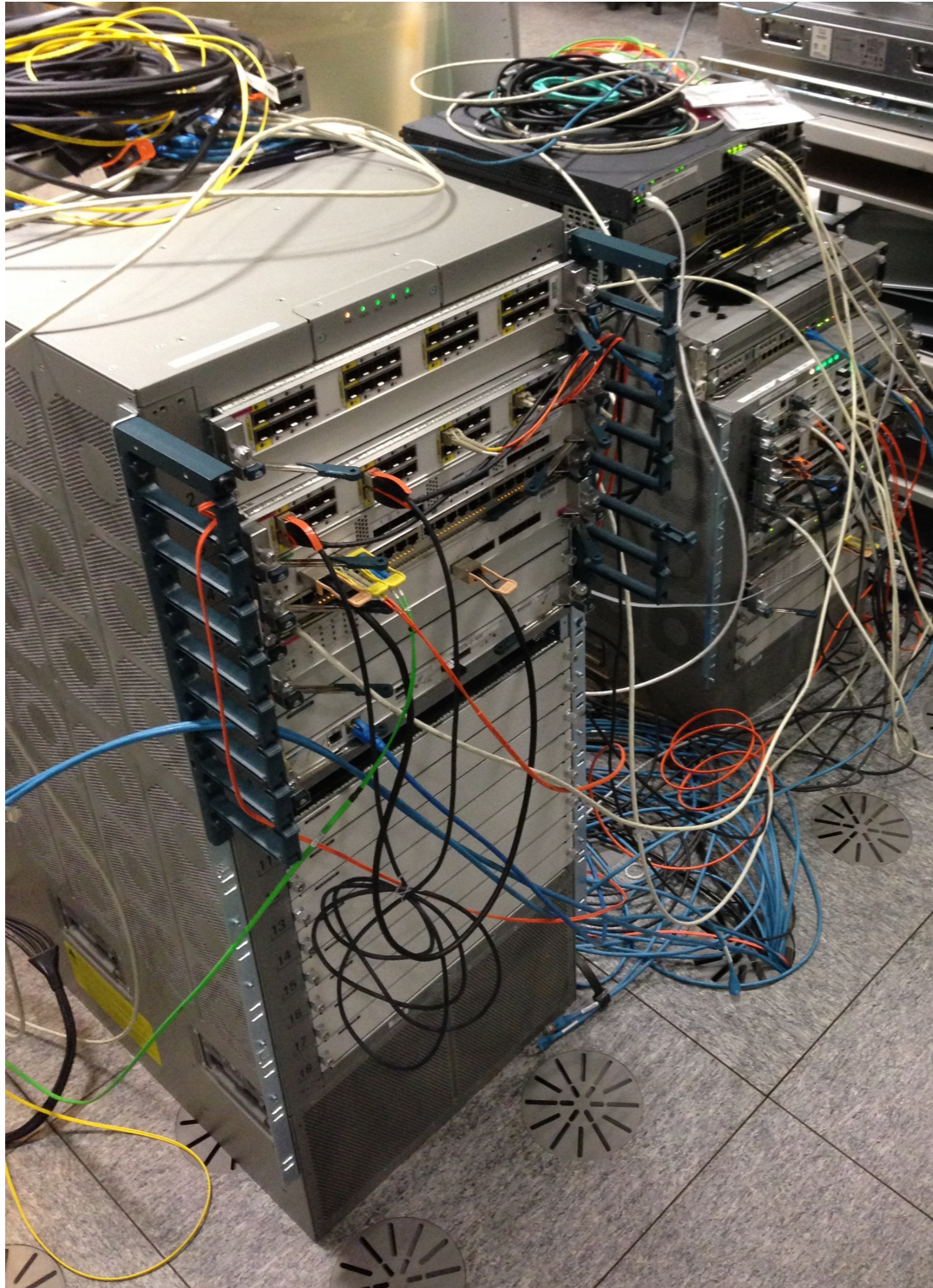
>12 Tbps

(>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)



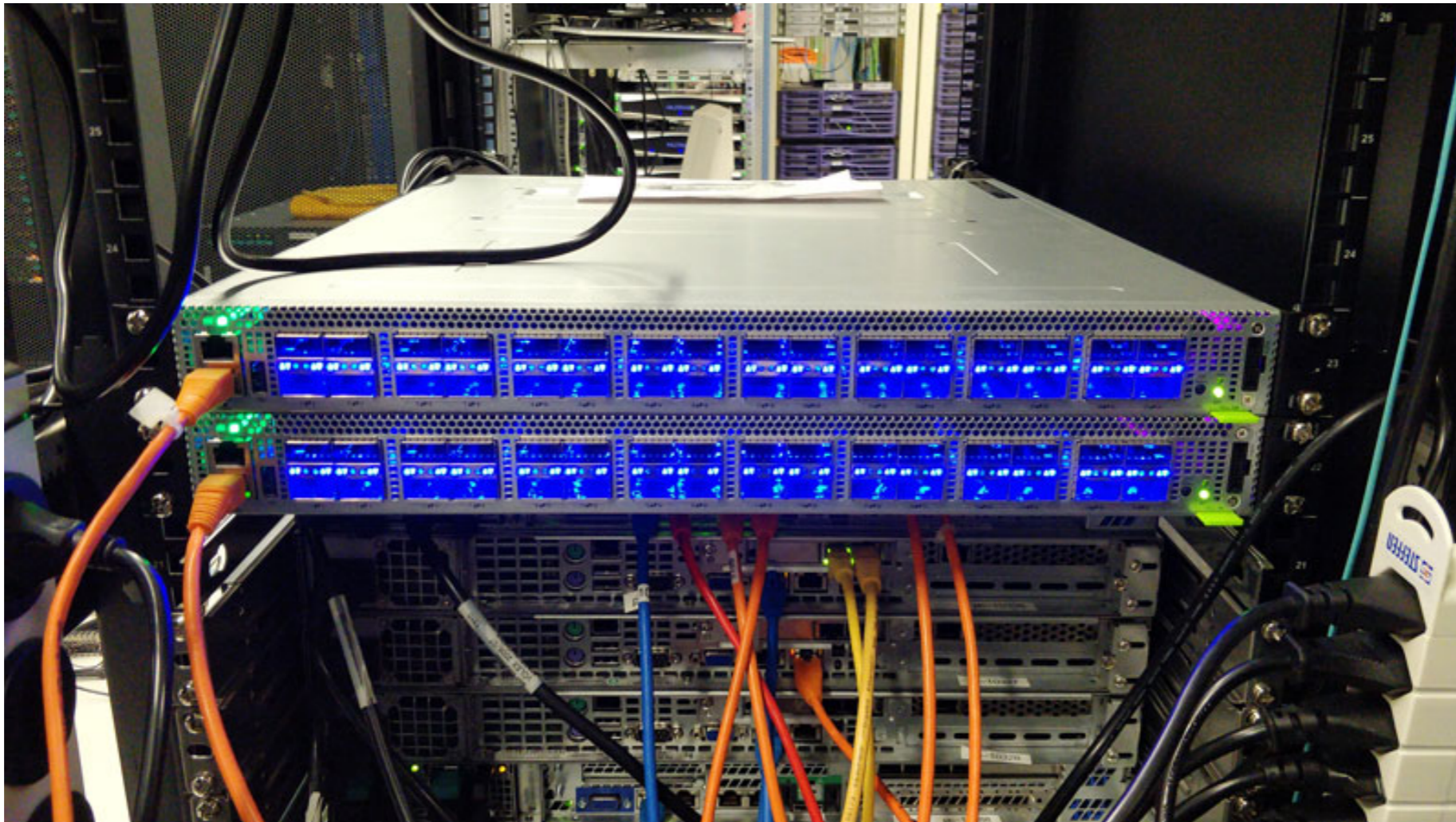


Cisco Nexus 7k  
Routers @ETHZ

~25 deployed



Next-generation programmable switches  
up to **25.6 Tbps** of backplane capacity\*

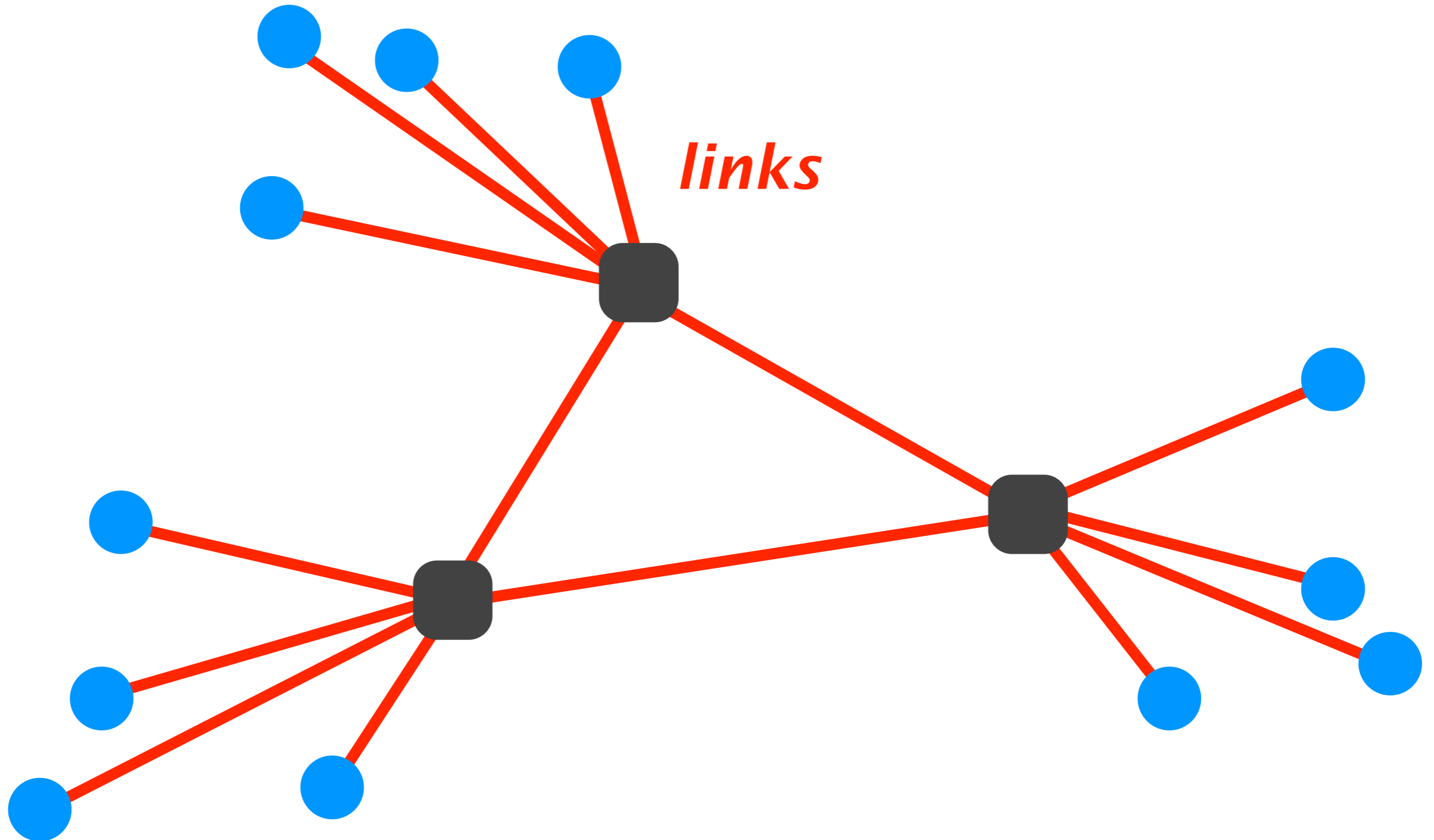


Barefoot Tofino Wedge 100BF-32X

part of our NSG lab

\* <https://www.intel.com/content/www/us/en/products/network-io/programmable-ethernet-switch/tofino-3-brief.html>

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



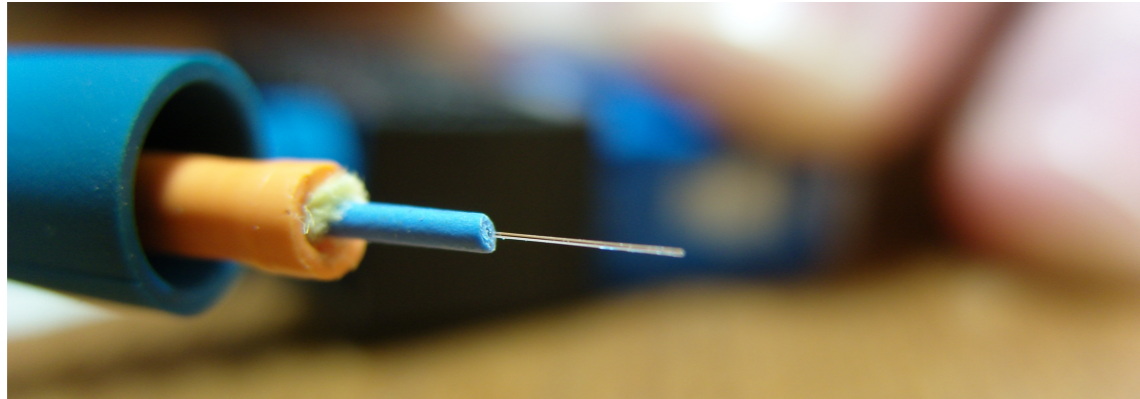


# Links, too, vary in size and usage



Copper

ADSL, RJ-45,...



Optical fibers



Wireless link

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?

# A good network topology fulfills at least three requirements

## Tolerate failures

>1 path should exist between each node

## Allow sharing to be feasible & cost-effective

# links should not be too high

## Provide ample capacity

# links should not be too small

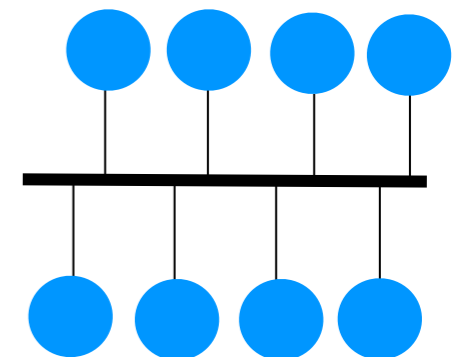
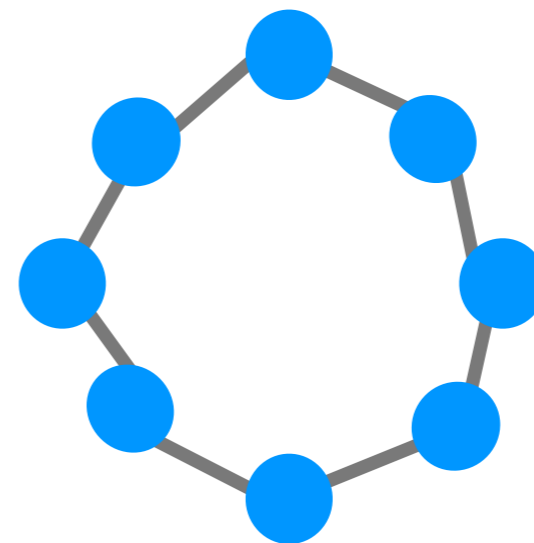
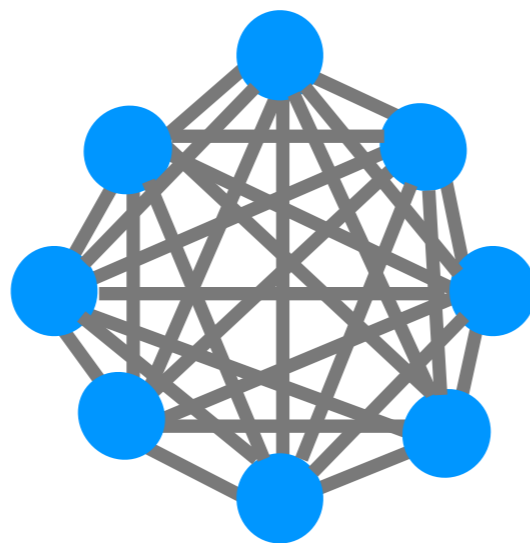
# Compare these three designs in terms of **sharing**, **resiliency**, and **per-node capacity**

design

full-mesh

chain

bus



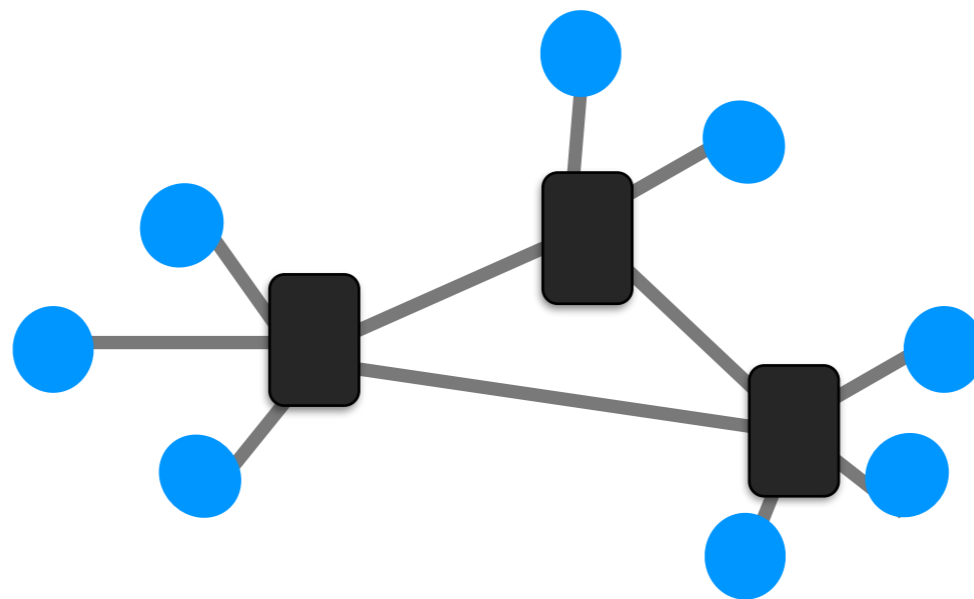
advantages

disadvantages

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

design

switched



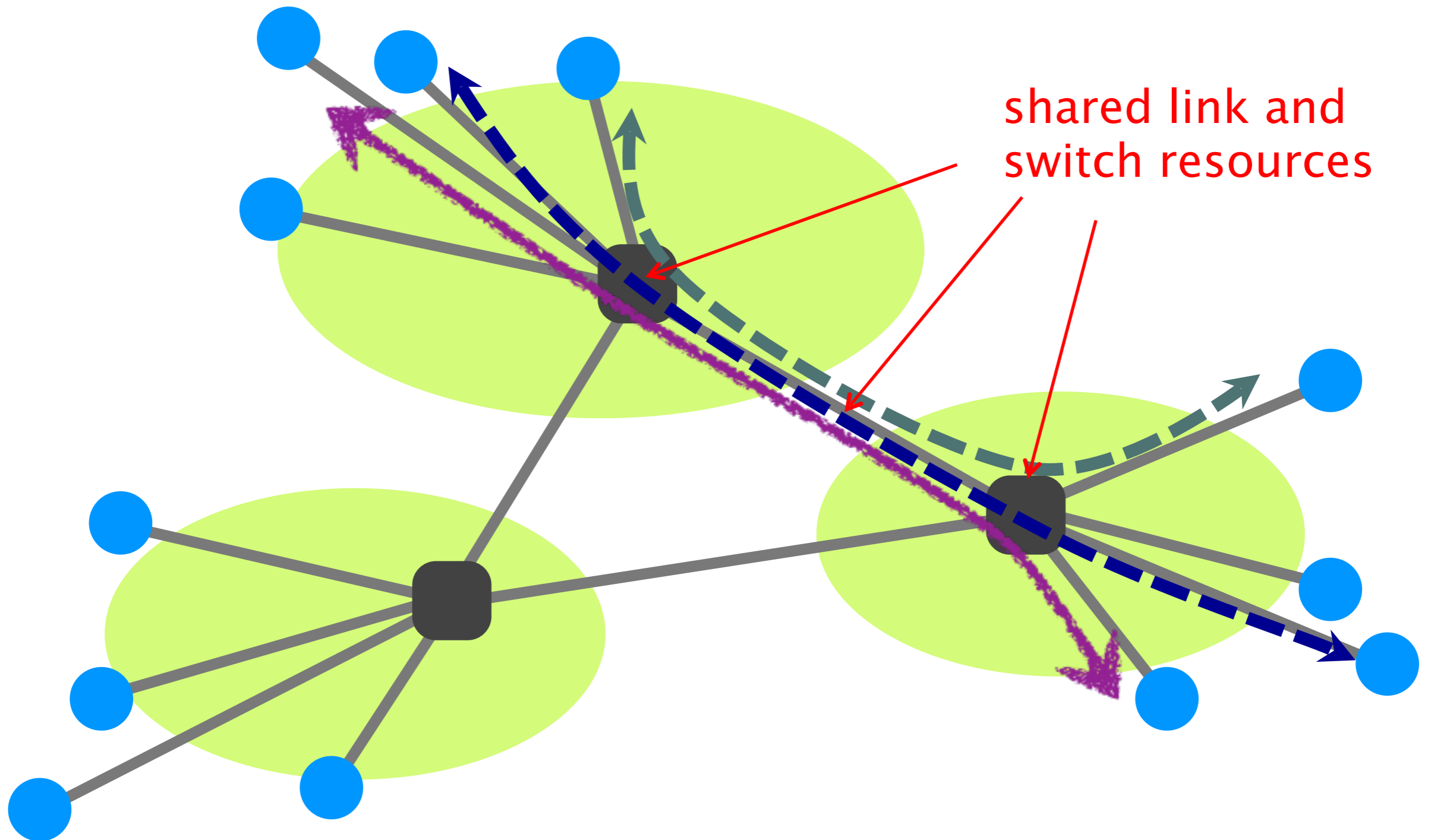
advantages

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**

A light green rectangular box with the word "Reservation" centered inside in a dark gray font.

Reservation

A light green rectangular box with the words "On-demand" centered inside in a dark gray font.

On-demand

principle

reserve the bandwidth  
you need in advance

send data when you need

Both are examples of **statistical multiplexing**



Reservation



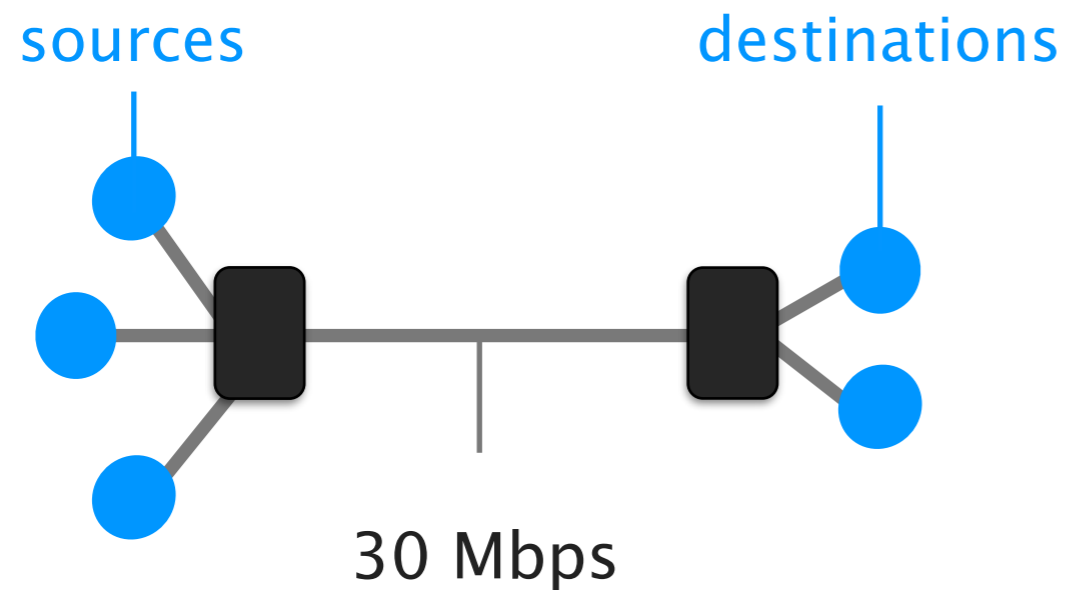
On-demand

multiplexing

**at the flow-level**

**at the packet-level**

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

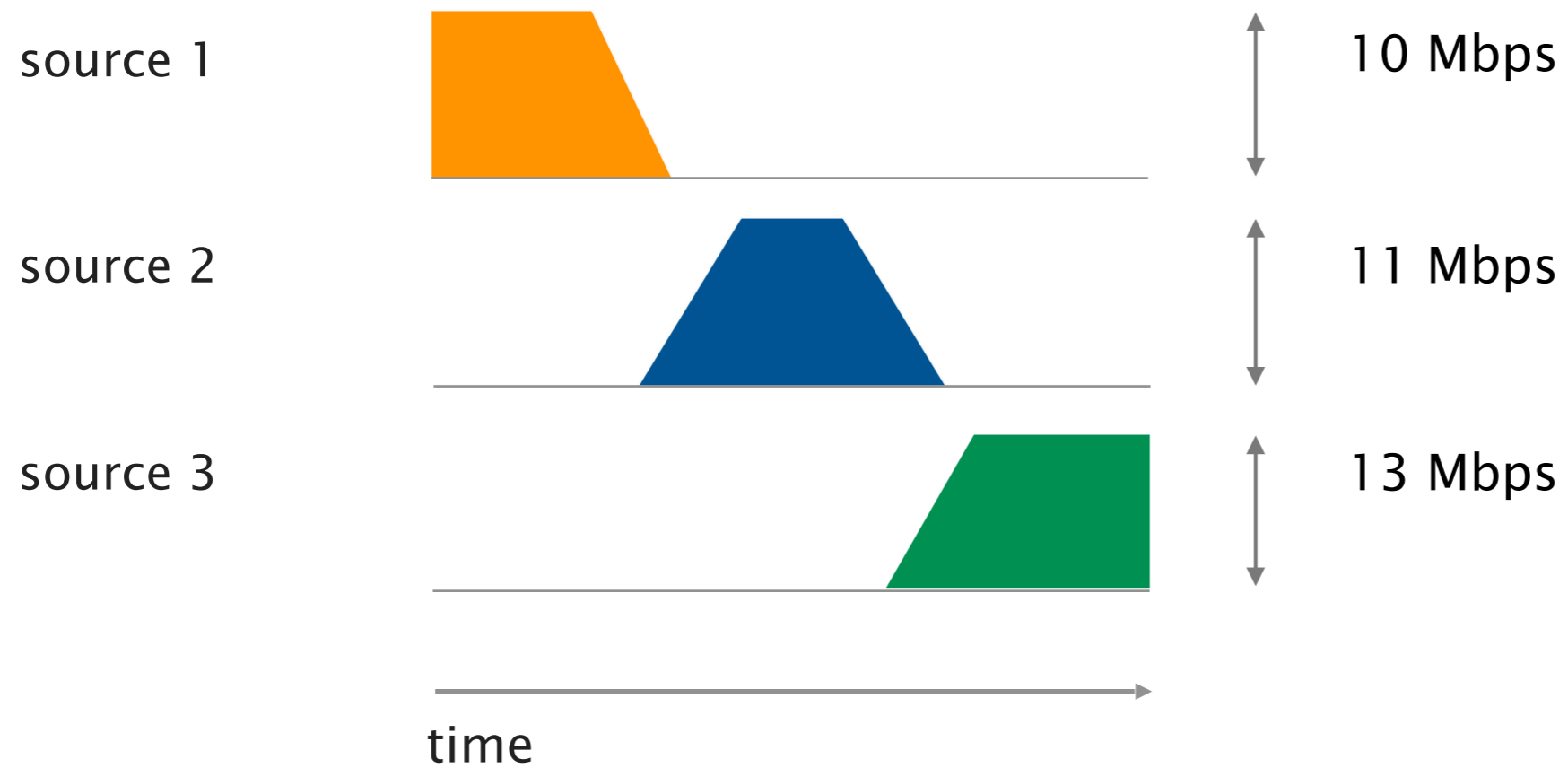


Consider that each source  
needs 10 Mbps

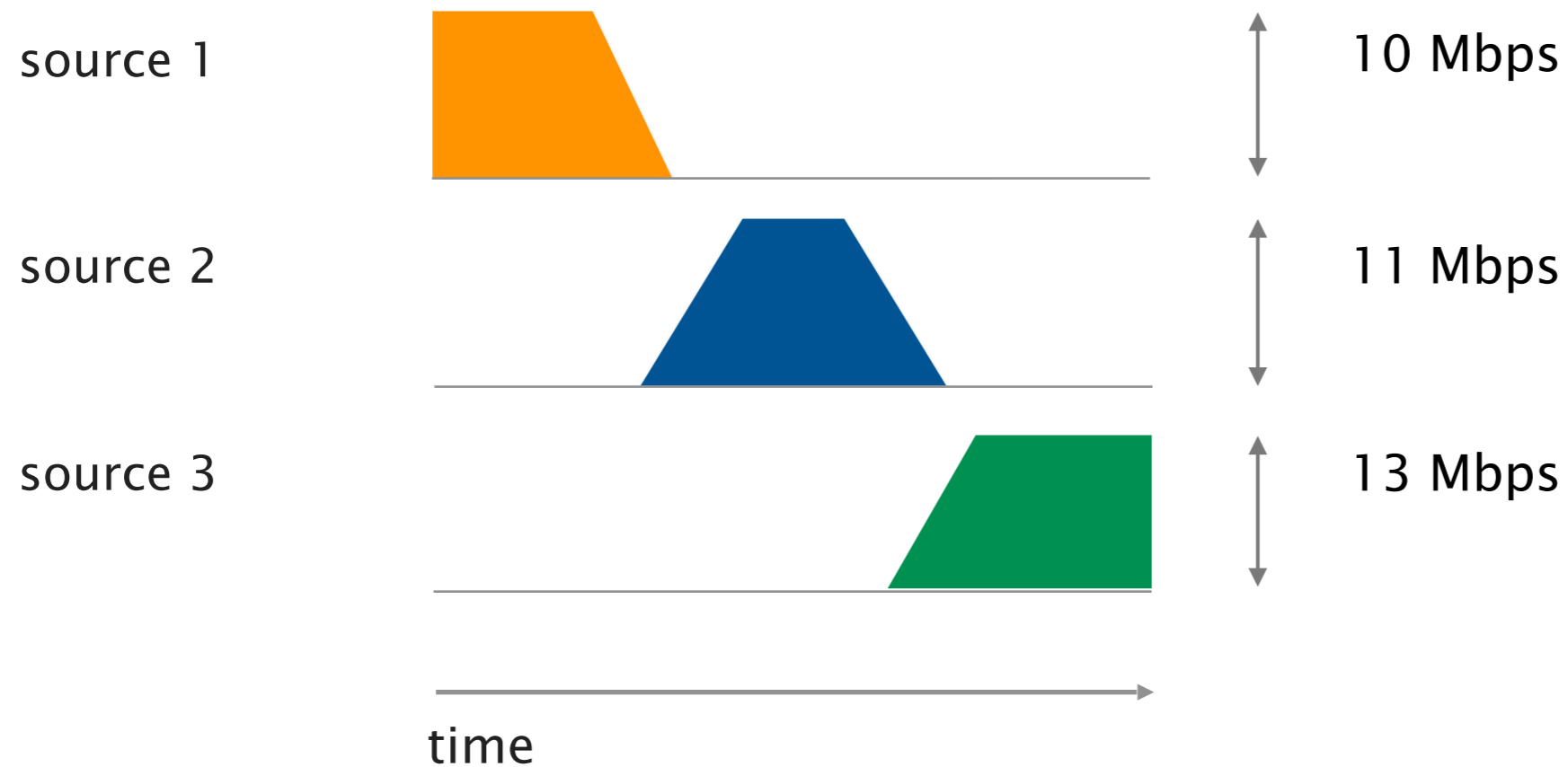
What do they get with:

- 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

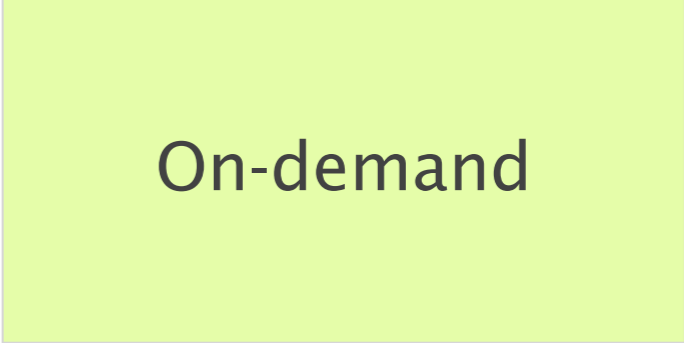
Reservation **wastes capacity** when  $P/A$  is big

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



implem.

circuit-switching

packet-switching

Reservation

On-demand

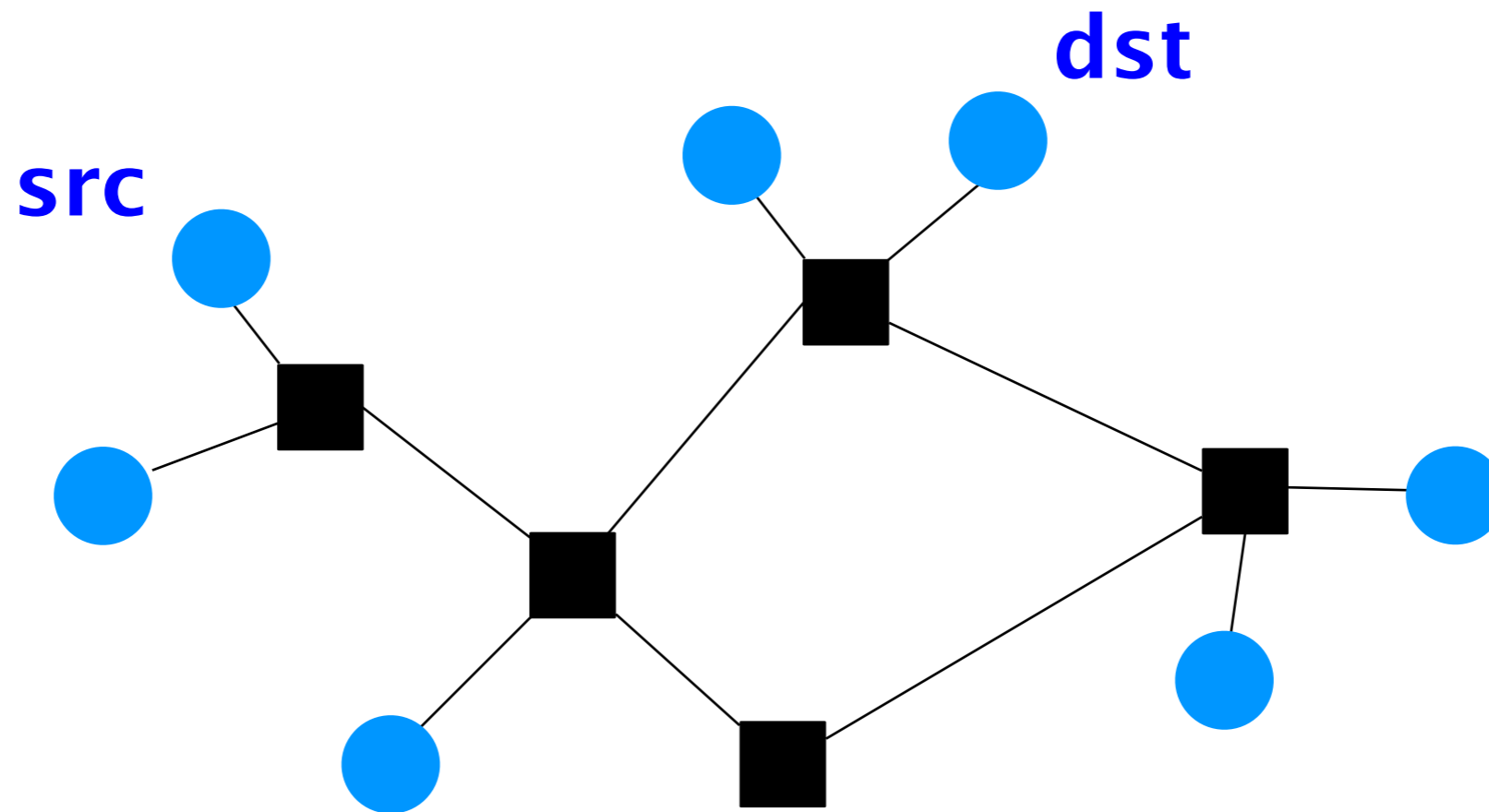
implem.

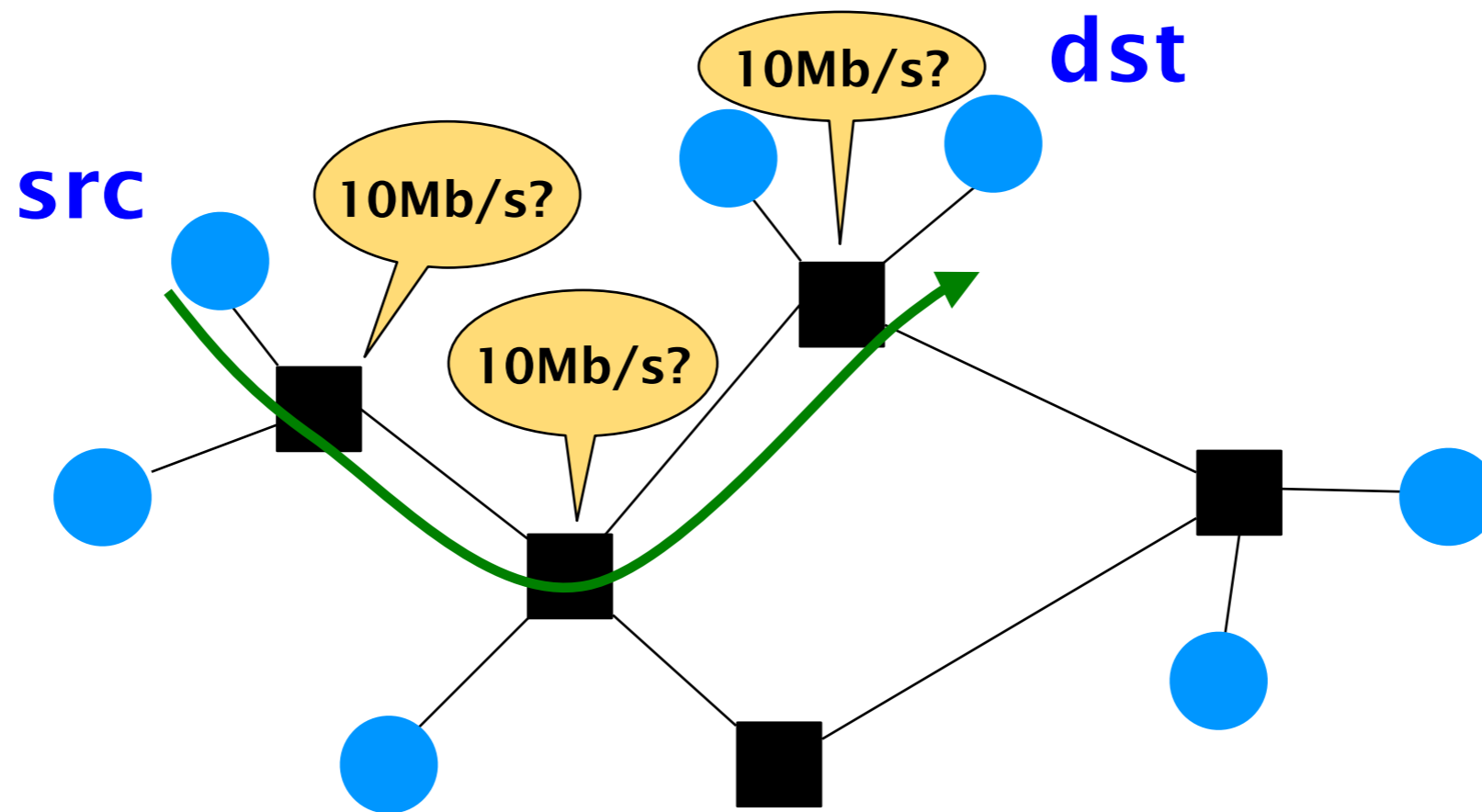
circuit-switching

packet-switching



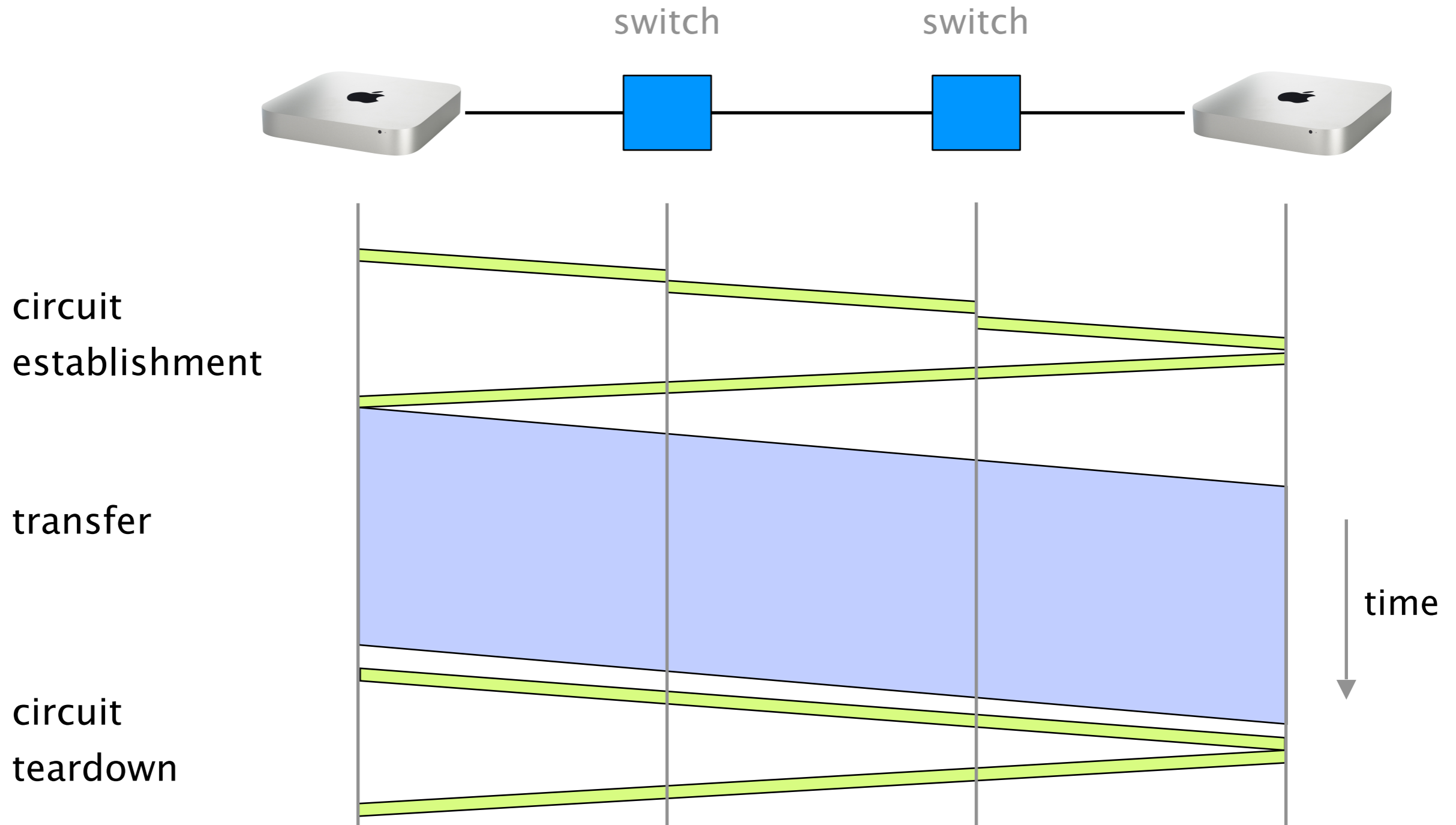
Circuit switching relies on  
the Resource Reservation Protocol





- (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

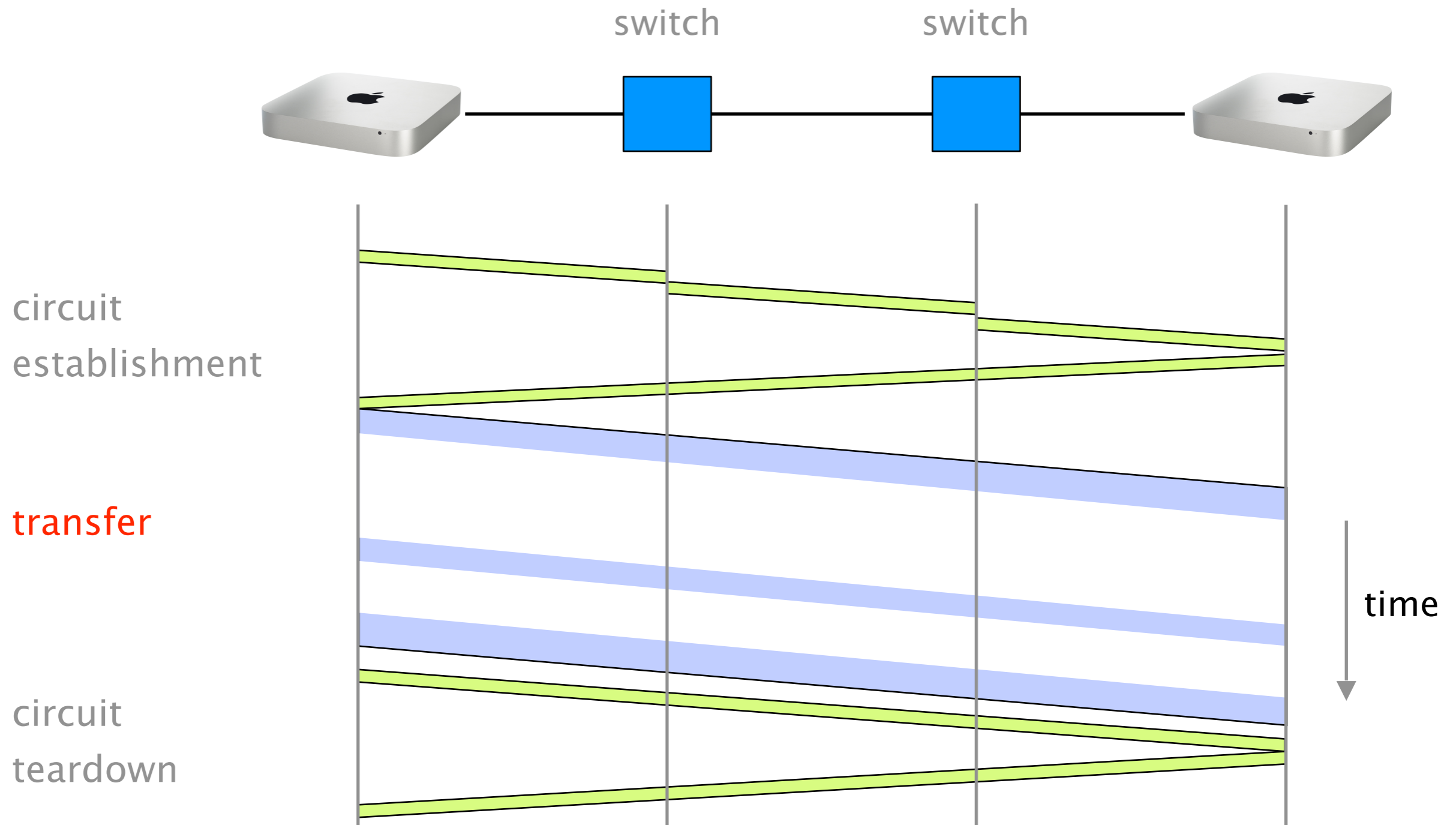
# Let's walk through example of data transfer using circuit switching



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

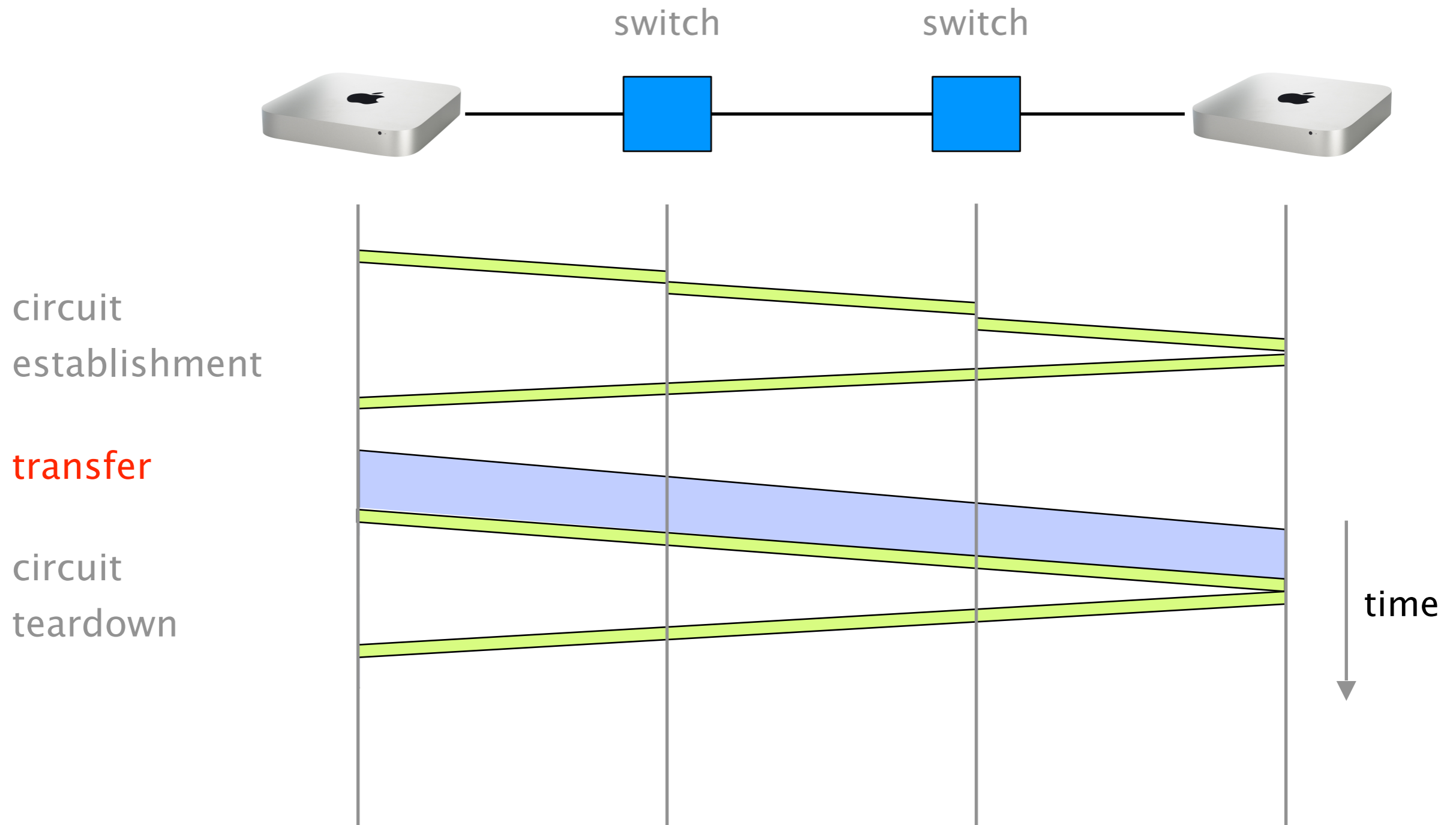
This is an example of poor efficiency.

The circuit is mostly idle due to traffic bursts

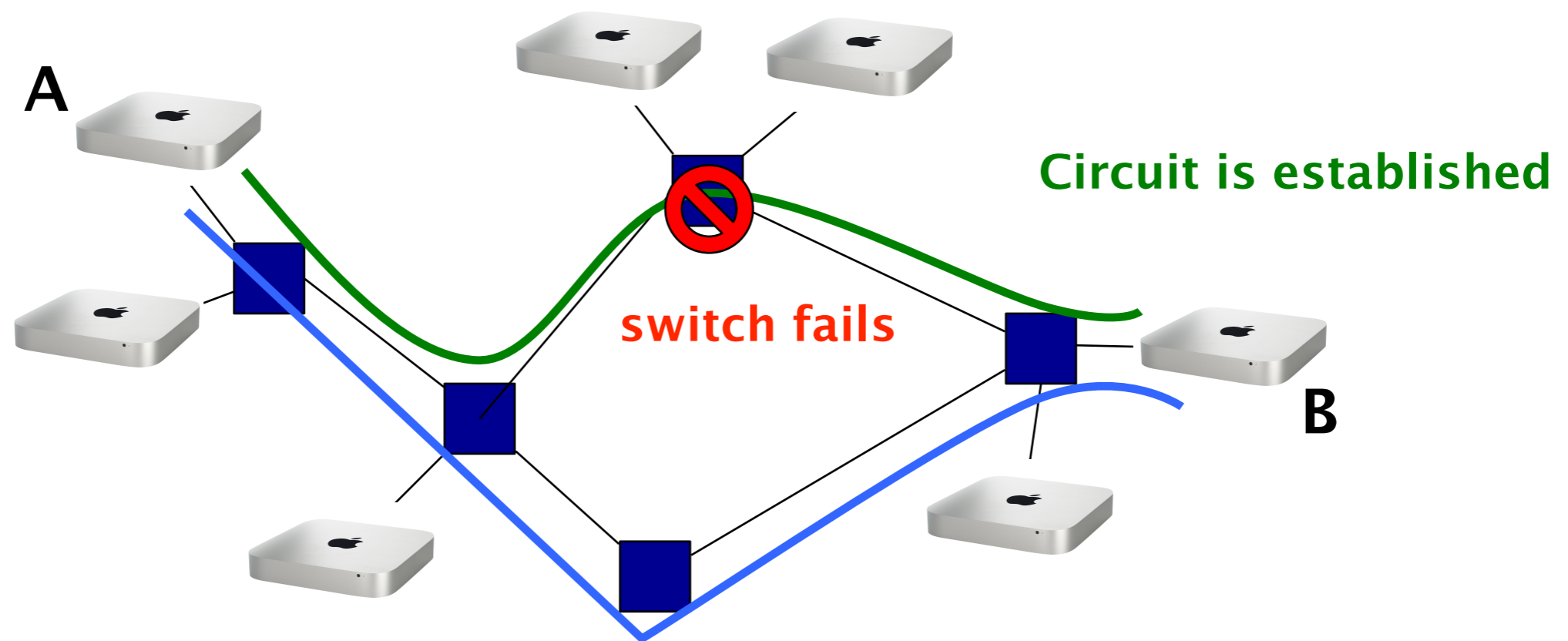




This is another example of poor efficiency.  
The circuit is used for a short amount of time



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?

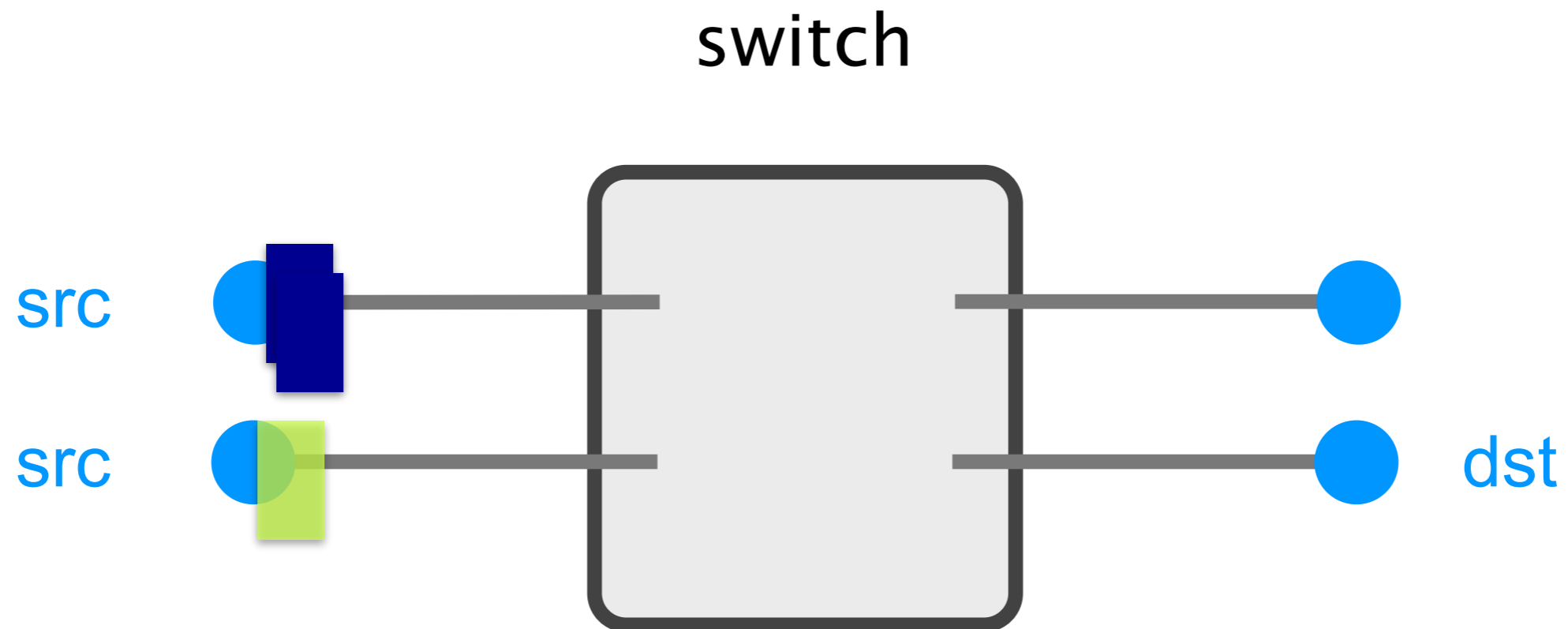
Reservation

On-demand

circuit-switching

packet-switching

In packet switching,  
data transfer is done using independent packets



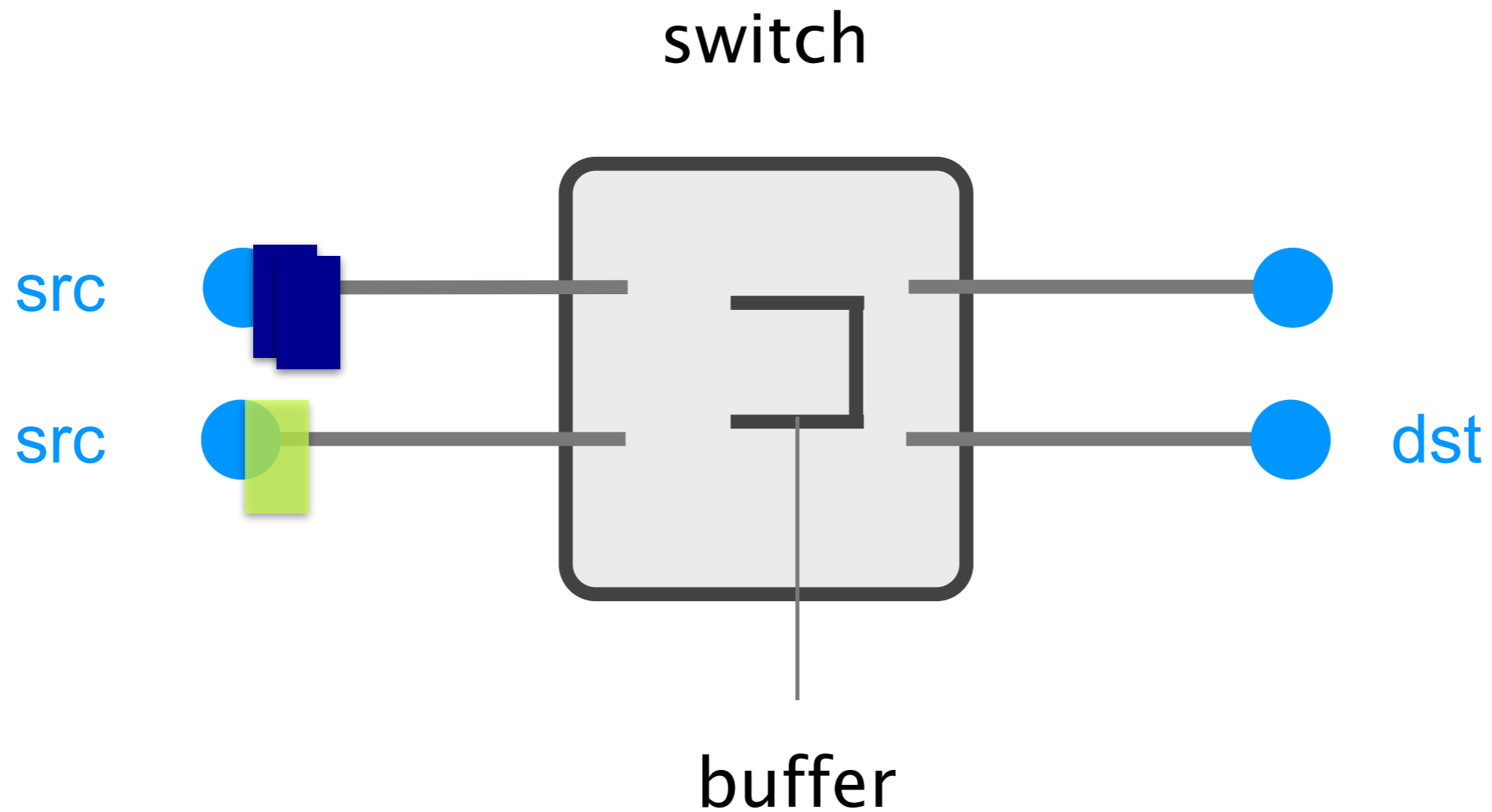
Each packet contains a destination (**dst**)

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

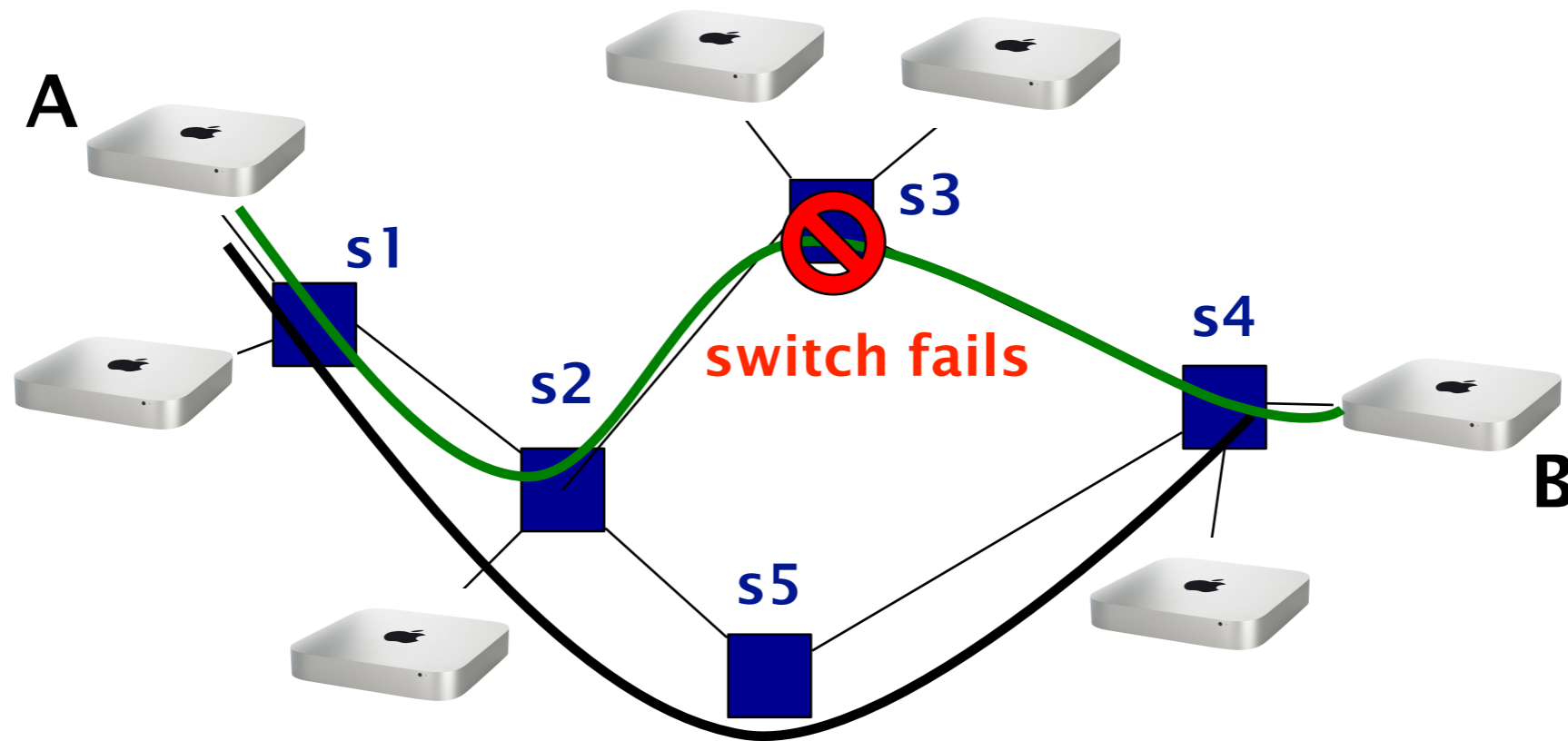


To absorb transient overload,  
packet switching relies on buffers

To absorb transient overload,  
packet switching relies on buffers



# Packet switching routes around trouble



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?

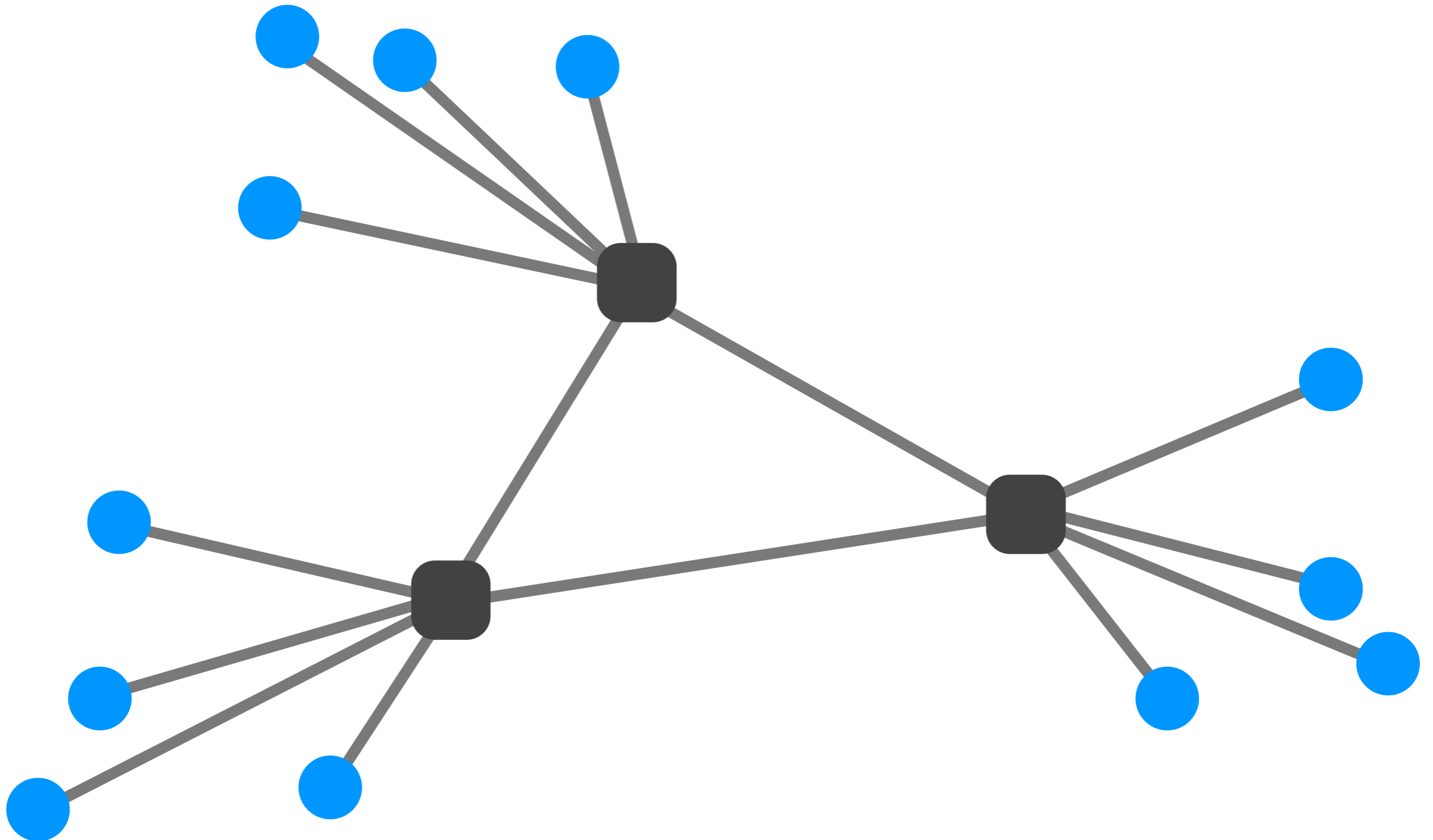
**#3** **How is it organized?**

How does communication happen?

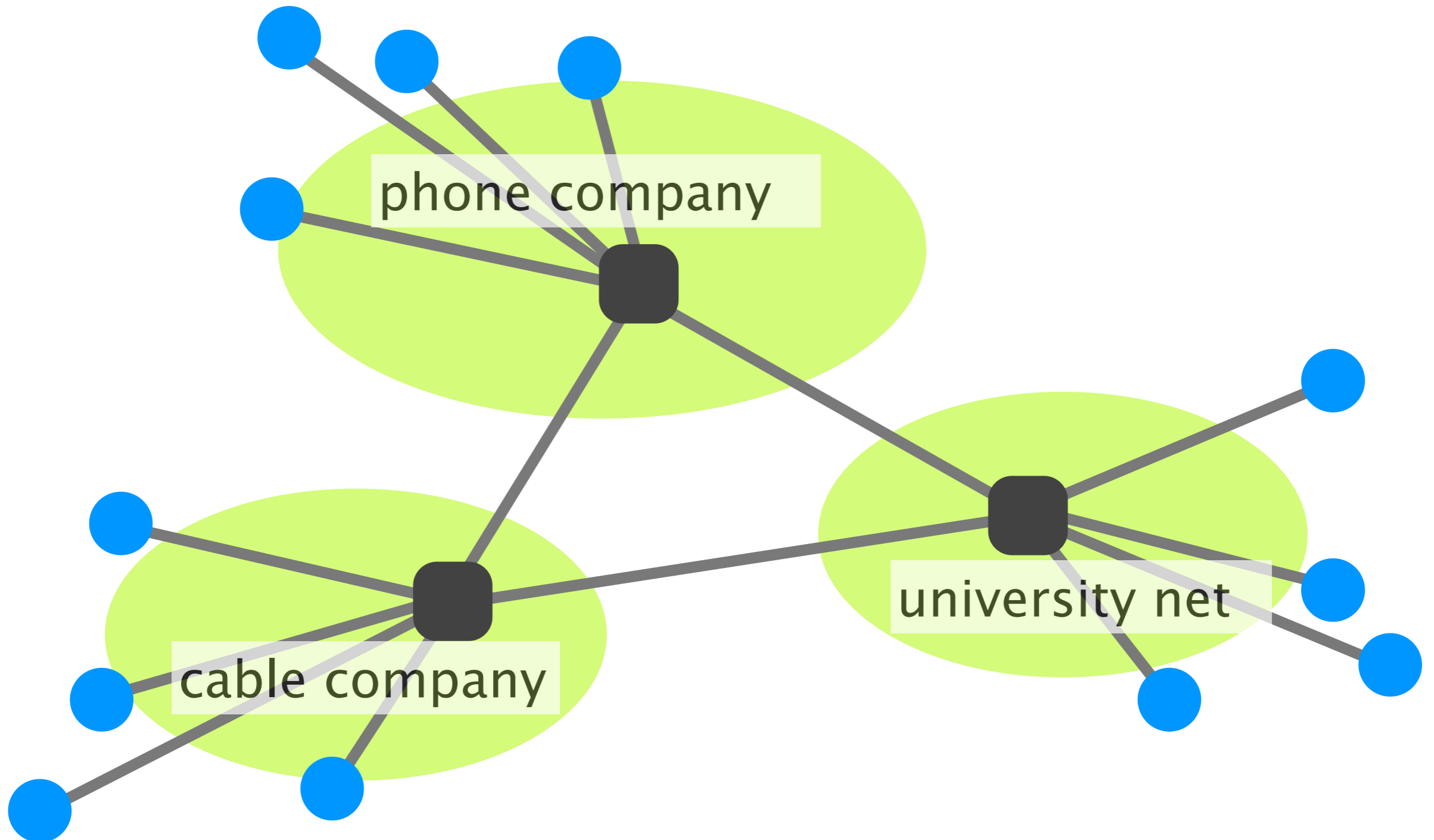
How do we characterize it?



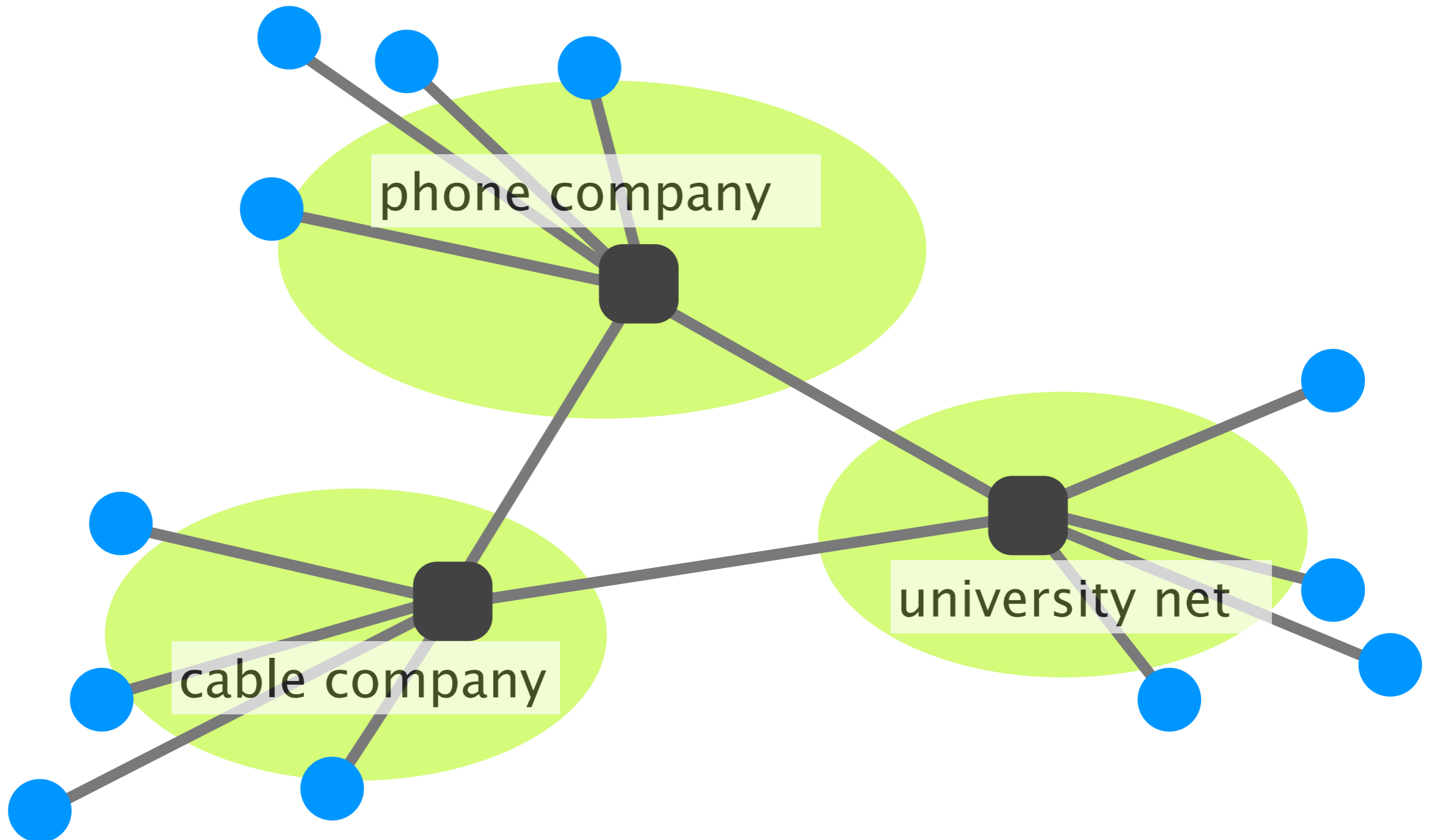
The *Inter*net is a network of networks



# Internet Service Providers

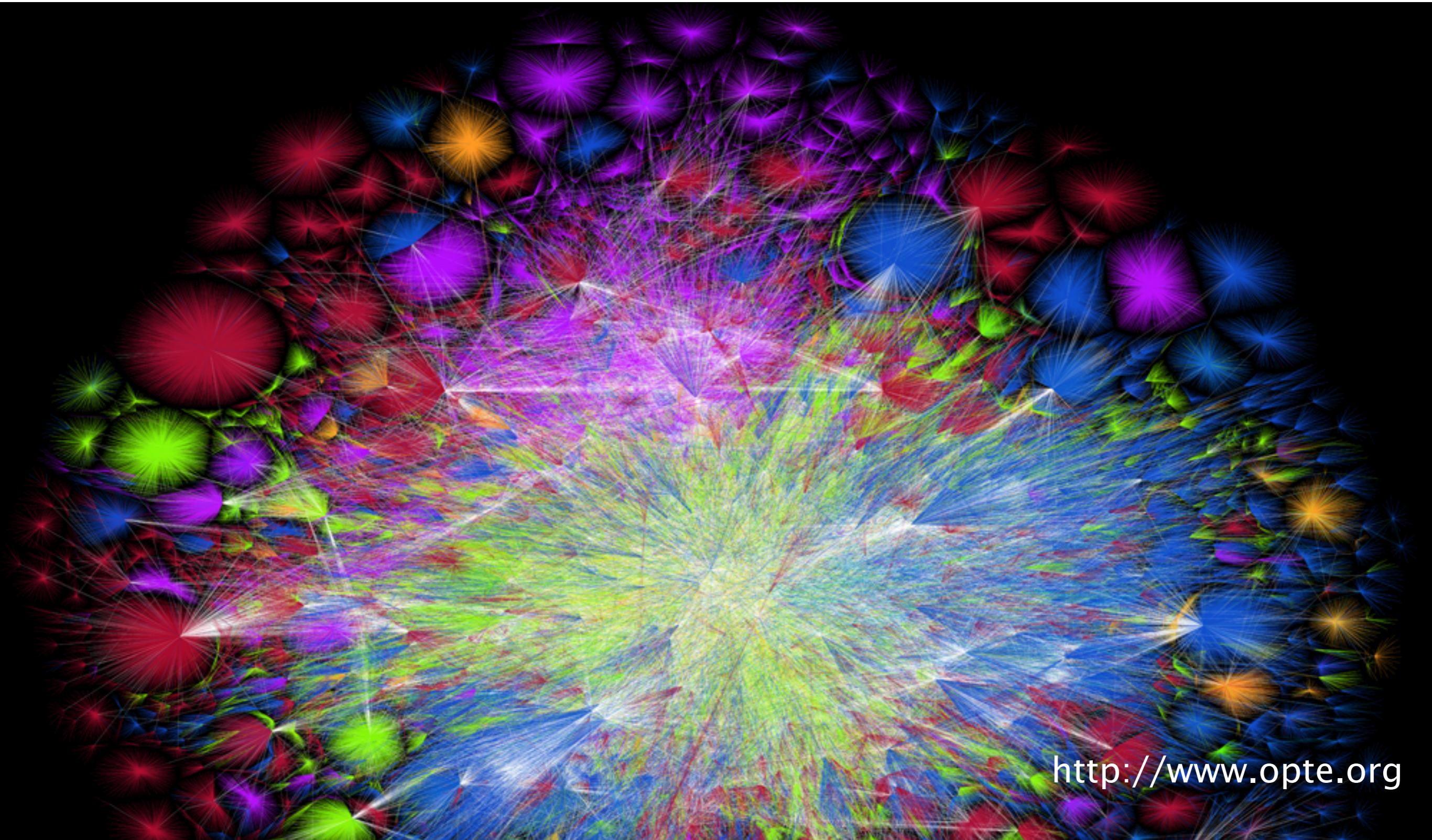


So far, this is our vision of the Internet...



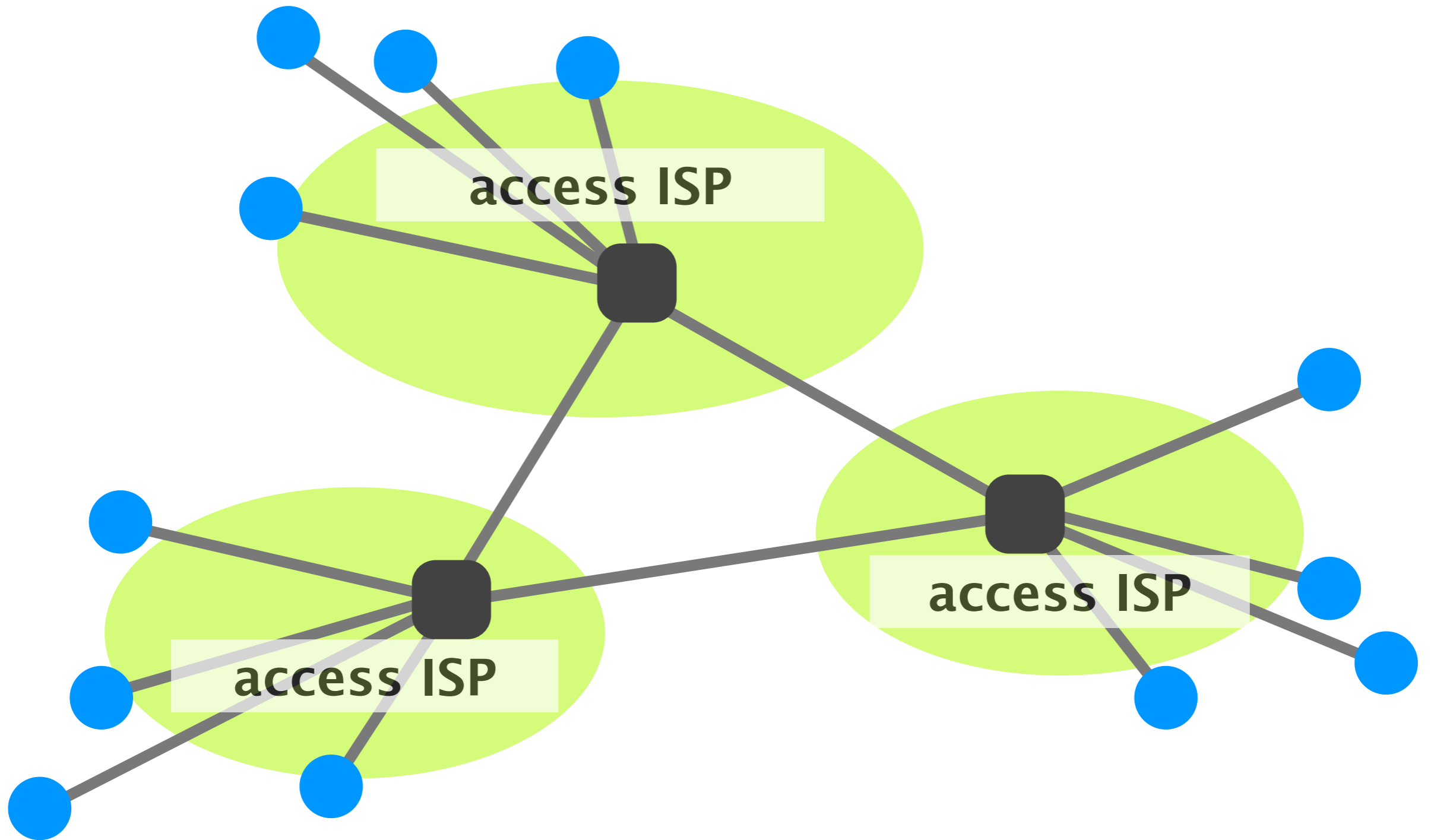


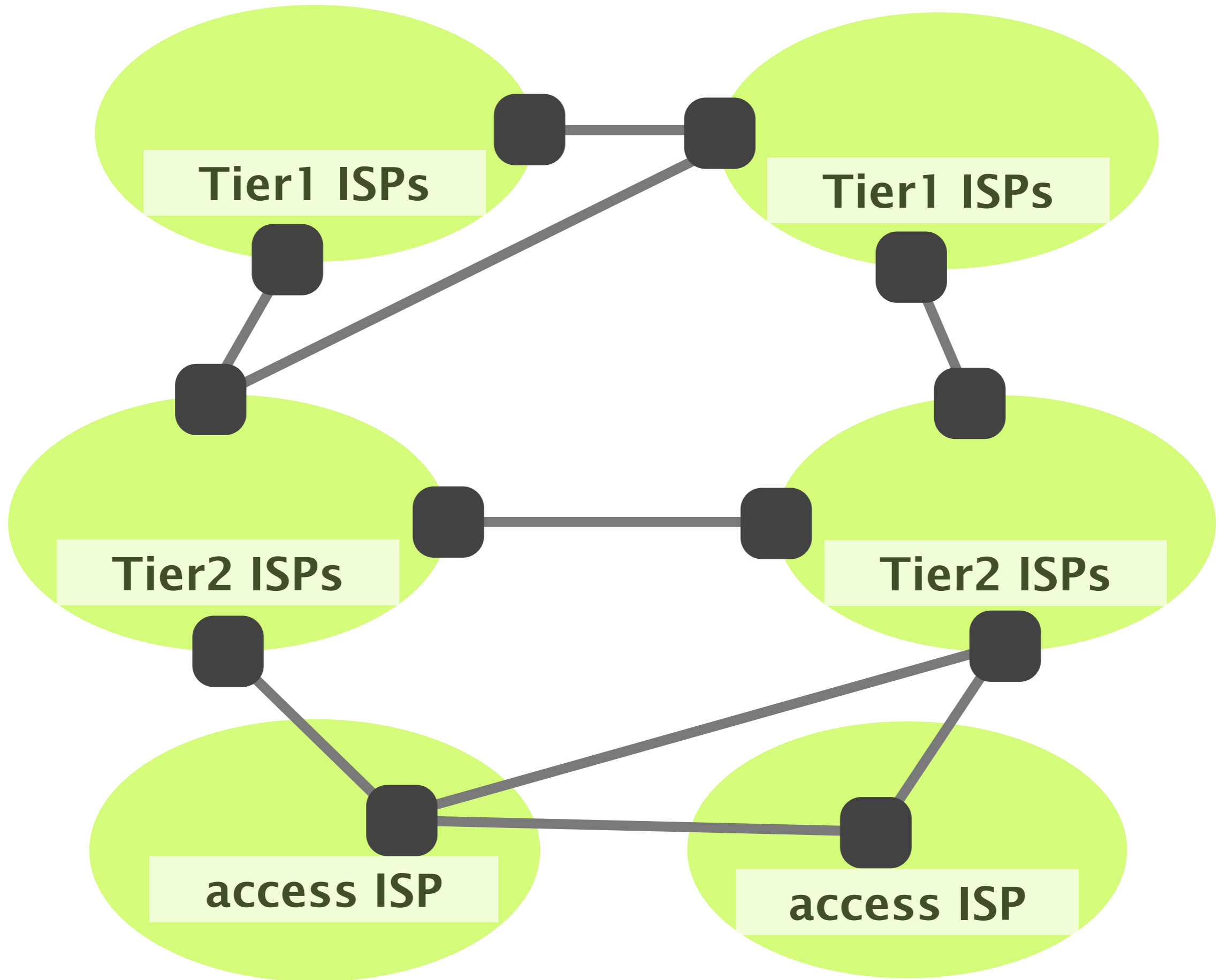
The real Internet is a “tad” more complex



<http://www.opte.org>









# The Internet has a hierarchical structure

Tier-1

international

have no provider

Tier-2

national

provide transit to Tier-3s

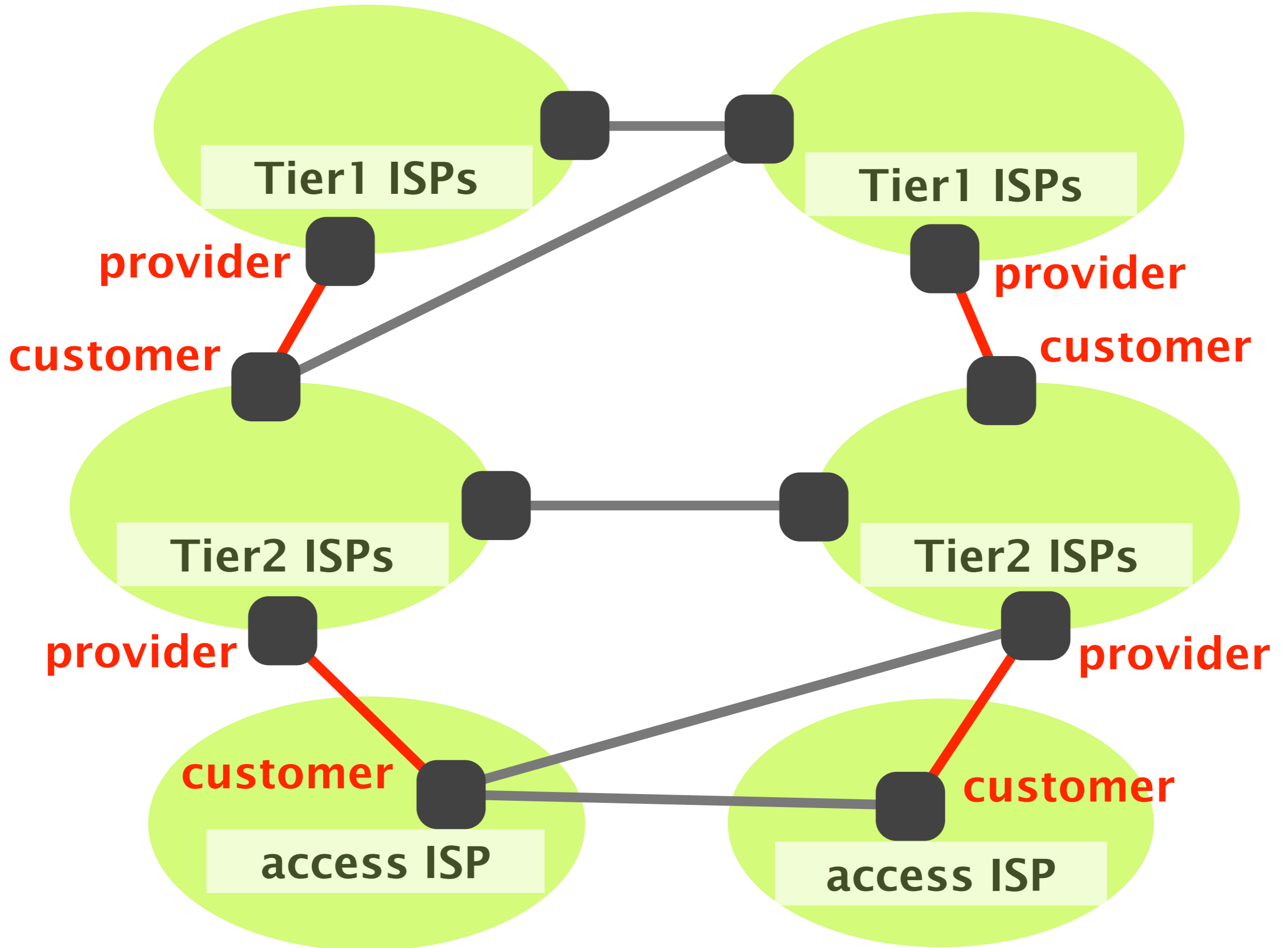
have at least one provider

Tier-3

local

do not provide any transit

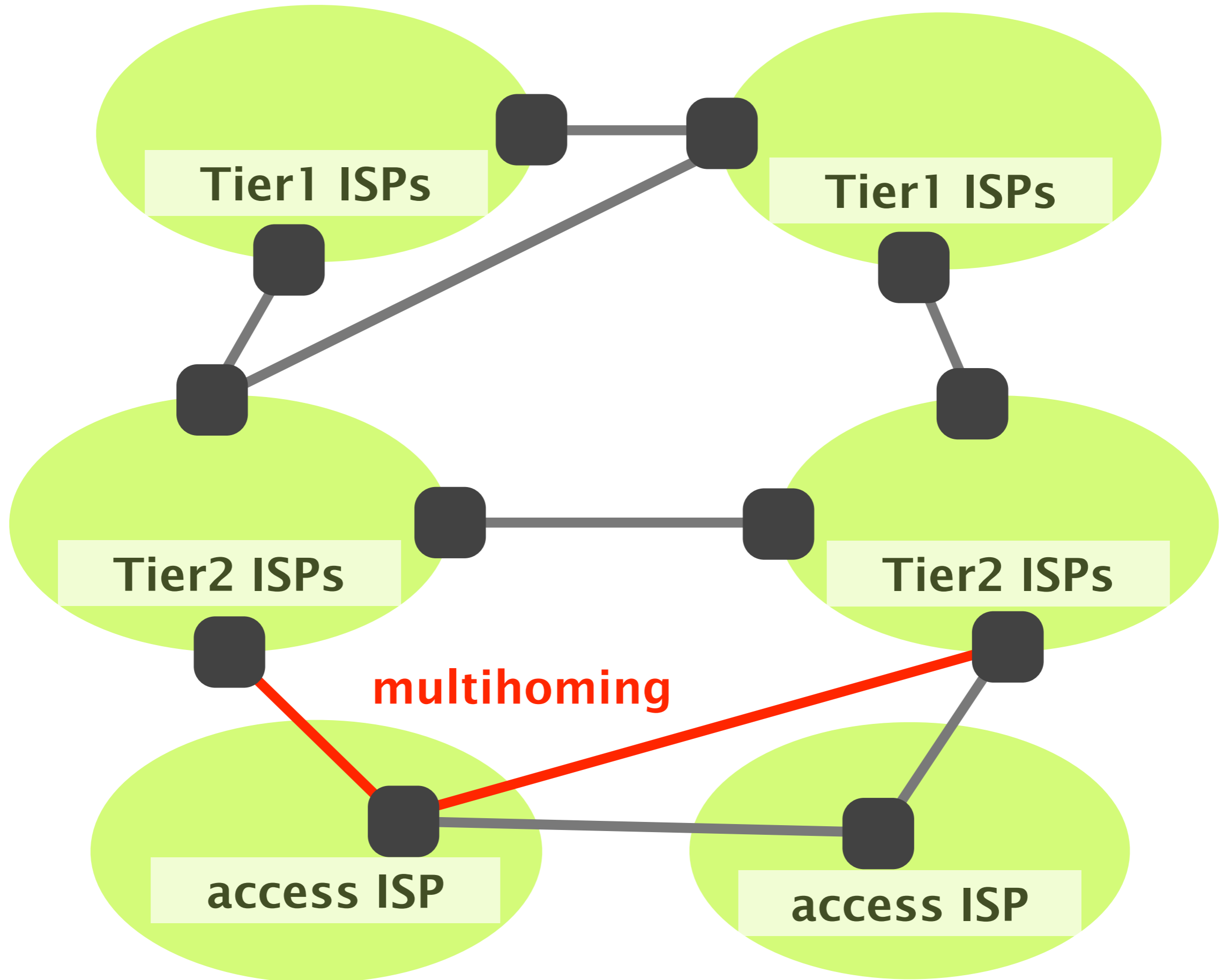
have at least one provider



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

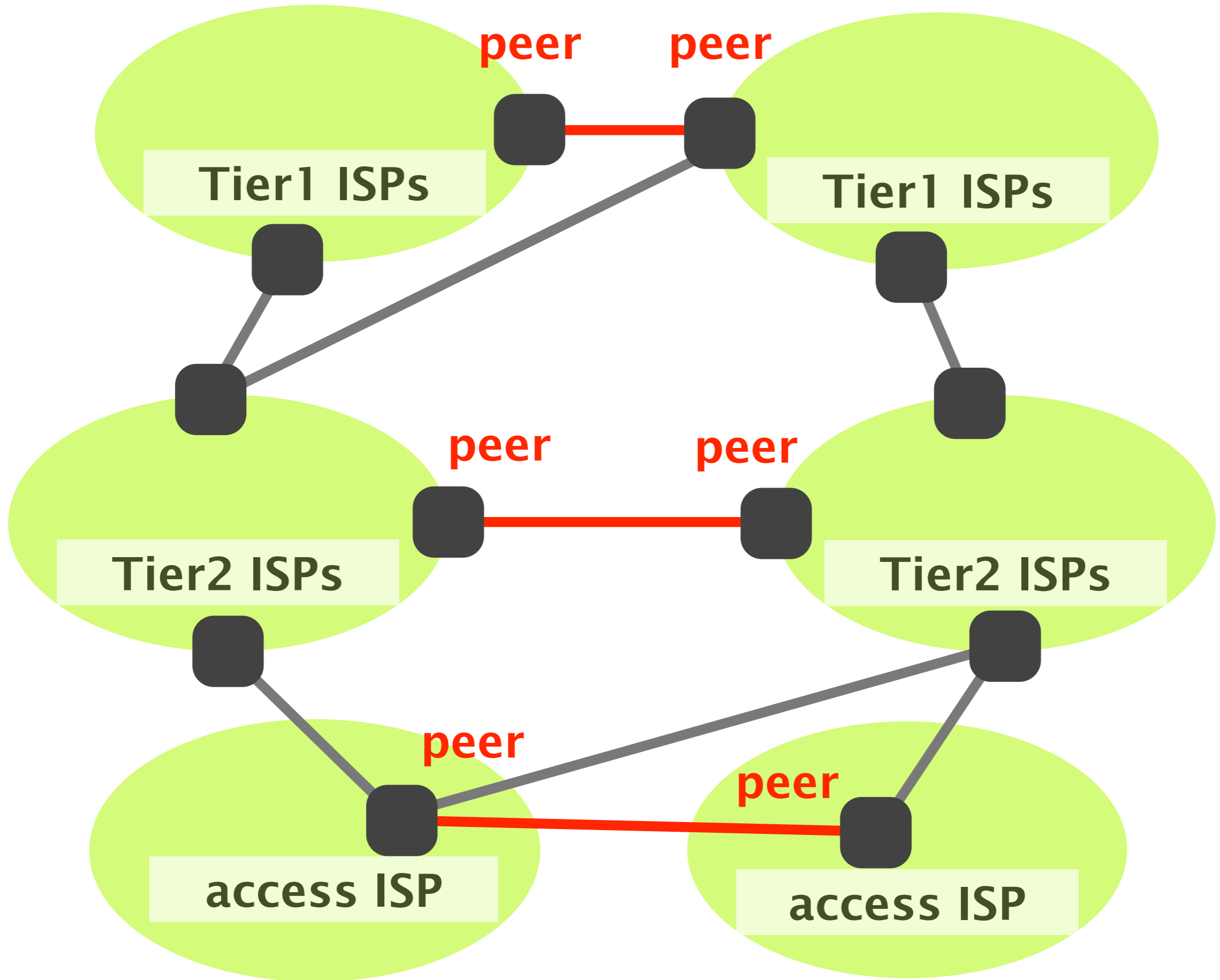
total ~70,000  
networks

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

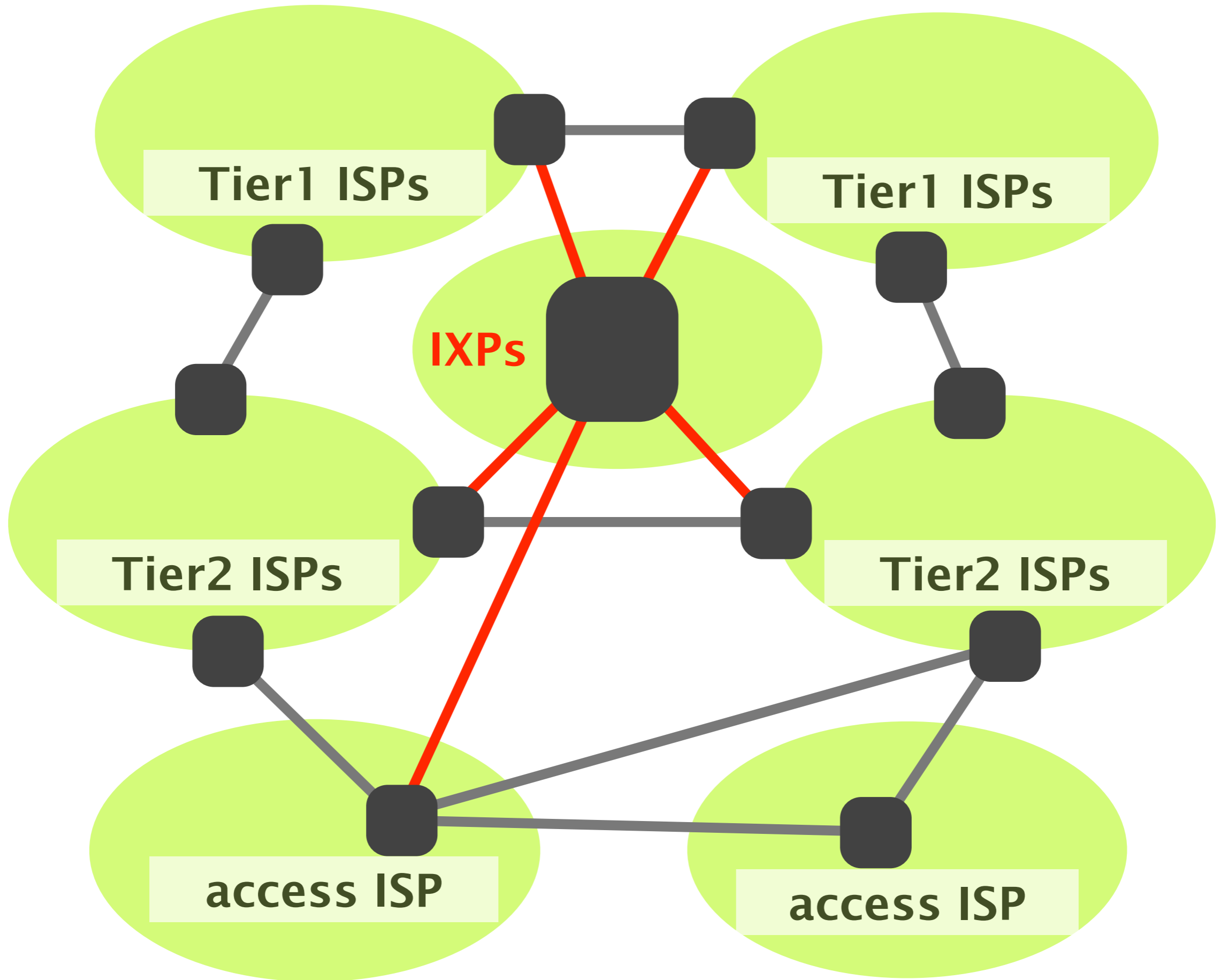
## Bandwidth costs

a lot of links are not necessarily fully utilized

## Human costs

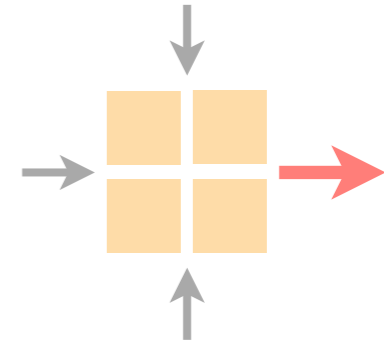
to manage each connection individually

Internet eXchange Points (IXPs) solve these problems by letting *many* networks connect in one location



# 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