Computer Networks

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Eötvös Loránd University

Based on the slides of Laurent Vanbever.
Further inspiration: Scott Shenker & Jennifer Rexford & Phillipa Gill

Hello!

- Welcome to Computer Networks
  - Are you in the right classroom?
  - Okay, good.

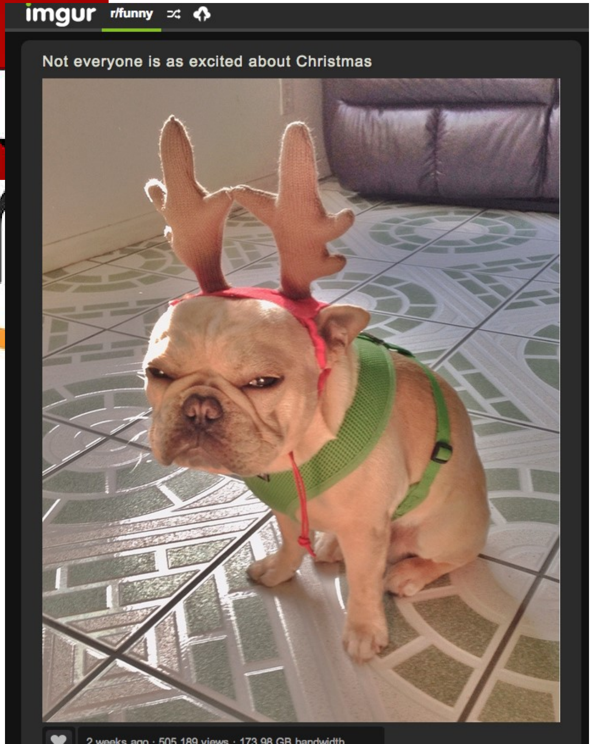
- Who am I?
  - Sándor Laki, PhD
  - Assistant Professor at Dept. Of Information Systems
  - lakis@inf.elte.hu
  - Office: Southern Building, Room 2.506
  - Office Hours: 10-11 Thursday, in room 2.506

Why Take This Course?

- How many of you have checked your e-mail, FB, text…
  - Today?
  - In the past hour?
  - Since I started talking?

Computer networks are ubiquitous

- Networks touch every part of our daily life
  - Web search
  - Social networking
  - Watching movies
  - Ordering merchandise
  - Wasting time



Computer networks are ubiquitous

- Networking is one of the most critical topics in CS
  - There would be no…
    - Big Data
    - Cloud
    - Apps or Mobile Computing
  - … without networks

The Internet

a really exciting place

17.1 billion

17.1 billion

number of devices connected to Internet in 2016 (estimation*)

* Cisco Visual Networking Index 2016—2021

27.1 billion

number of devices connected to Internet in 2021 (estimation*)

* Cisco Visual Networking Index 2016—2021

~3 exabyte

the daily total Internet traffic in 2016 (estimation*)

[1EB = 10^{18} Bytes = 1 000 000 000 000 000 000 Bytes]

* Cisco Visual Networking Index 2017

If  = 1 Gigabyte

~ 1 exabyte

~9 exabyte

the daily total Internet traffic in 2021 (estimation*)

* Cisco Visual Networking Index 2017

~55%

video traffic of the total Internet traffic in 2016 (estimation*)

* Sandvine 2016 Global Internet Phenomena

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

sandvine

* Sandvine 2016 Global Internet Phenomena

(https://www.sandvine.com/hubfs/downloads/archive/2016-global-internet-phenomena-report-latin-america-and-north-america.pdf)

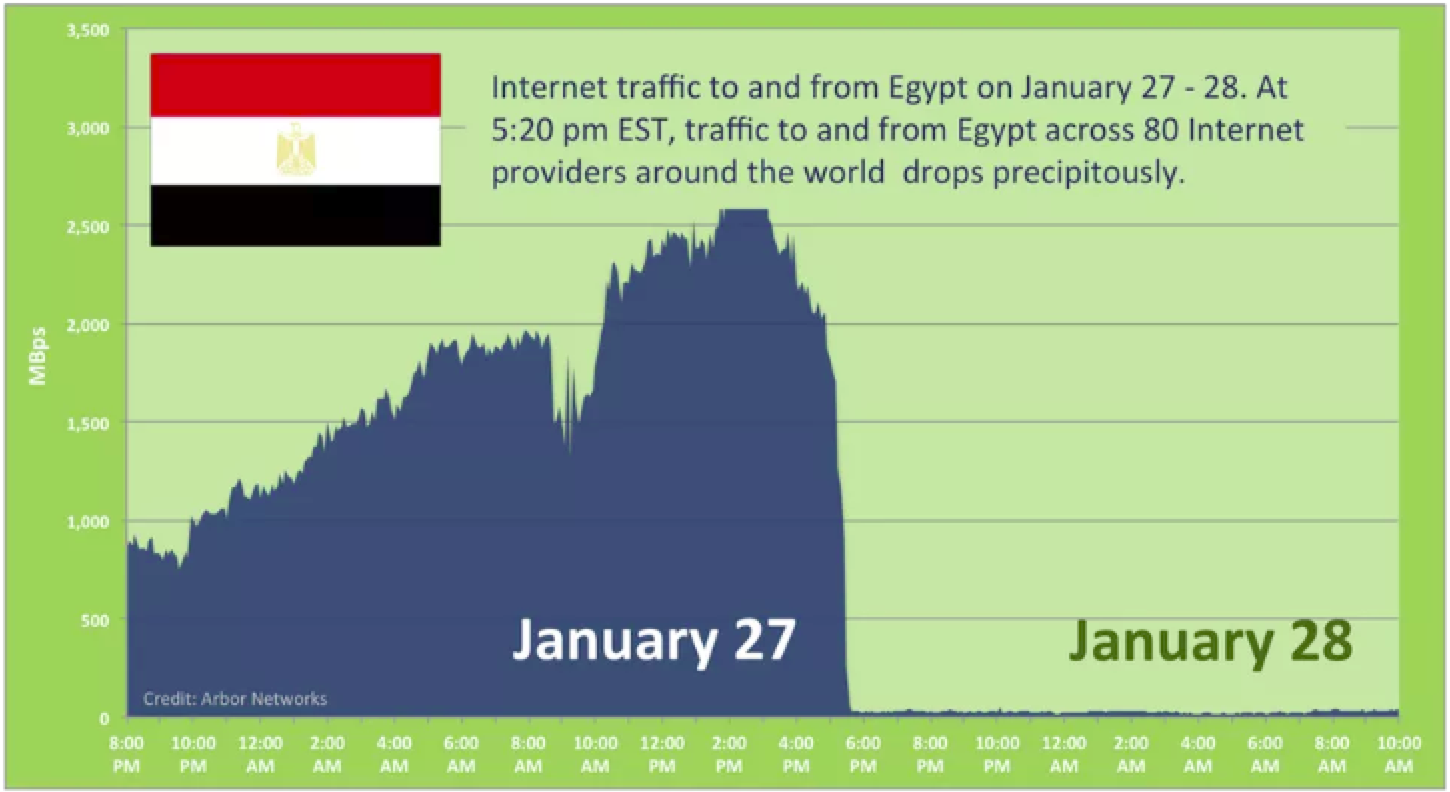
~80%

video traffic of the total Internet traffic in 2021 (estimation*)

* Cisco Visual Networking Index 2017

The other side…

Internet traffic from/to Egypt in January 2011



* http://huff.to/1KxxoZF

Syria - 2013

NEWS / POLITICS

Syria cut off from global internet

International internet companies say Syria has been disconnected from "internet communication with the rest of world".

8 May 2013

* aljazeera.com

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

By MATT KAMEN

Tuesday 3 January 2017

Credit: Shutterstock

Governments around the world enacted internet shutdowns over 50 times in the last year, according to a report focusing on the impact of such draconian actions.

In purely monetary terms, the shutdowns resulted in economic slowdowns that cost a total of $2.4bn (£1.9bn), according to research by The Brookings Institution, a Washington, DC-based

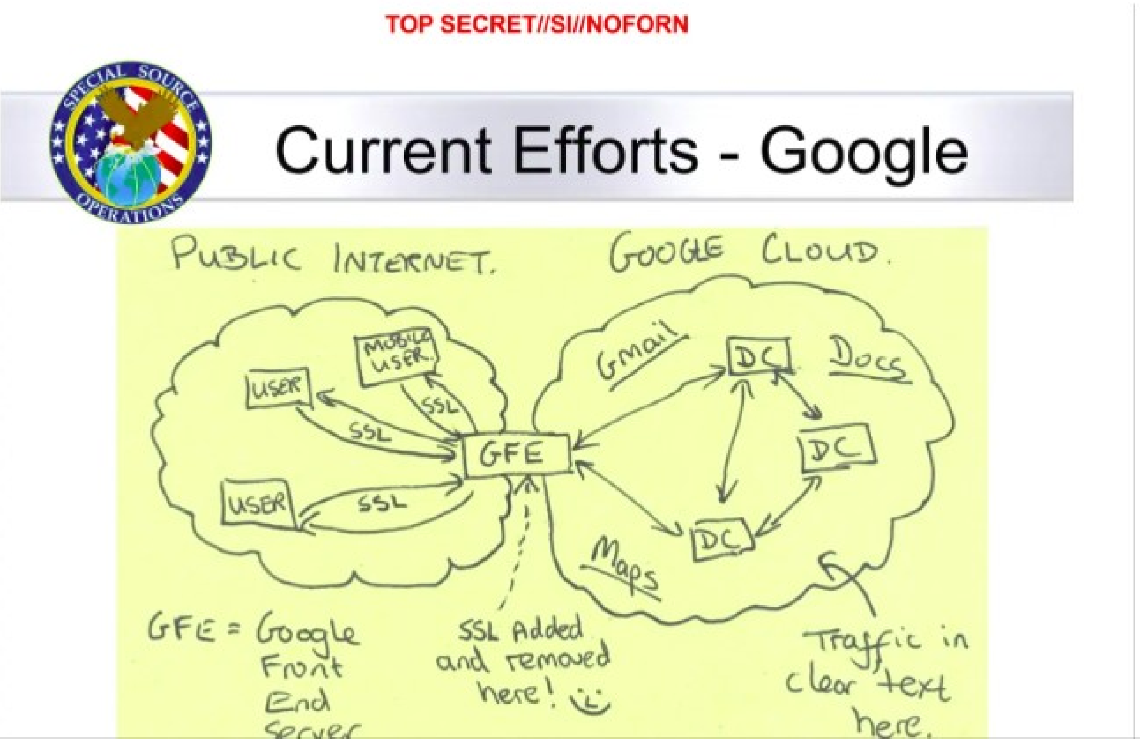
* https://www.wired.co.uk/article/over-50-internet-shutdowns-2016

The Washington Post
Democracy Dies in Darkness

Sign In

National Security

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



* http://wapo.st/1UVKamr

The top-secret PRISM program

* https://www.washingtonpost.com/wp-srv/special/politics/prism-collection-documents/

Network Neutrality

- Can the Internet Service Provider (ISP) selectively slow down traffic?

The New York Times

2015

F.C.C. Sets Net Neutrality Rules

The Federal Communications Commission is to take a more active role in regulating the Internet as a public utility, which is expected to provoke court cases from major broadband providers.

* http://nyti.ms/2kZUnDA

The New York Times

2017

F.C.C. Repeals Net Neutrality Rules

Ajit Pai, the F.C.C. chairman, said the rollback of the net neutrality rules would eventually help consumers because broadband providers like AT&T and Comcast could offer people a wider variety

* 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

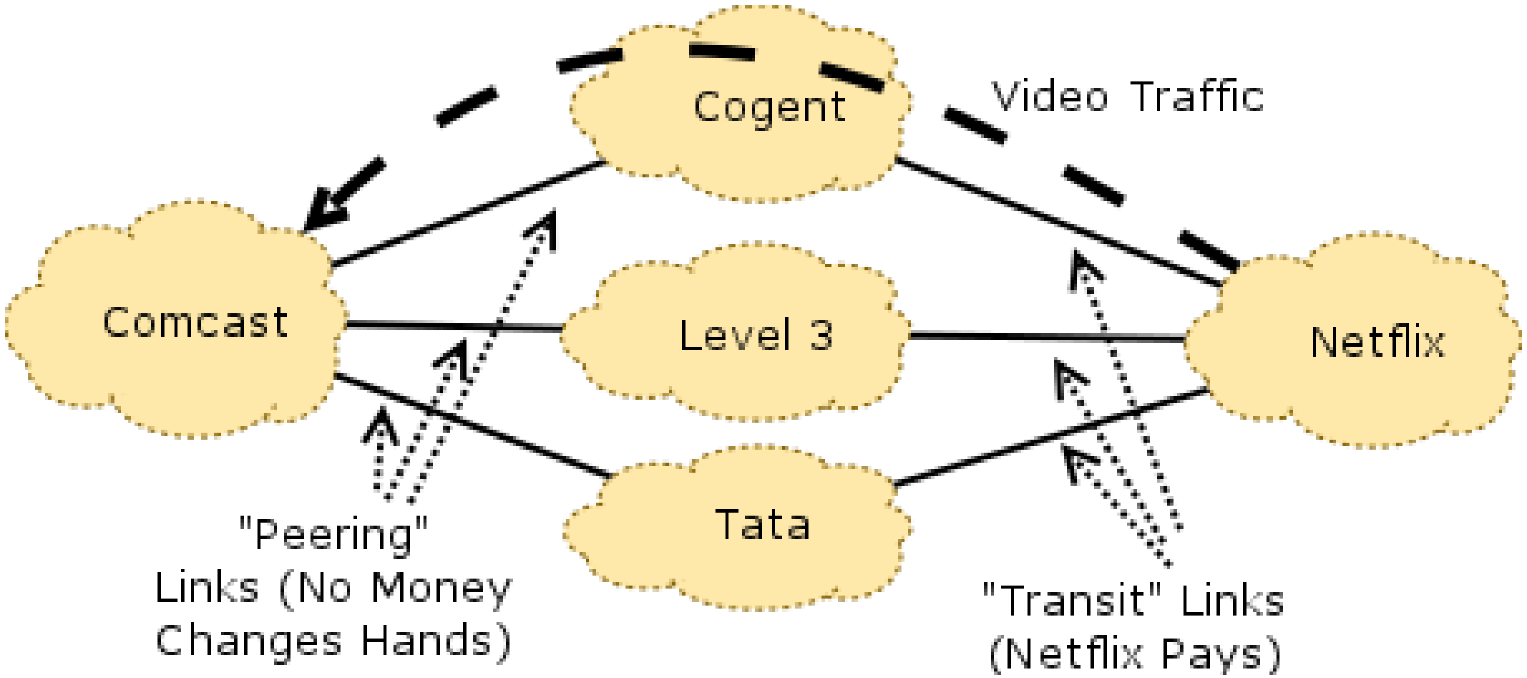
335,726 Retweets 831,986 Likes

7.1K 336K 832K

Who should pay for the Internet connection?

Netflix VS ISPs

The Netflix-Comcast conflict



* https://freedom-to-tinker.com/2015/03/25/why-your-netflix-traffic-is-slow-and-why-the-open-internet-order-wont-necessarily-make-it-faster/

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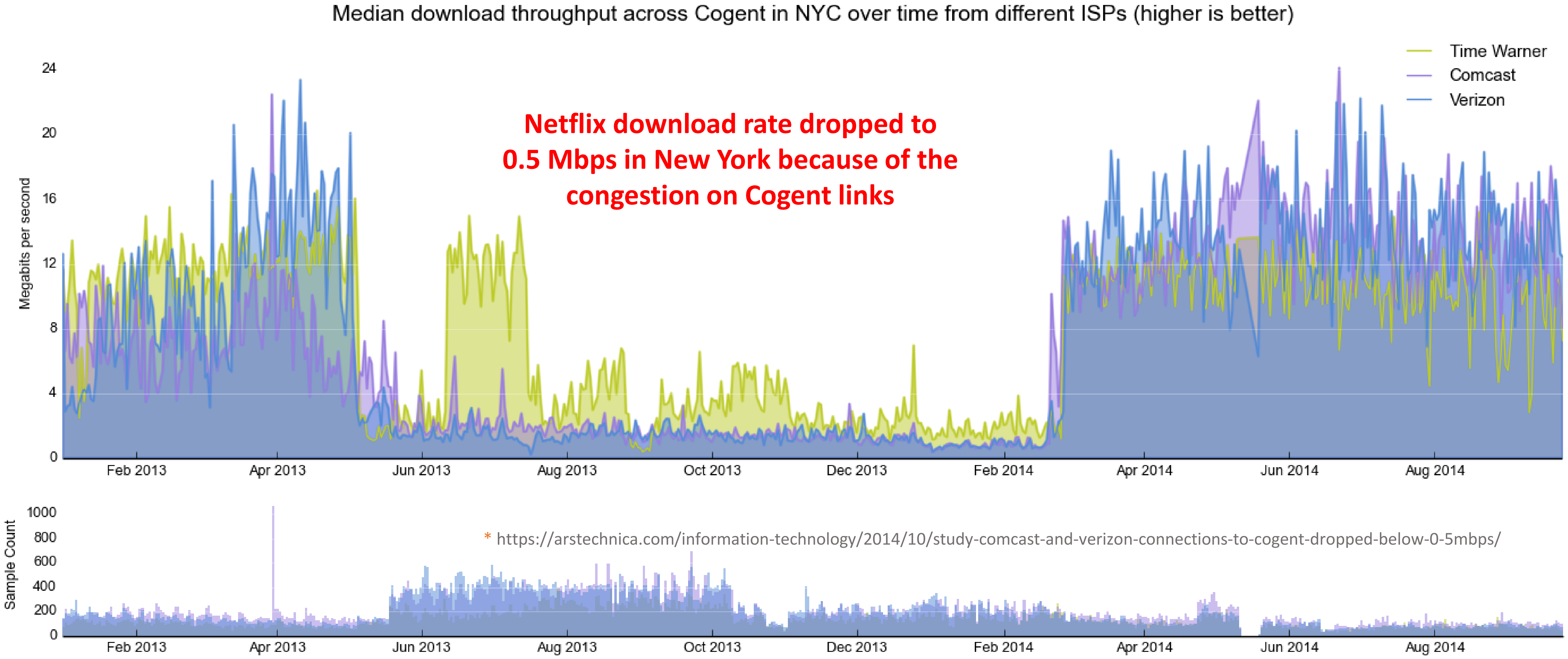

Netflix download rate dropped to 0.5 Mbps in New York because of the congestion on Cogent links

* https://arstechnica.com/information-technology/2014/10/study-comcast-and-verizon-connections-to-cogent-dropped-below-0-5mbps/

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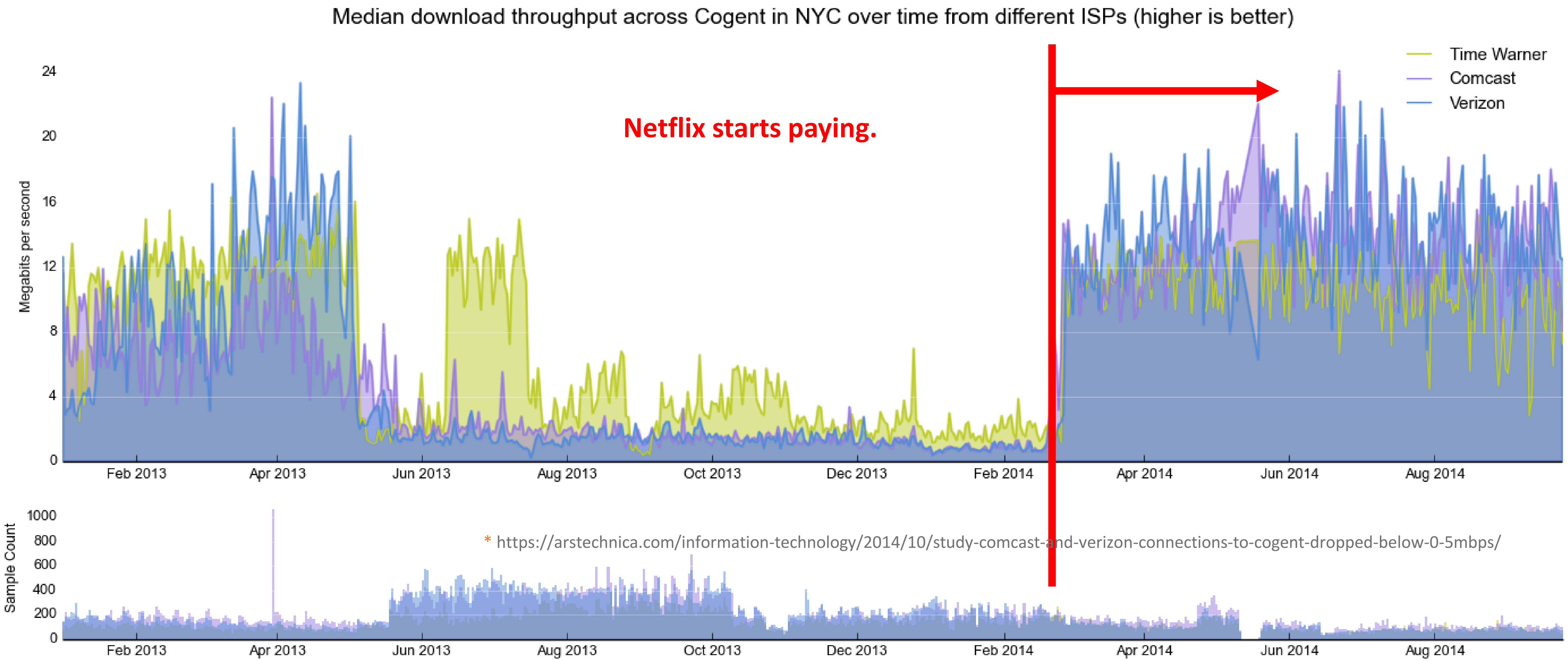


* https://arstechnica.com/information-technology/2014/10/study-comcast-and-verizon-connections-to-cogent-dropped-below-0-5mbps/

A Fragile place

ORACLE + Dyn DNS Security Other Products Company Support SIGN IN CONNECT

VANTAGEPOINT
IN: RESEARCH

Widespread impact caused by Level 3 BGP route leak

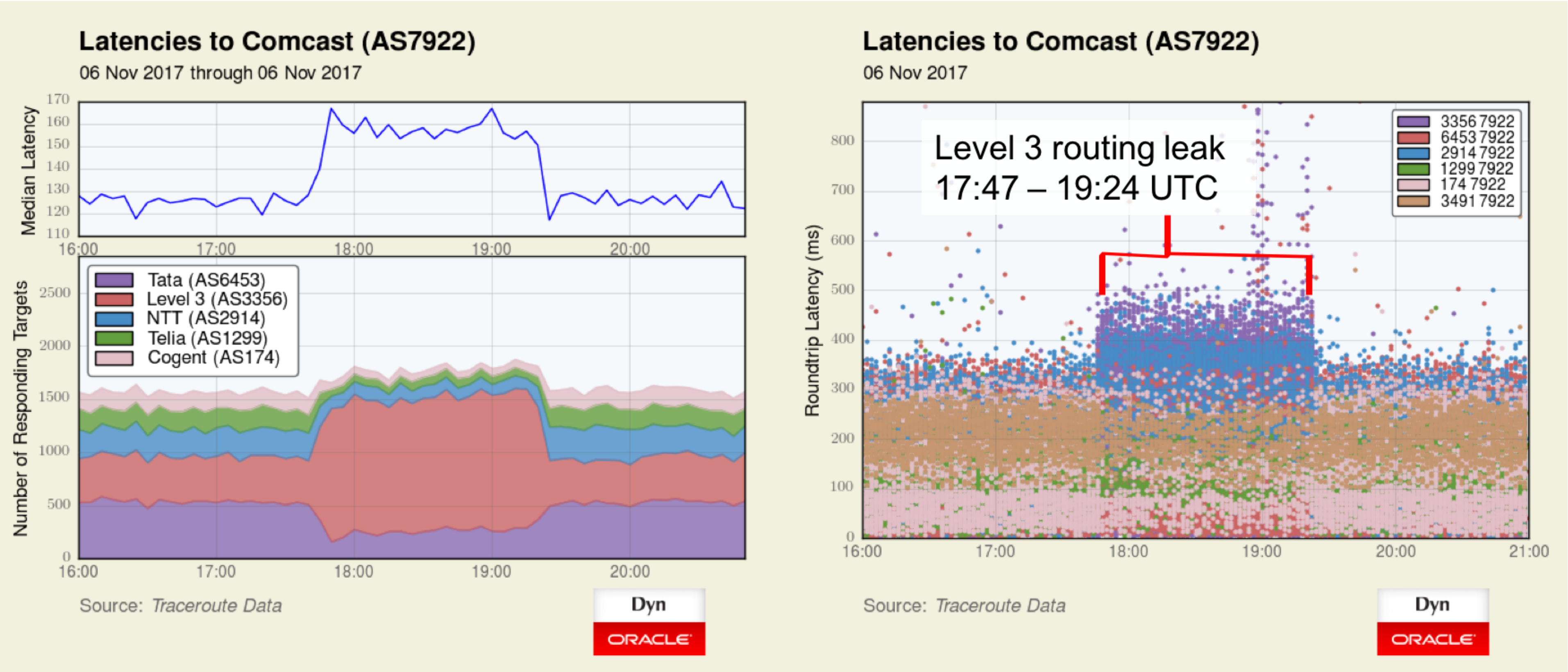
Research // Nov 7, 2017 // Doug Madory

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 latest botnet threat? Not this time. The cause was yet another BGP routing leak — a router misconfiguration directing internet traffic from its intended path to somewhere else.

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

We have a little problem here...

- A little outage
  – **for more than 90 mins**
- **Affected millions of users from the US and world-wide**
- Cause: BGP route leaking
  - **A misconfigured router** directed Internet traffic from its intended path to somewhere else.



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

August 2017

The Register®
Biting the hand that feeds IT

DATA CENTRE SOFTWARE SECURITY DEVOPS BUSINESS PERSONAL TECH SCIENCE E

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

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

Human factor

- People also often mistakenly destroy their own infrastructure

11,353 views | Jul 8, 2015, 03:36pm

United Airlines Blames Router for Grounded Flights

Alexandra Talty Senior Contributor
Personal Finance

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.

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.

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

Jupiter Networks, What's Behind Network Downtime?, 2008

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

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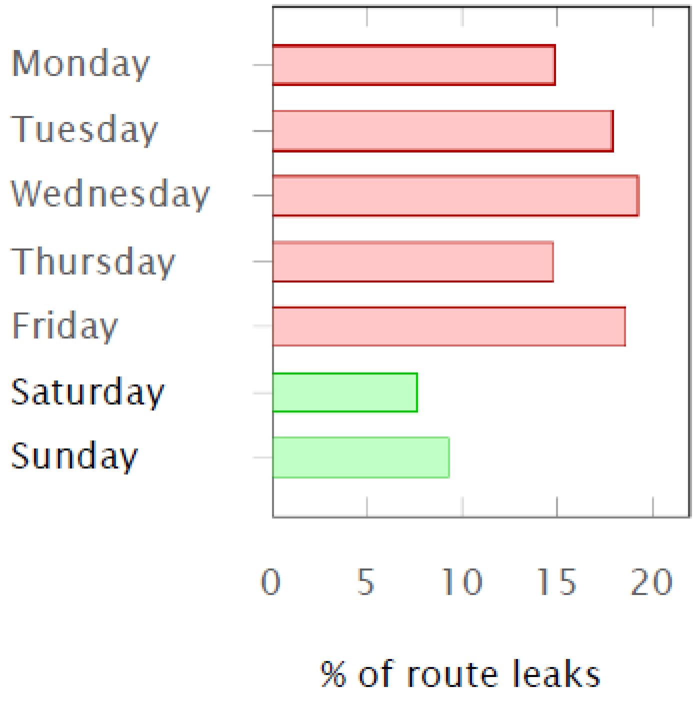
Data networks work better during week-ends…☺



source: Job Snijders (NTT)

Computer Networks Course

Goals of this course

- **Understand how and why Internet works…**

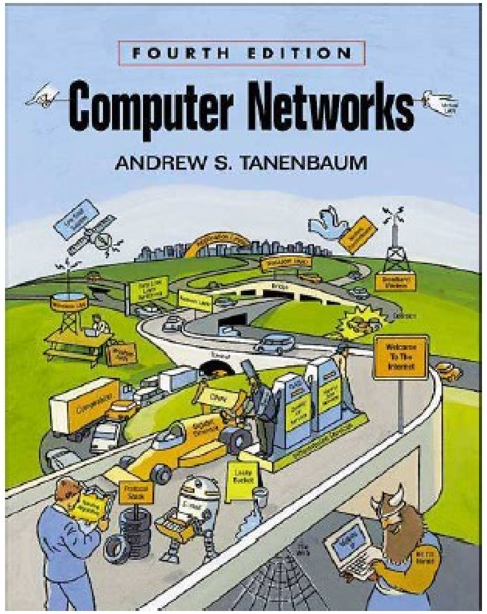
- Main topics
  - **Addressing**
    - How to address devices, services and protocols?
  - **Layering**
    - How to handle complexity?
  - **Routing**
    - How to go from A to B?
  - **Reliability**
    - How to communicate reliably over an unreliable mediums?
  - **Resource sharing**
    - How to divide scare resources among competing parties?

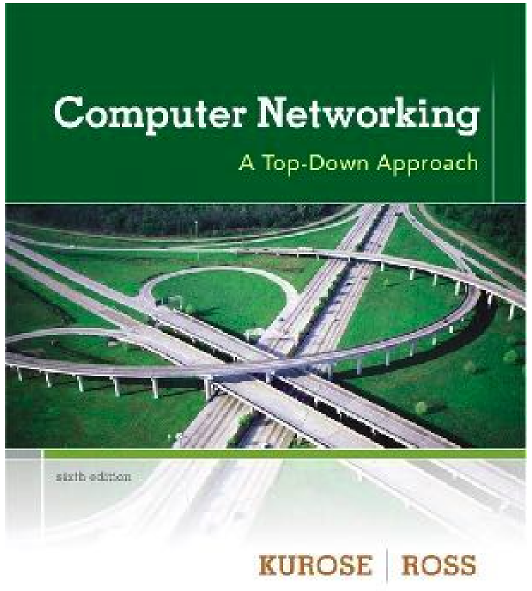
Skills – that are also essential in Matrix

Trinity from Matrix Reloaded running a **port scan**, using the tool **nmap**…

Sources

- Slides:
  - http://lakis.web.elte.hu
- Books →→→→→→





Teaching Style

- I am a network researcher
  - Things make sense to me that may not make sense to you
  - If you do not understand something, do not be shy to stop me and ask
  - Seriously, ask questions!!!
  - Standing up here in silence is very awkward
  - I will stand here until you answer my questions
- Help me learn your names
  - Say your name before each question

Course = Lecture + Practice

- Practice
  - Lecturer: Peter Vörös, Teaching assistant
  - Requirements will be announced at the first class

- Lecture
  - After a successfully passed practical part…
  - Final exam at end of the semester
    - one occasion per week in the exam period
    - written exam – tests + essay

Cheating

- Do not do it
  - Seriously, don’t make me say it again
- Cheating is an automatic zero
  - Will be referred to the university for discipline and possible expulsion

Final Grades

- At the end of the semester, all of your grades will sum to 100 points

- Final grades are based on a simple scale:
  - 5 - >85,
  - 4 - 70-85,
  - 3 - 60-70,
  - 2 - 50-60,
  - 1 - 0-50

After typeing www.google.com into a browser,

and pressing enter…

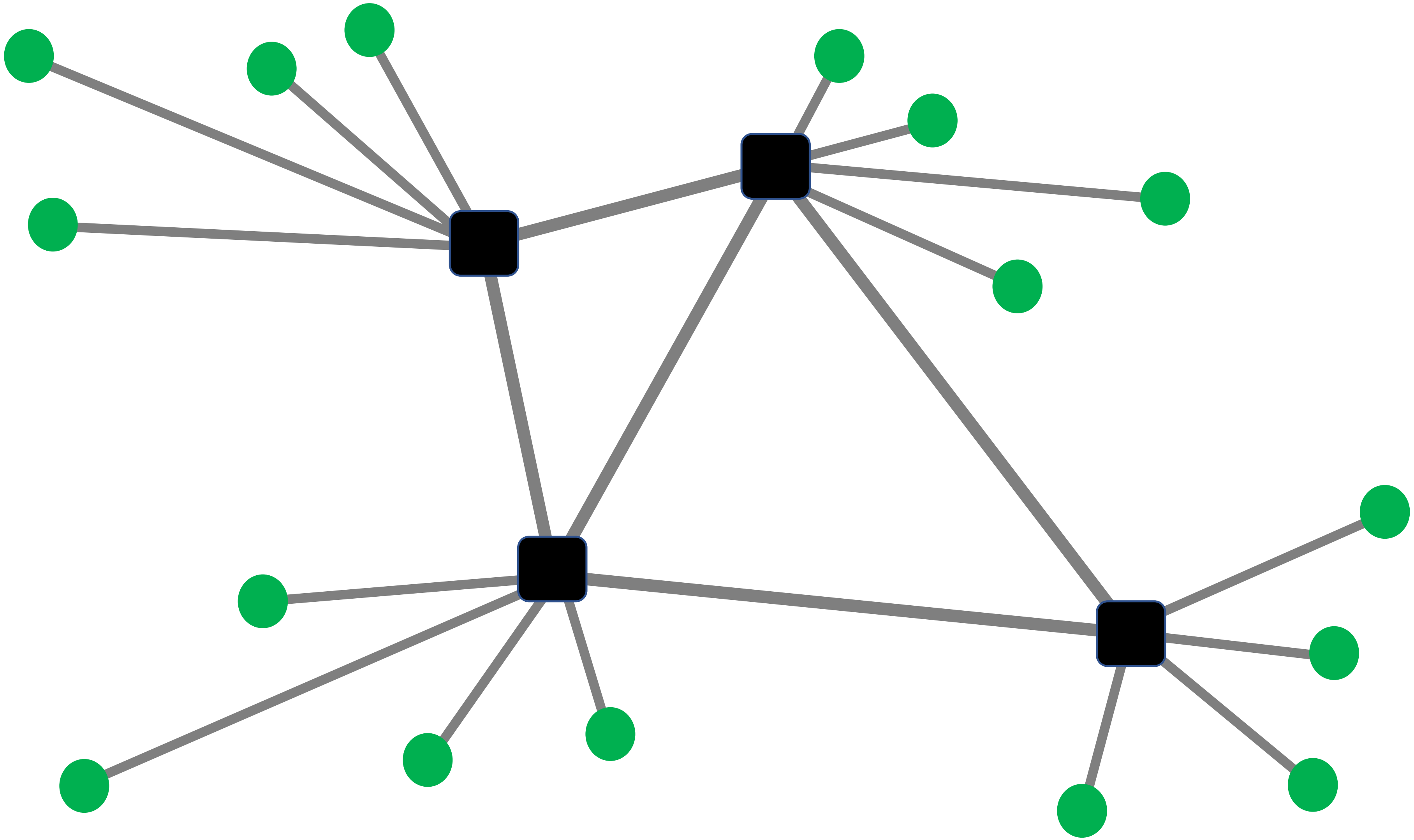
What happens?

Can you list any technologies,
principles,
protocols and
applications used…

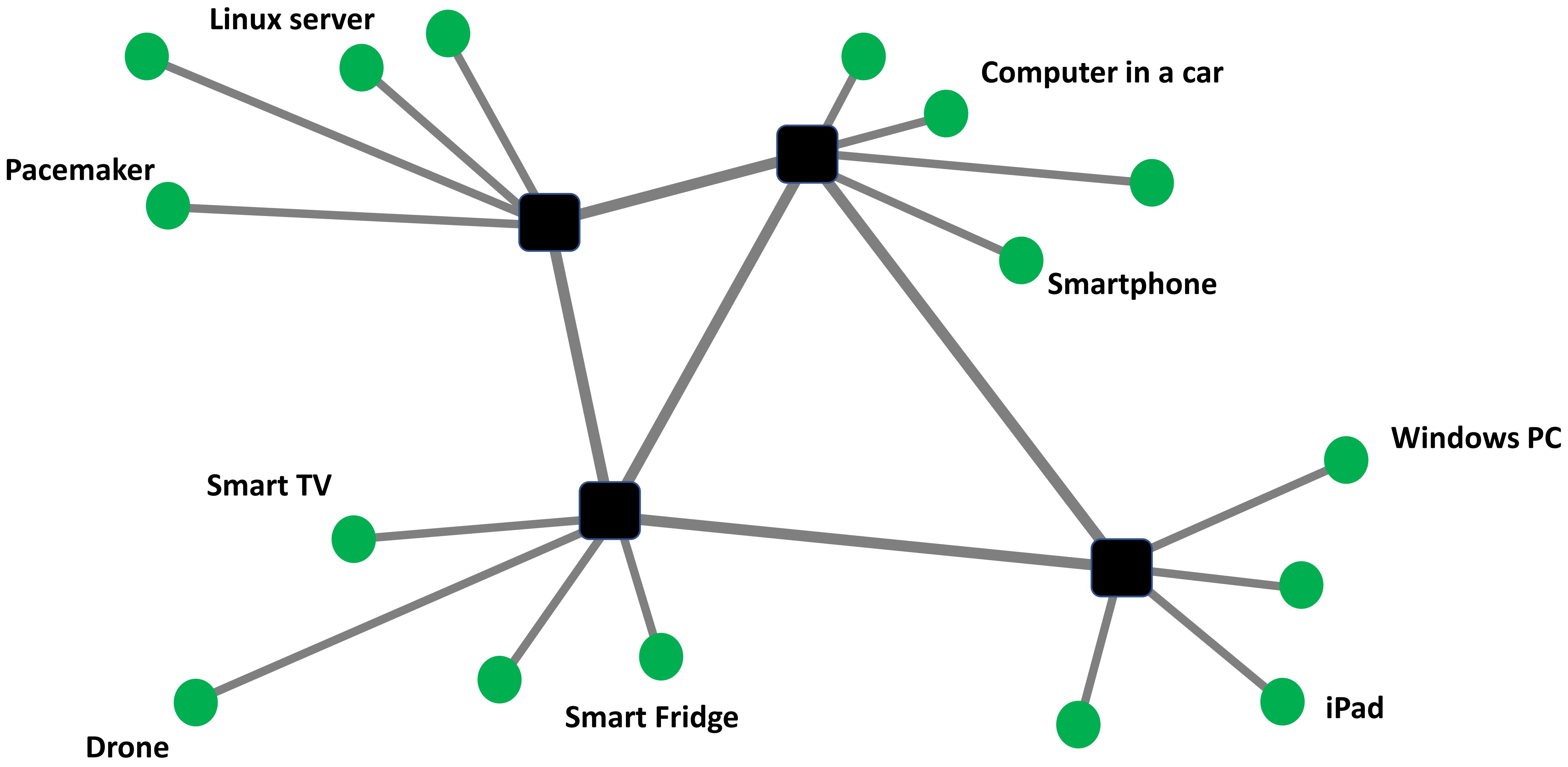
Overview

What is a network made of?

Three main components

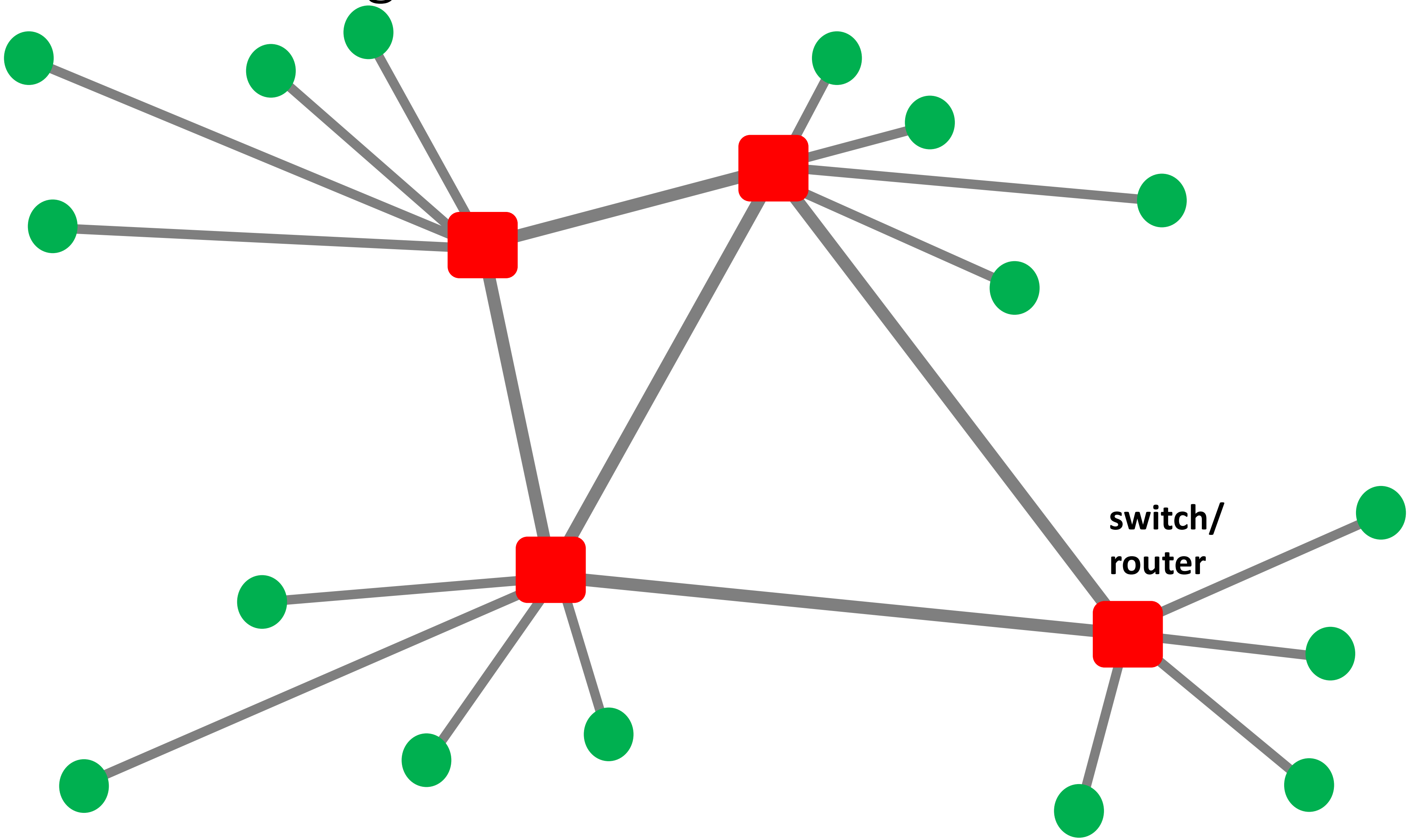


Data sending and receiving end-points



Data forwarding switches and routers

Data forwarding towards a destination



Routers

different sizes, features and applications

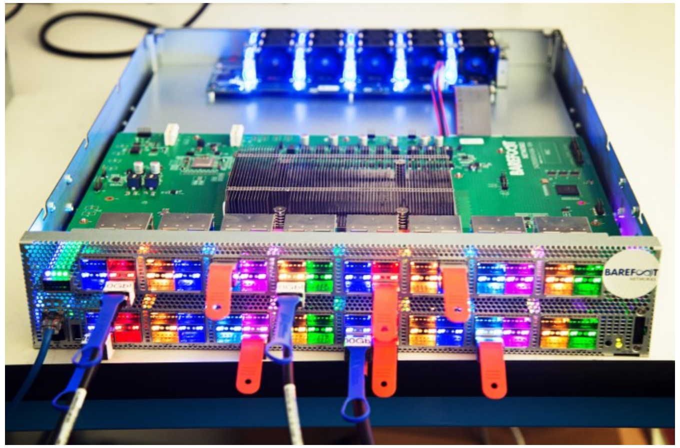
Home router

~20 cm

0,5 kg

1 Gbps

data center router



~50cm

~ 5 kg

1,8-6,5 Tbps

Internet core router

>200 cm

~700 kg

12,8 Tbps

(up to 922 Tbps)

Kbps? Mbps? Tbps?

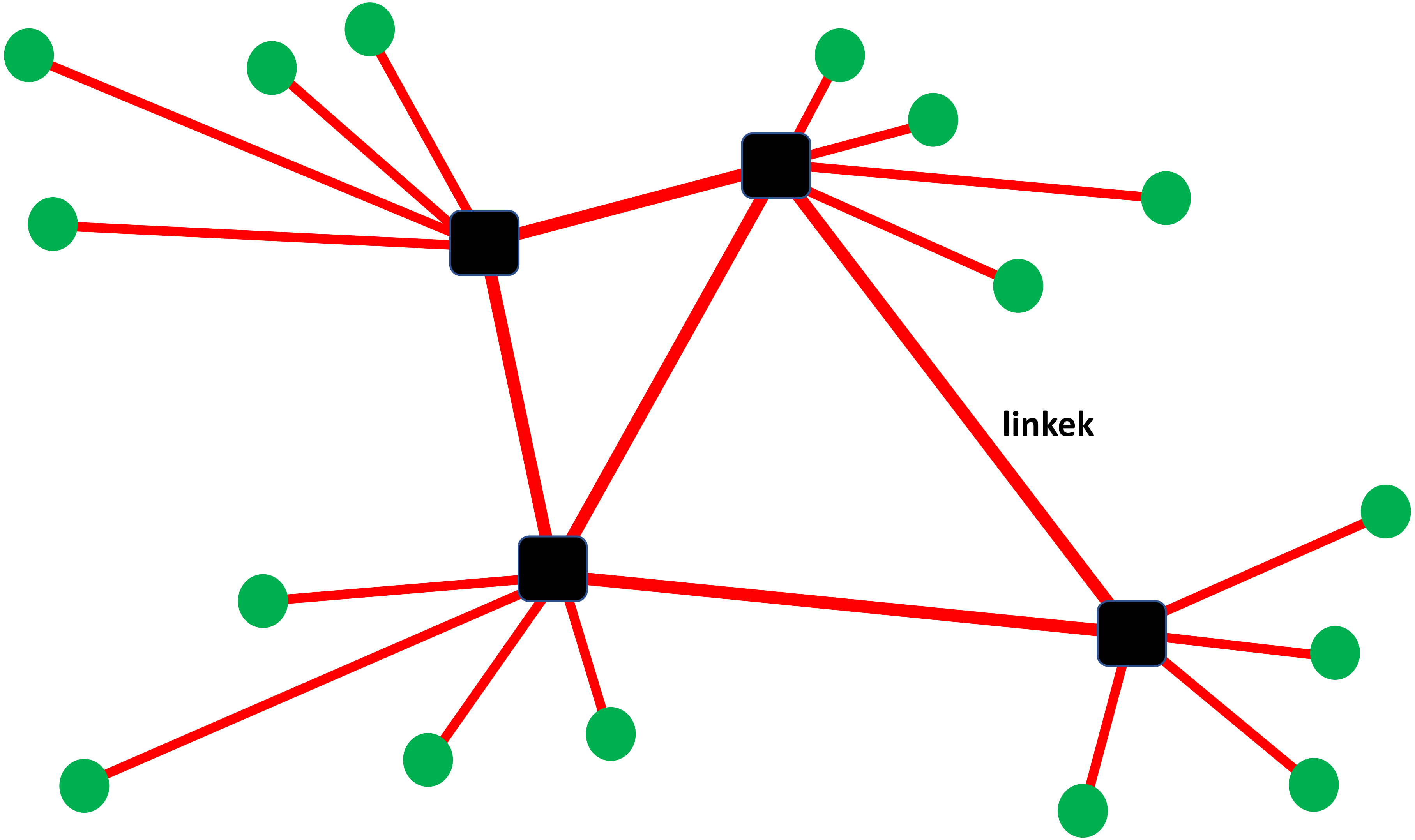
- **Bandwidth**
  The bandwidth is used to measure and quantify the available or used communication resources. It is expressed in bit per second (bps), meaning how many bits can be transmitted in a second.

SI standard

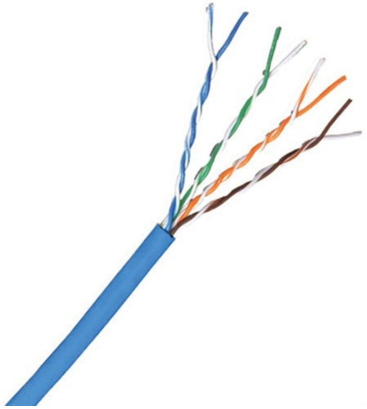
$8*10^3$ bit/sec	1 KB/s	Kilobyte
$8*10^6$ bit/sec	1 MB/s	Megabyte
$8*10^9$ bit/sec	1 GB/s	Gigabyte
$8*10^{12}$ bit/sec	1 TB/s	Terrabyte
$8*10^{15}$ bit/sec	1 PB/s	Petabyte
$8*10^{18}$ bit/sec	1 EB/s	Exabyte

Links

connect end-points to switches and switches to each other

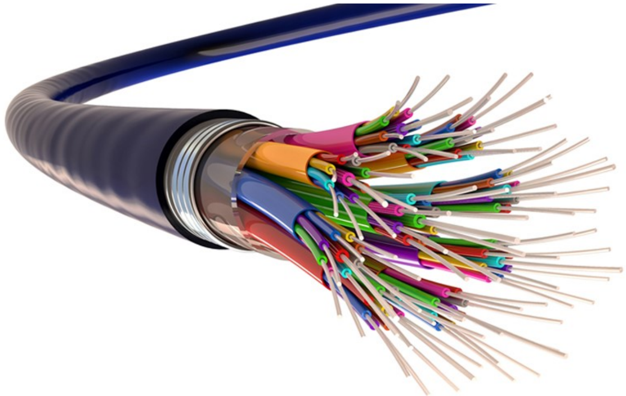


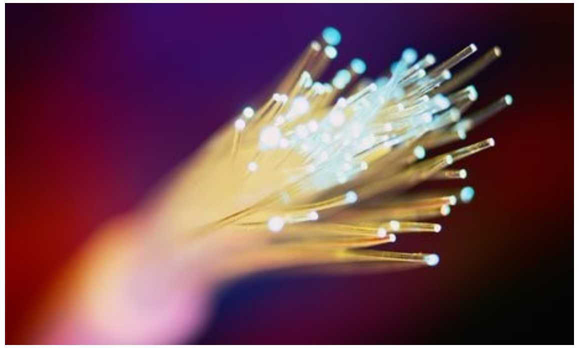
Links – examples



Copper cable

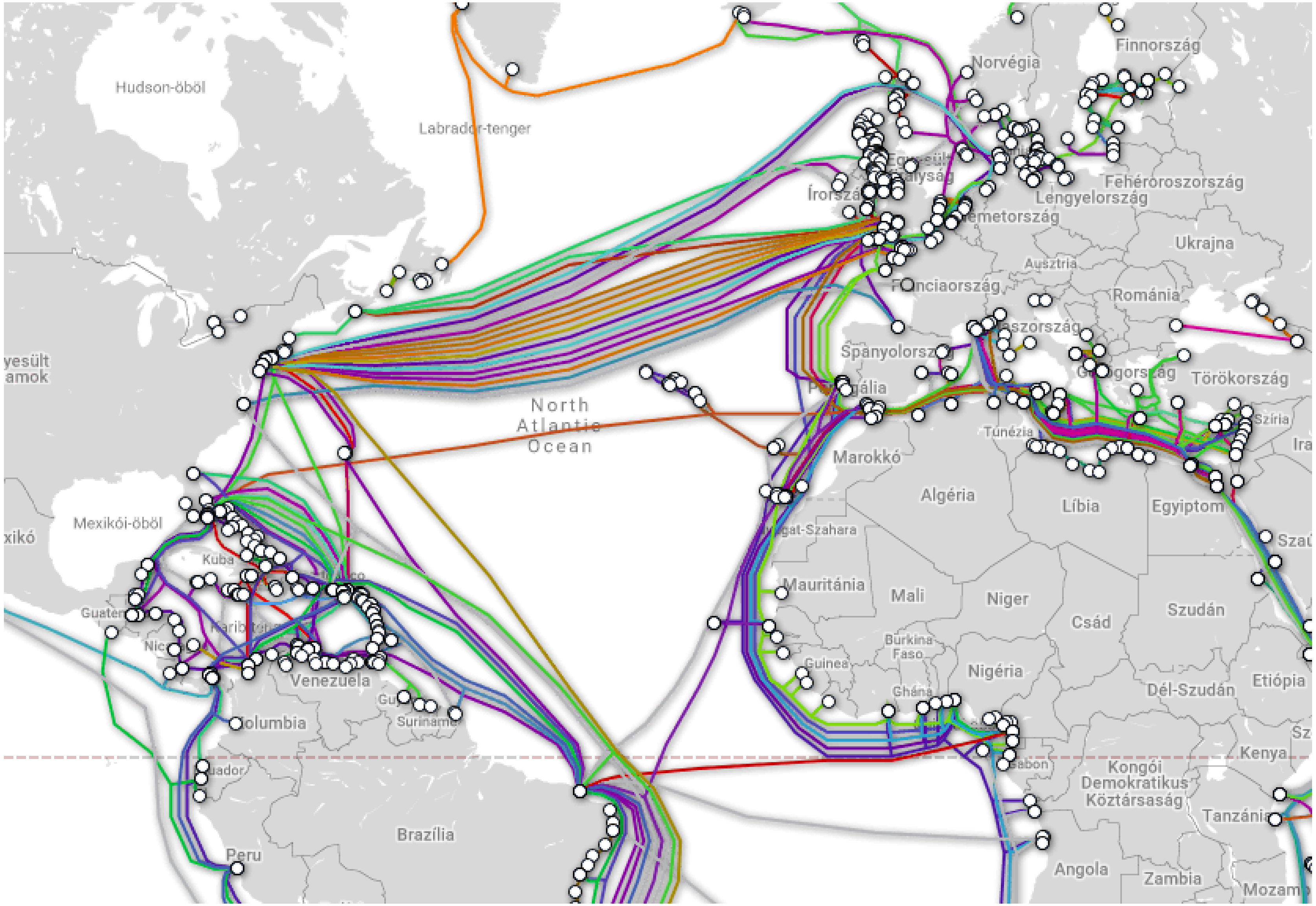
ADSL, RJ-45, Coax



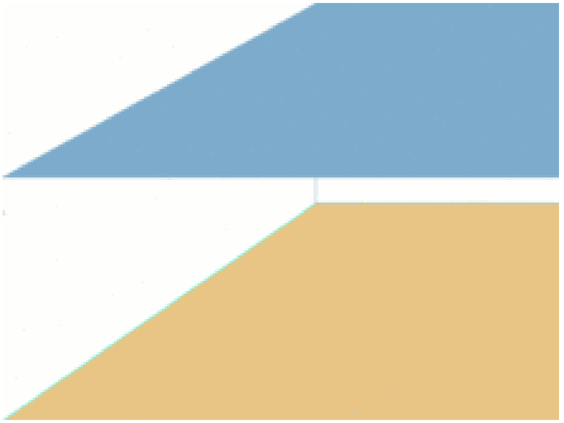


Optic fiber

Wireless

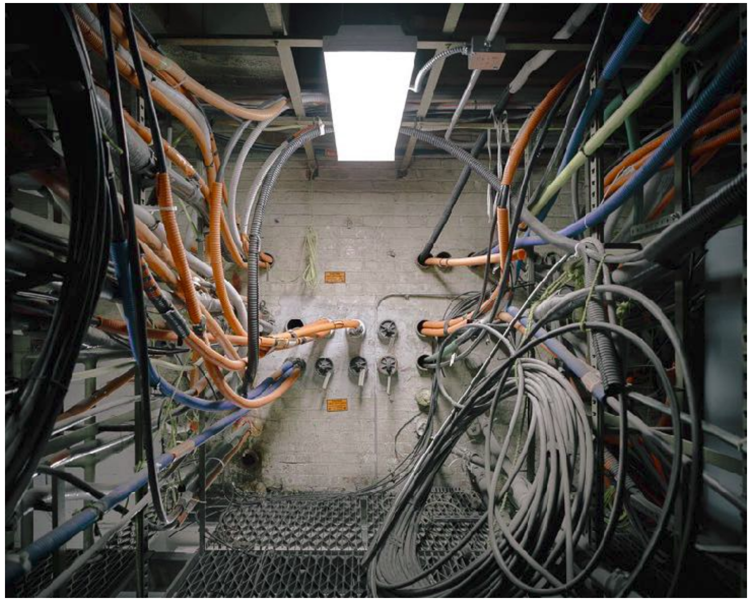


* https://www.submarinecablemap.com/



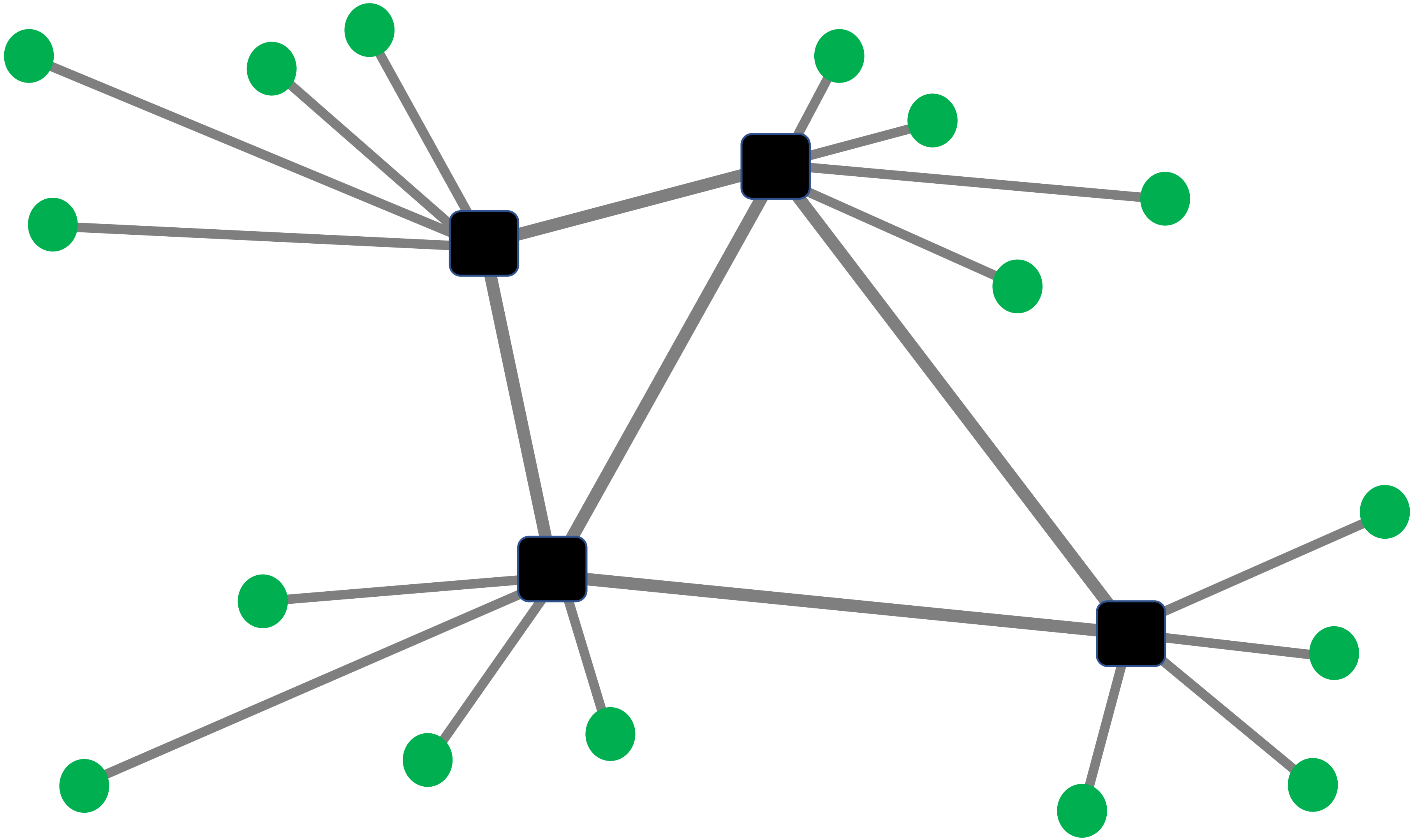
Deepsee cable fixing

René Descart
cable ship



Somewhere in Manhatten

Internet = Network of networks



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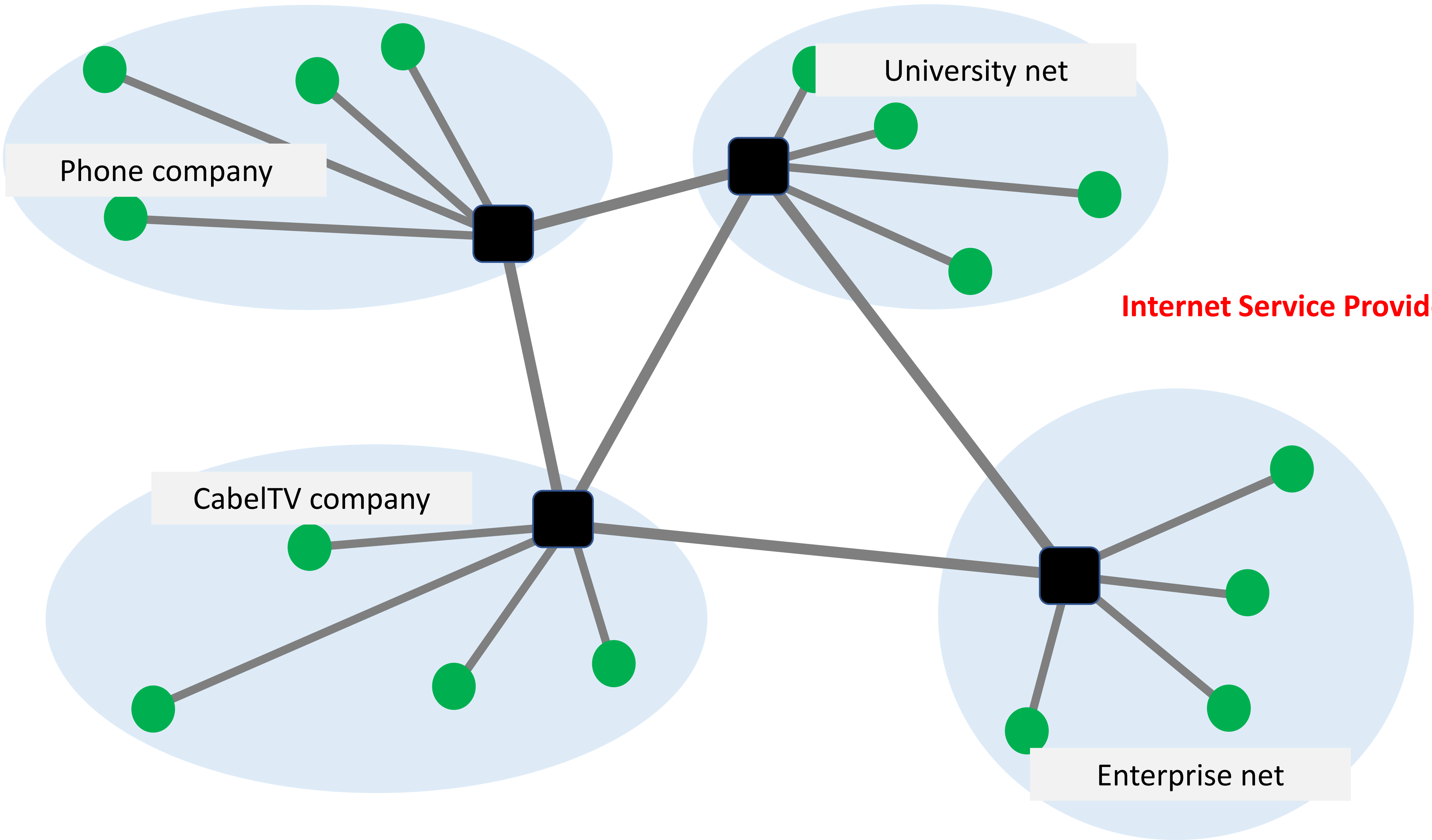
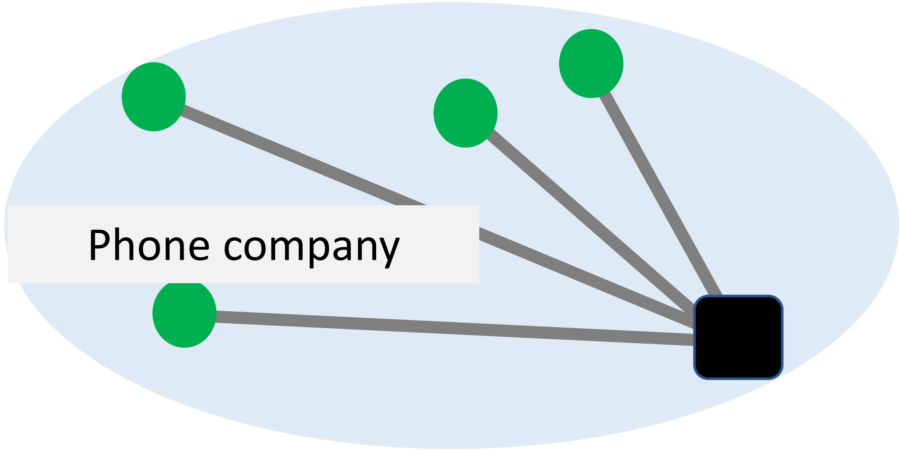


Internet Service Providers = ISPs

Internet access over phone network

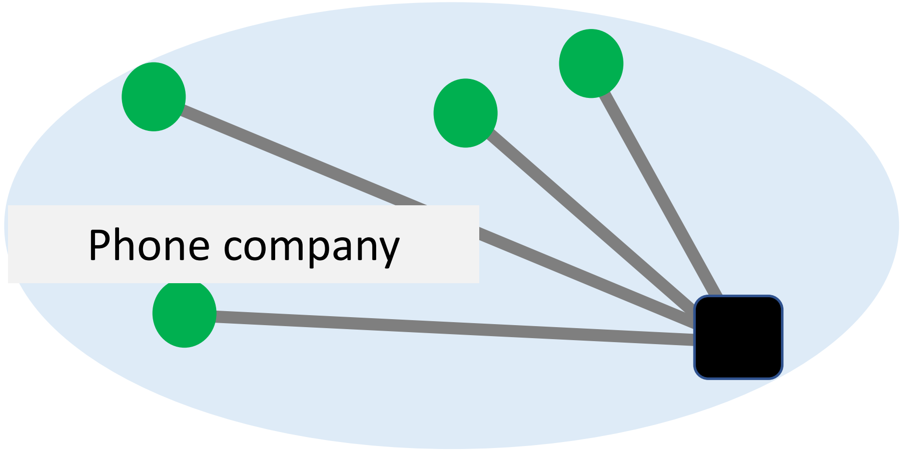


Digital Subscriber Line (DSL)

- Providing high bandwidth access to households over **phone lines**

?????????????

Internet access over phone network



Digital Subscriber Line (DSL)

- Providing high bandwidth access to households over **phone lines**

- 3 channel
  - **Downstream data channel**
    - Few hundred Mbps
  - **Upstream data channel**
    - Few tens Mbps
  - ***Two-way phone channel***
    - Only voice

Why is it asymmetric?

Over Cable TV network

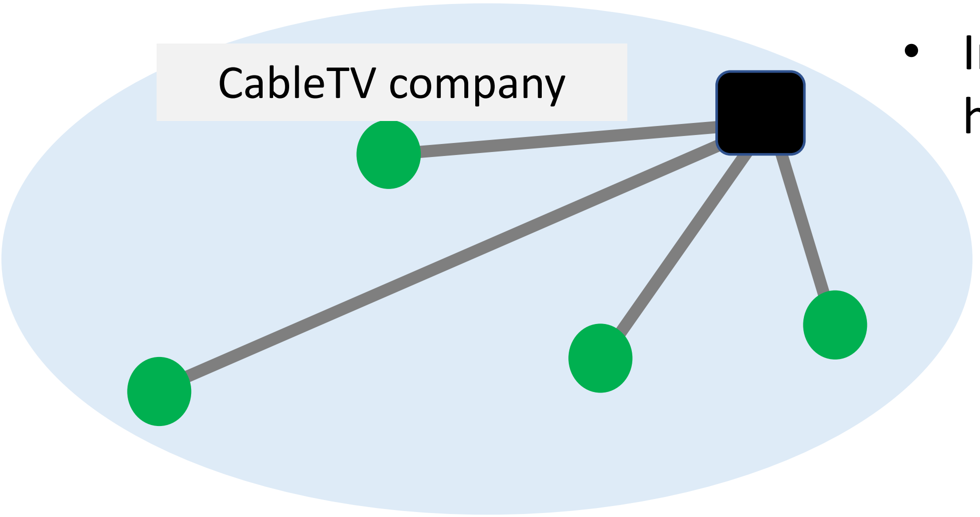
Copper coax cable

Cable Access Technology (CATV)

- Providing high bandwidth access to households over **cable tv network**

- **Downstream data channel**
  - Few hundred Mbps
- **Upstream data channel**
  - Few tens Mbps

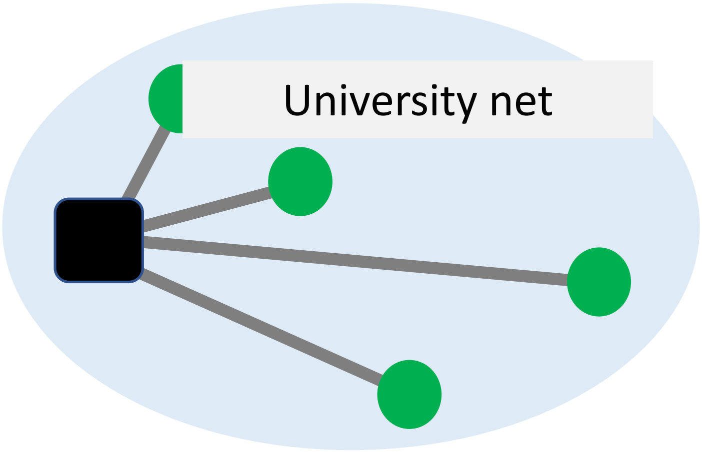
- In contrast to ADSL, the medium is shared among households.



Ethernet is widely used for Local Area Networks (LAN)

Twisted pair copper

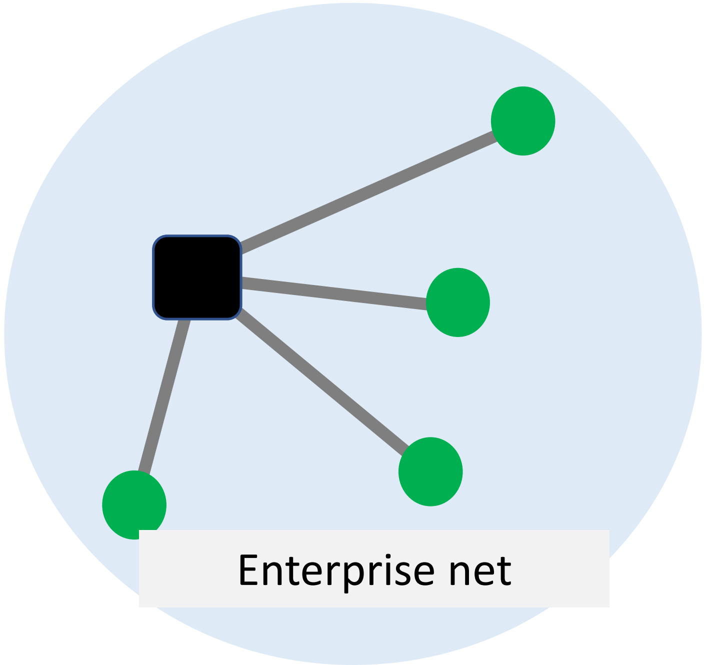
SFP+ Active Optical



1 Gbps, 10 Gbps, 40 Gbps, 100 Gbps, …

Symmetric – full-duplex

100 Gbps NIC



Further technologies

- **Cellular** – smart phones
- **Satellite** – long distance communication in areas without infrastructure
- **FTTH** – households
- **Optical cables** (fibers, dark fibers) – Internet backbone
- **Infiniband** – HPC clusters
- …

Overview

How to share network resources?

How does the Internet core look like?

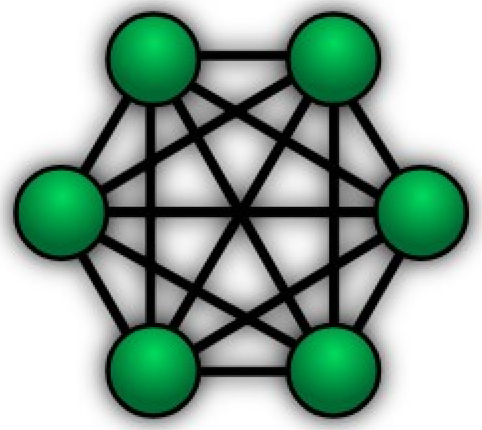
3 important requirements for the topology

- **Fault tolerance**
  - several paths between each source and destination
- **Flexible**
  - Possess enough sharing to be feasible & cost-effective
  - Number of links should not be too high
- **Enough per-node capacity**
  - number of links should not be too small

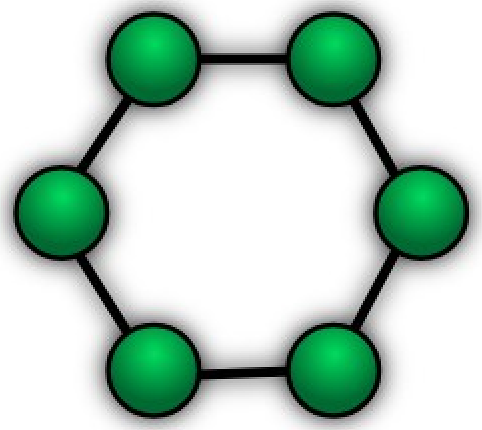
Let's see a few special topology

Internet is different...

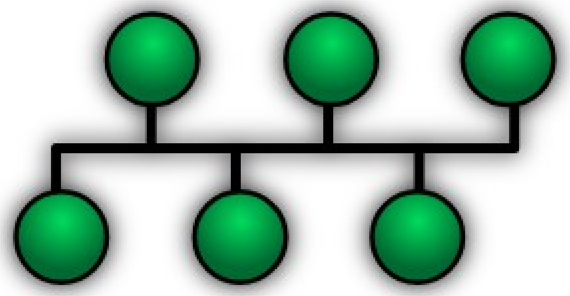
Fully connected (Full-mesh)



Chain/Ring



Bus

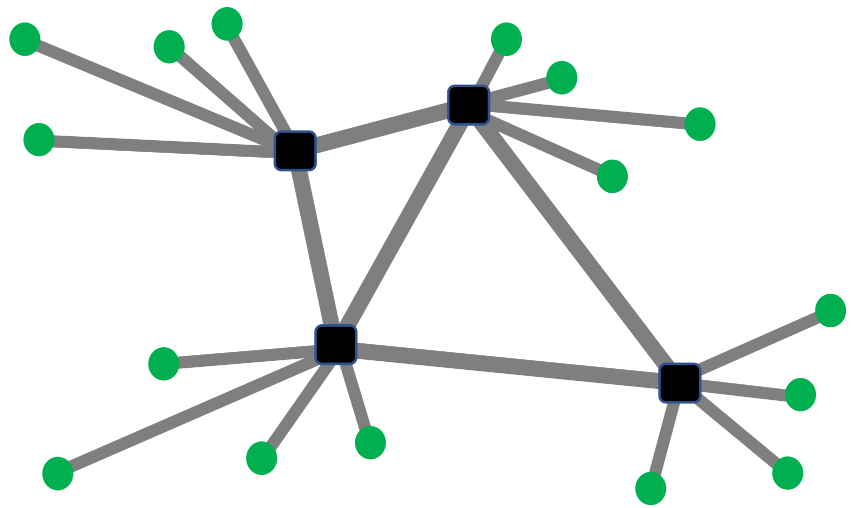


Advantages

Disadvantages

Switched networks provide reasonable and flexible compromise

Switched design

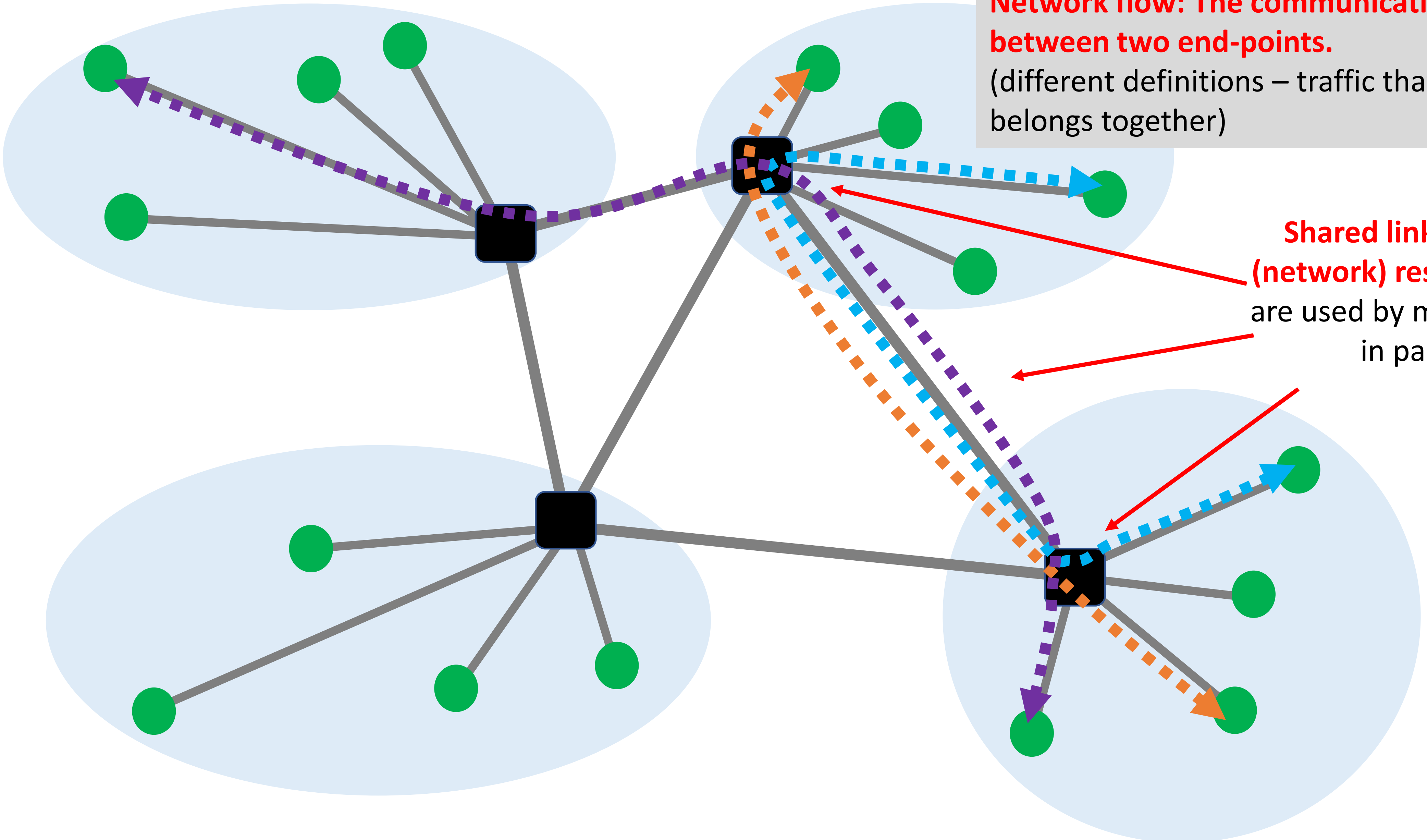


Advantages Sharing and per-node capacity can be adapted to fit the network needs

Disadvantages Require smart devices to perform: forwarding, routing, resource allocation

Sharing links and switches

Network flow: The communication/traffic between two end-points.
(different definitions – traffic that somehow belongs together)



Shared link és switch (network) resources: they are used by multiple flows in parallel

Resource handling
Two different approaches for sharing

Reservation

Reserve the needed bandwidth in advance

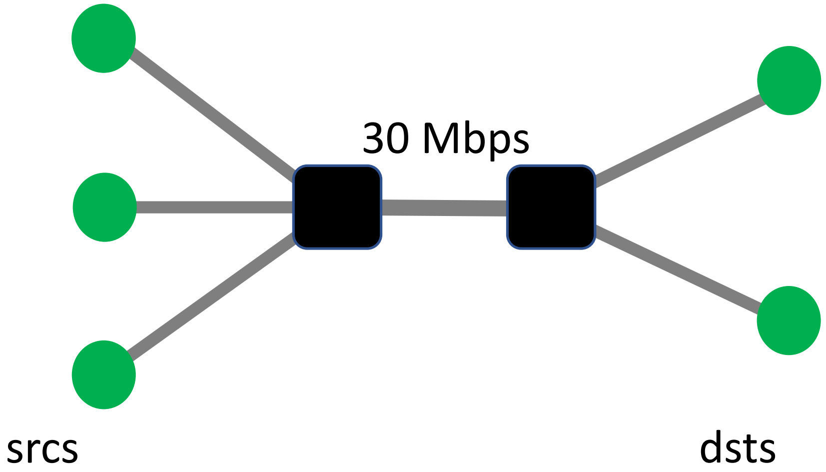
Flow-level multiplexing

On-demand

Send data when needed

Packet-level multiplexing

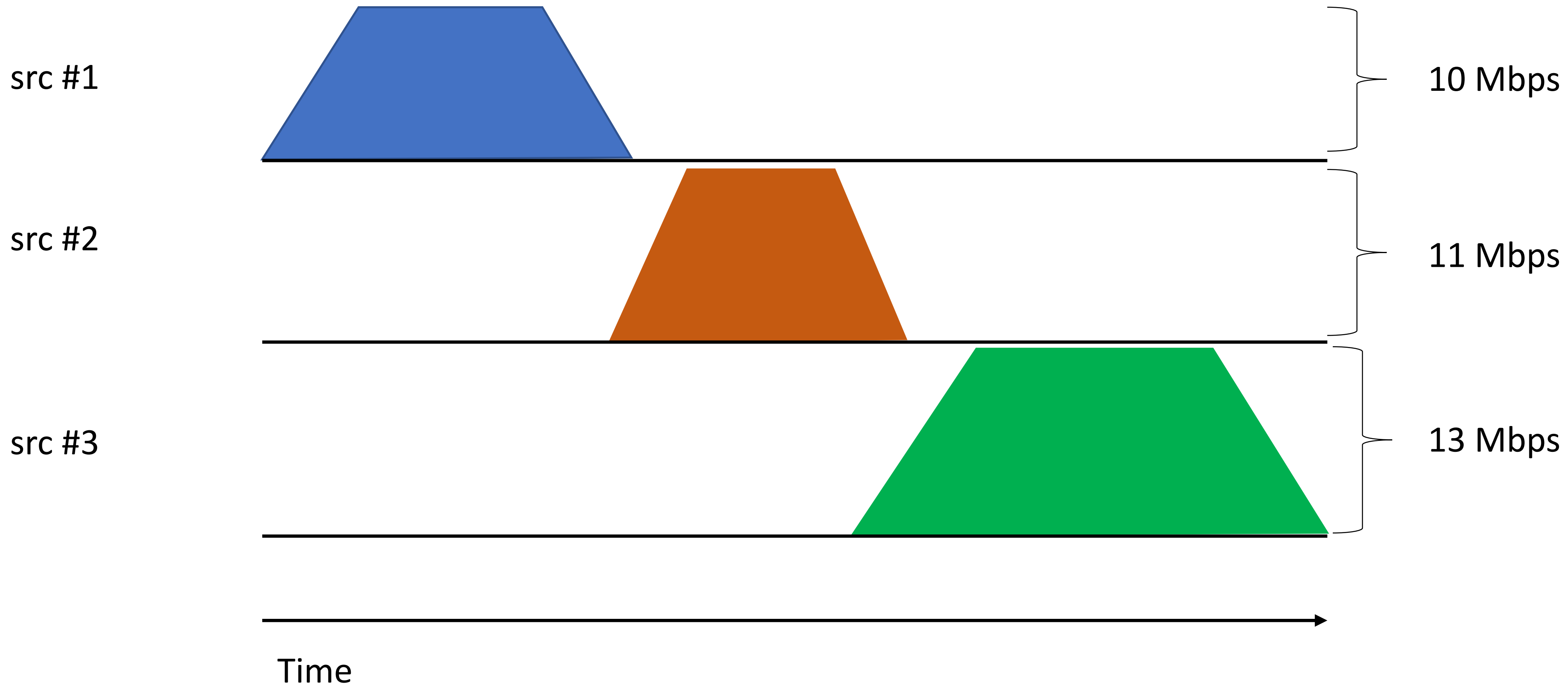
Which one is better?



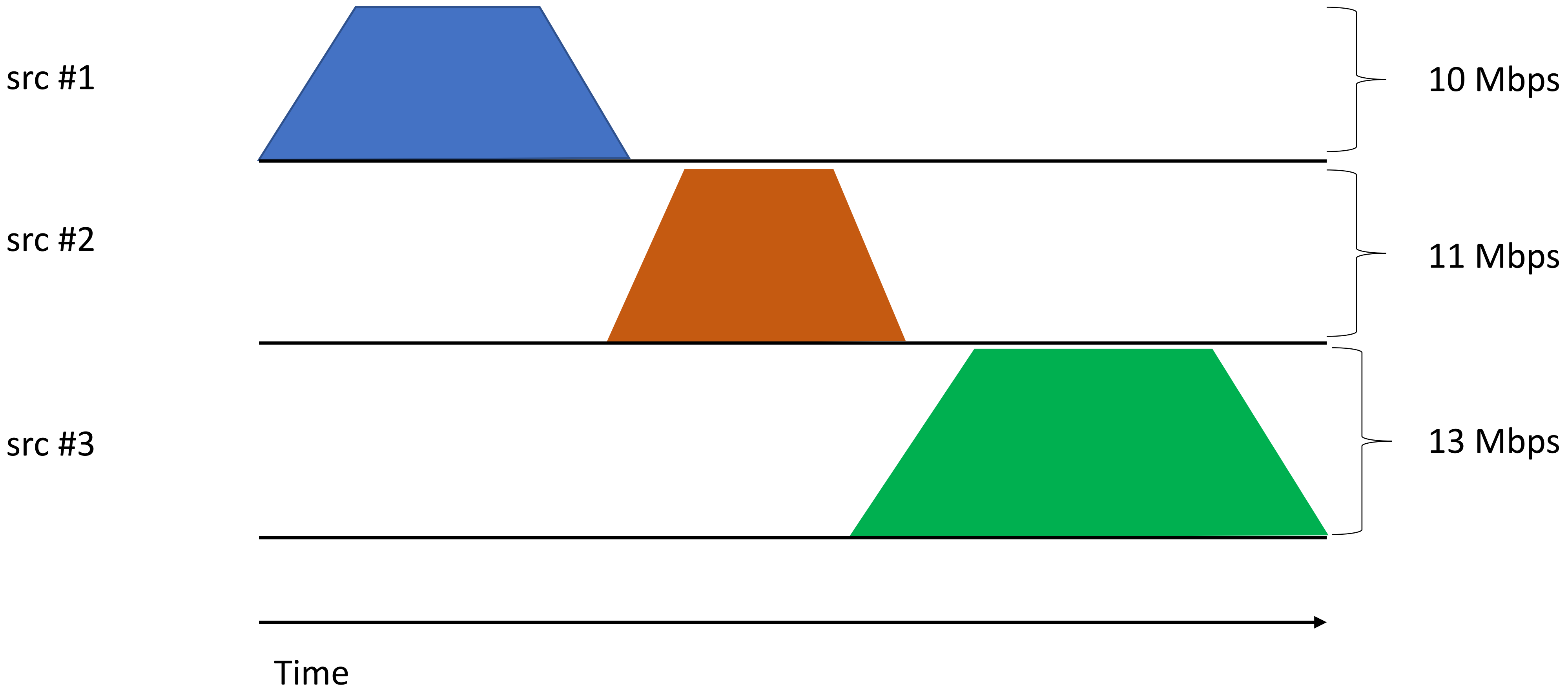
- Assume, each source needs 10 Mbps bandwidth

- 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 the level of utilization is A/P
- P=100 Mbps, A=10 Mbps, the level of utilization = 10%

On-demand can usually achieve higher level of utilization

- depends on degree of sharing and burstiness of flows

Which one is better?
It depends…

If P/A is small, reservation makes sense

- voice traffic has a ratio of 3 or so

If P/A is big, reservation wastes resources

- Data traffic is bursty
- The P/A ratios >100 are common

Which one is better?
It depends…

If P/A is small, reservation makes sense

- voice traffic has a ratio of 3 or so

If P/A is big, reservation wastes resources

- Data traffic is bursty
- The P/A ratios >100 are common

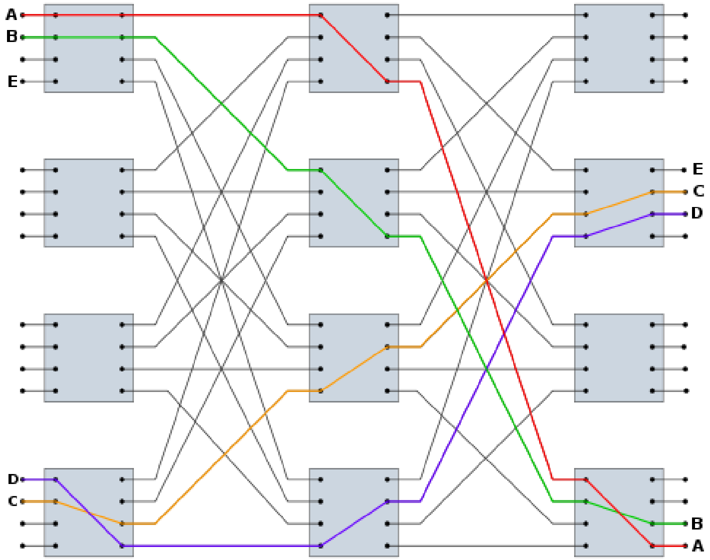
That's why the phone network used reservations

… and why the Internet does not!

Implementation

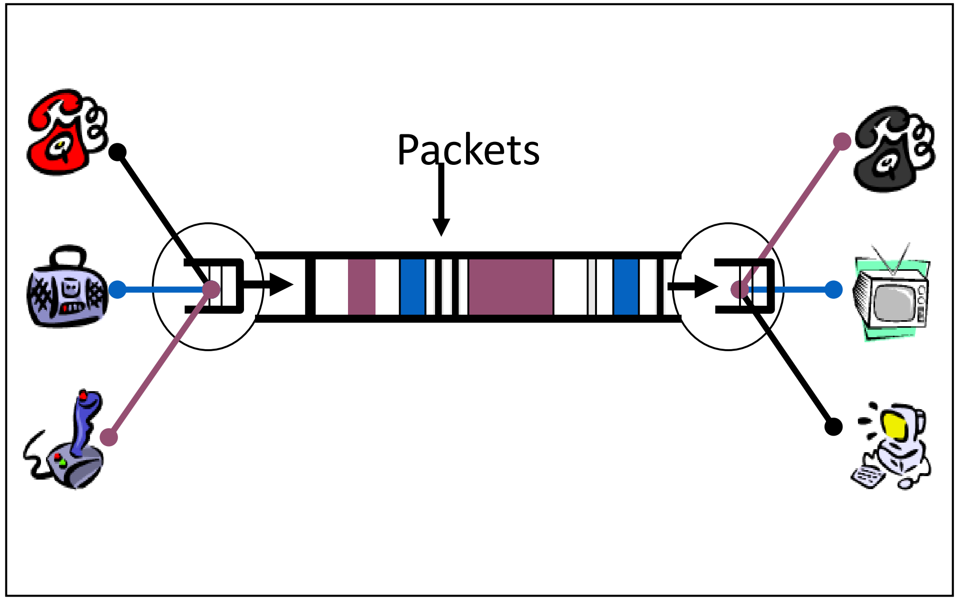
Reservation

Circuit-switching
e.g. landline phone networks



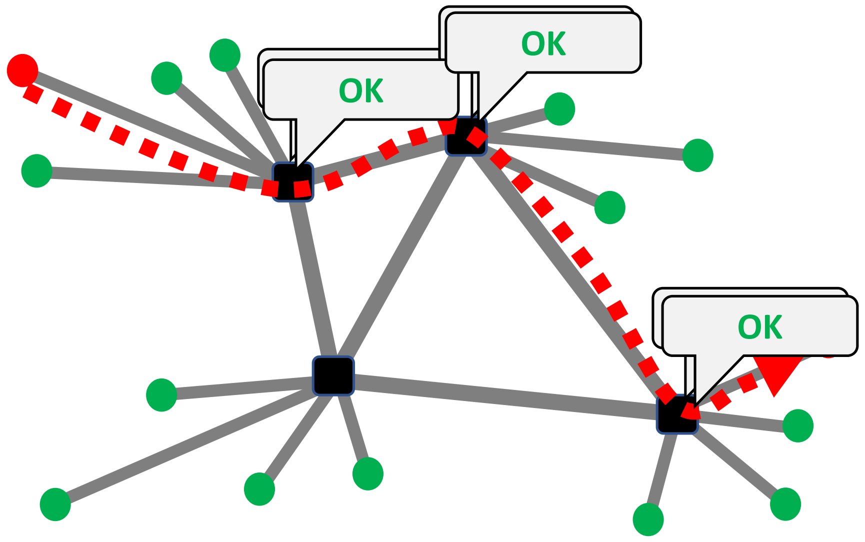
On-demand

Packet-switching
e.g. Internet



Circuit-switched networks rely on the Resource Reservation Protocol

Used for reservation management



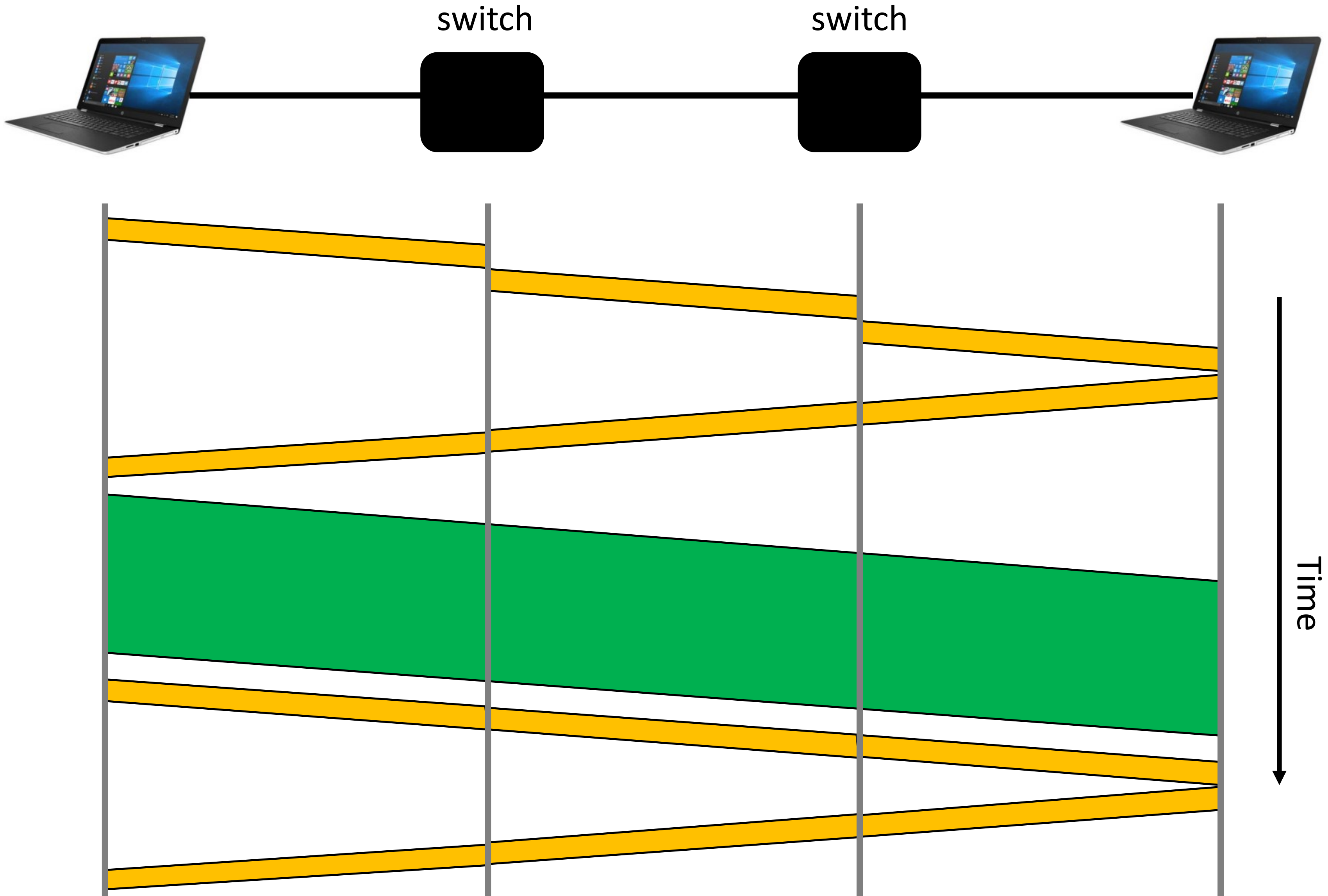
1. src sends a reservation request for 10Mbps to dst
2. switches "establish a circuit"
3. src starts sending data
4. src sends a "teardown circuit" message

Data transfer using circuit-switching

Circuit establishment

Data transfer

Circuit teardown



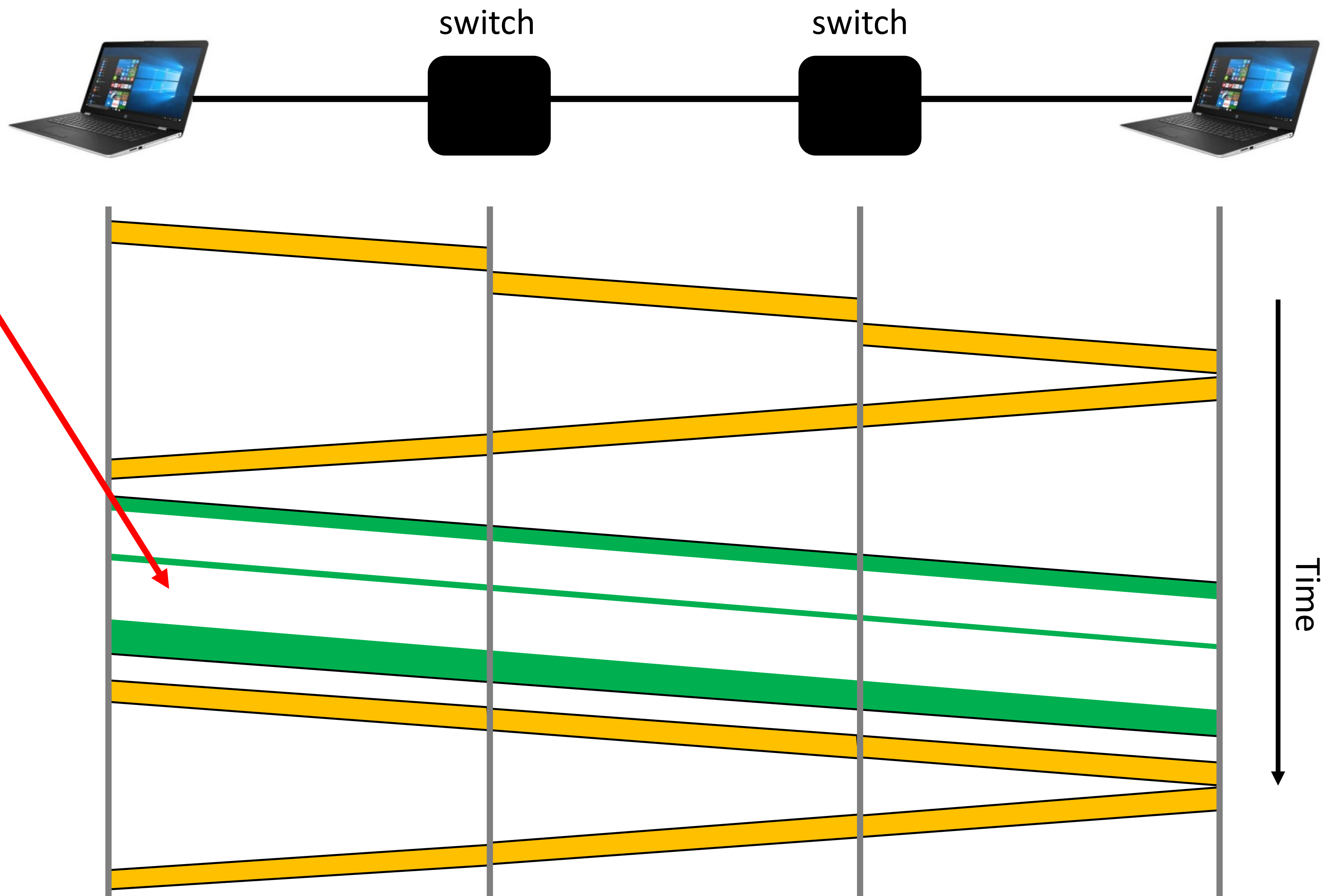
Burtsy traffic – Bad performance

The circuit is mostly idle…

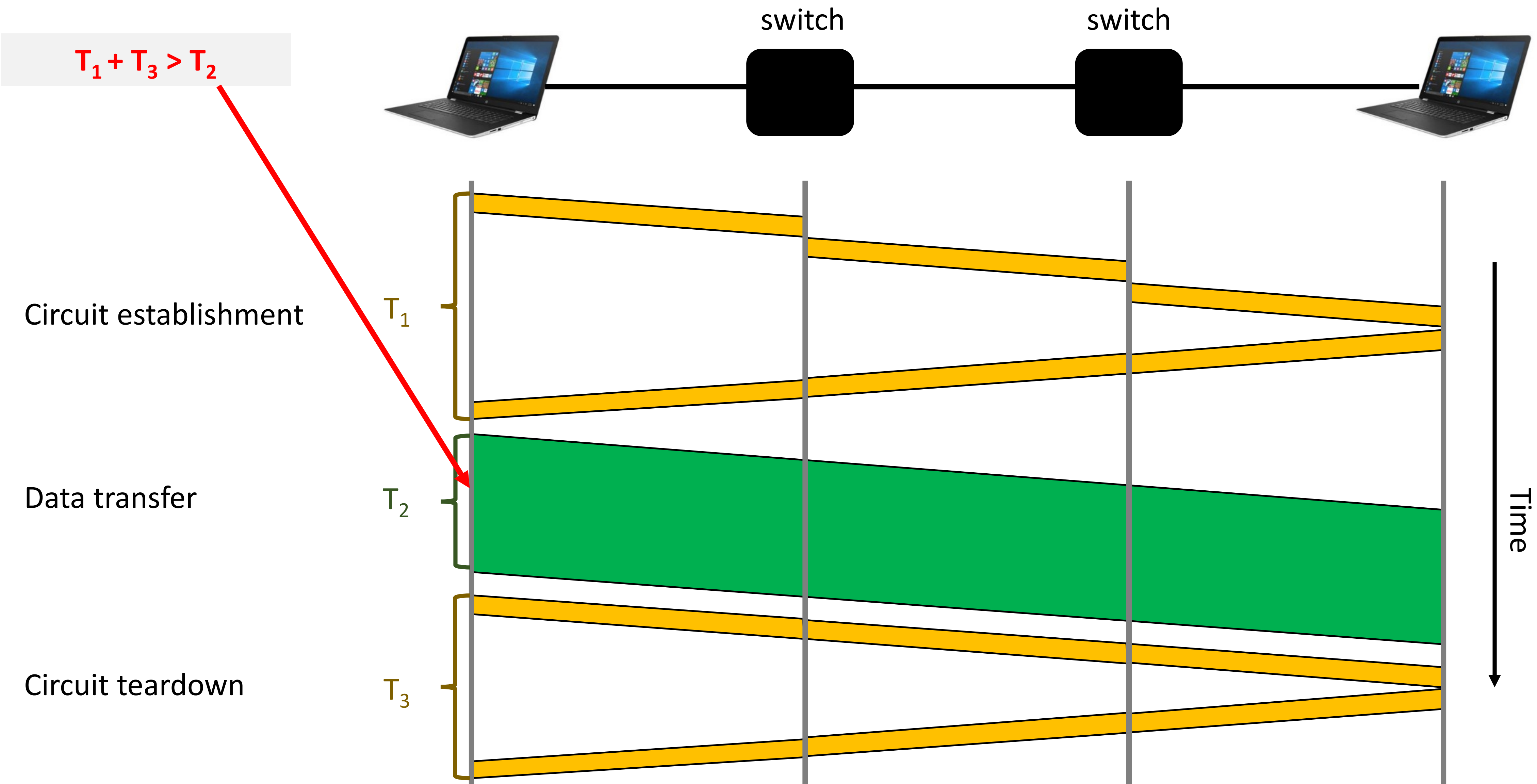
Circuit establishment

Data transfer

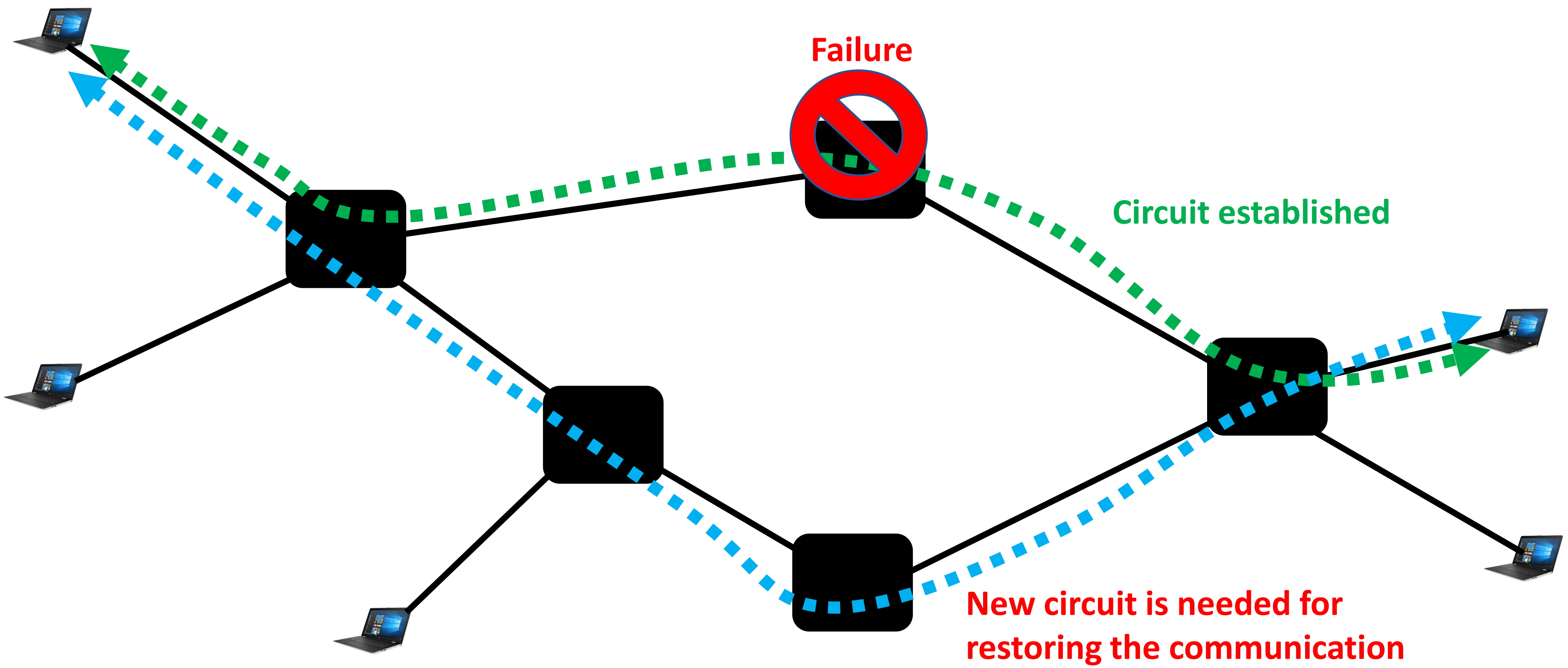
Circuit teardown



Short messages – Bad performance



Further problems –
it doesn't route around trouble



Pros & Cons

Pros

Predictable performance

Simple and fast switching
once circuit established

Cons

Low efficiency
- Bursty traffic
- Short flows

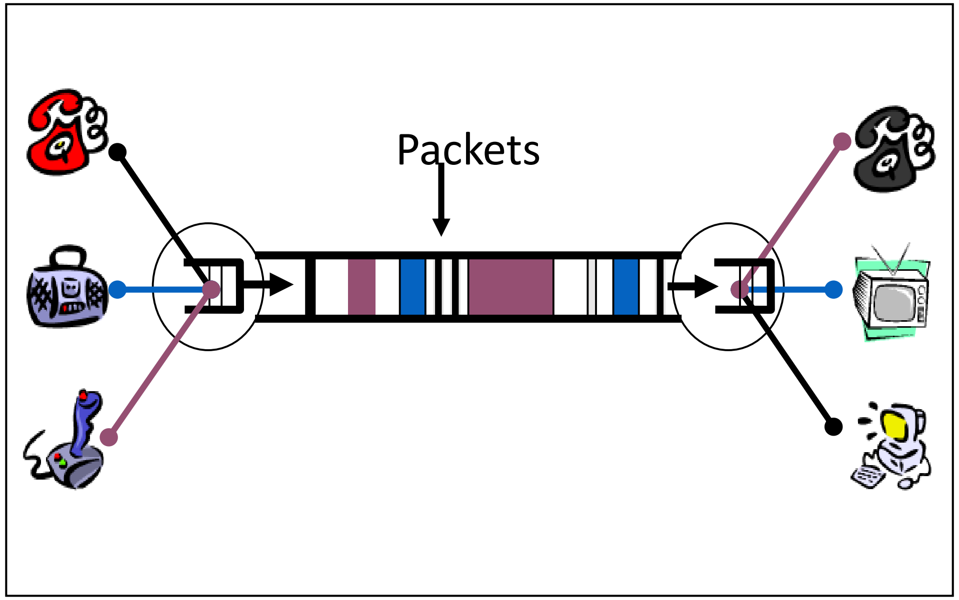
Complexity of circuit establ./teard.
Increased delay

New circuit is needed in case of failures

Implementation

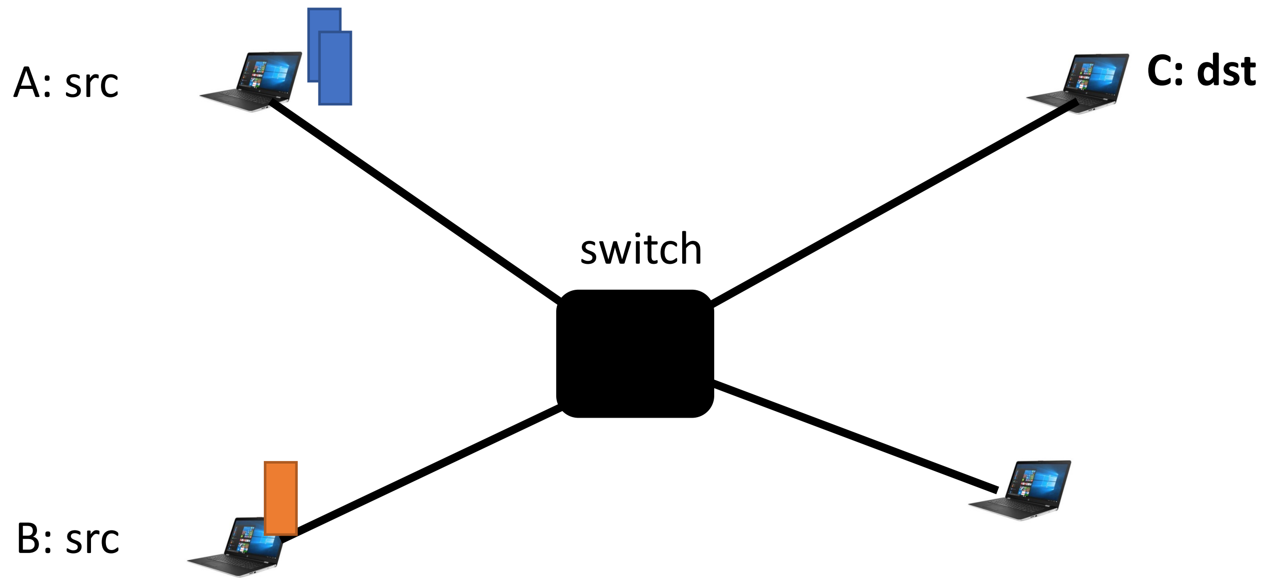
On-demand

Packet-switching
e.g. Internet



Packet-switching

Data transmission in individual packets



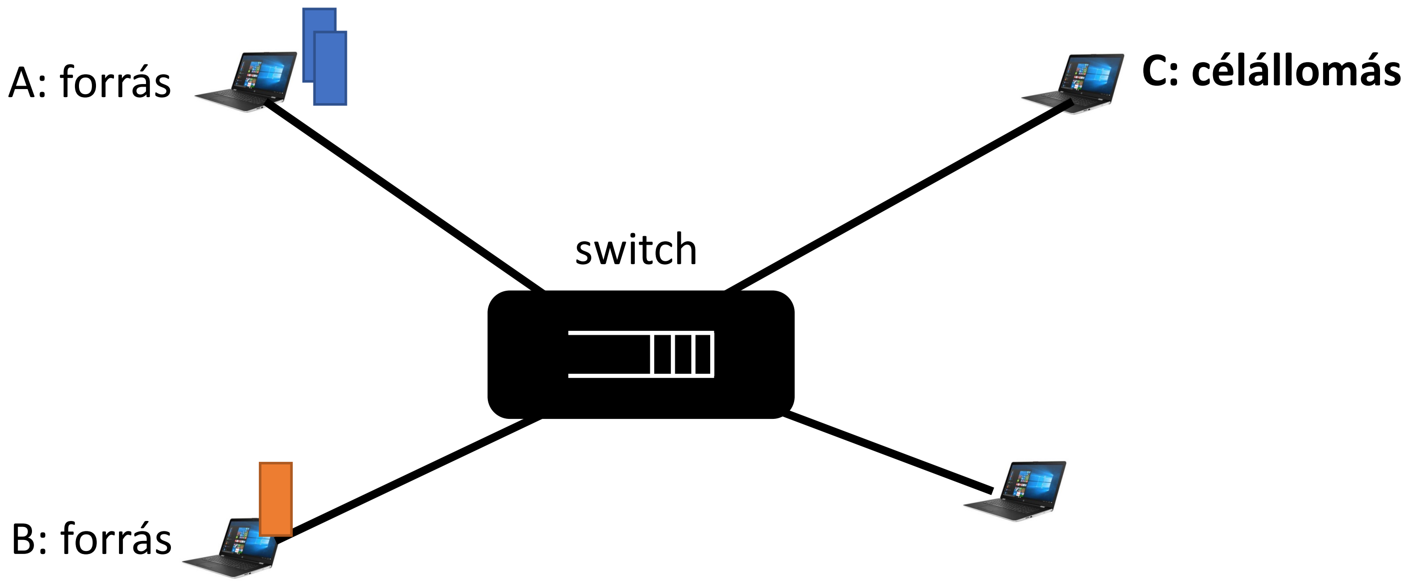
Each packet carries dst's address

No global coordination
Packets can conflict
with each other

Buffering is needed for handling bursts.

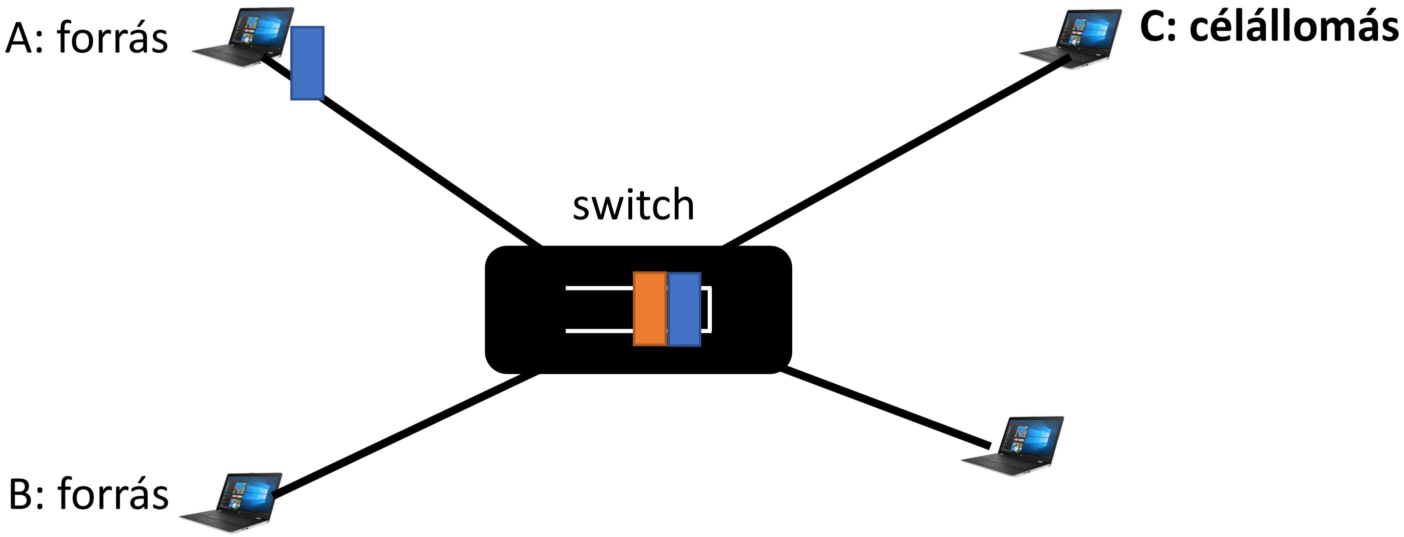
Packet-switching

Buffering to handle temporal overloads

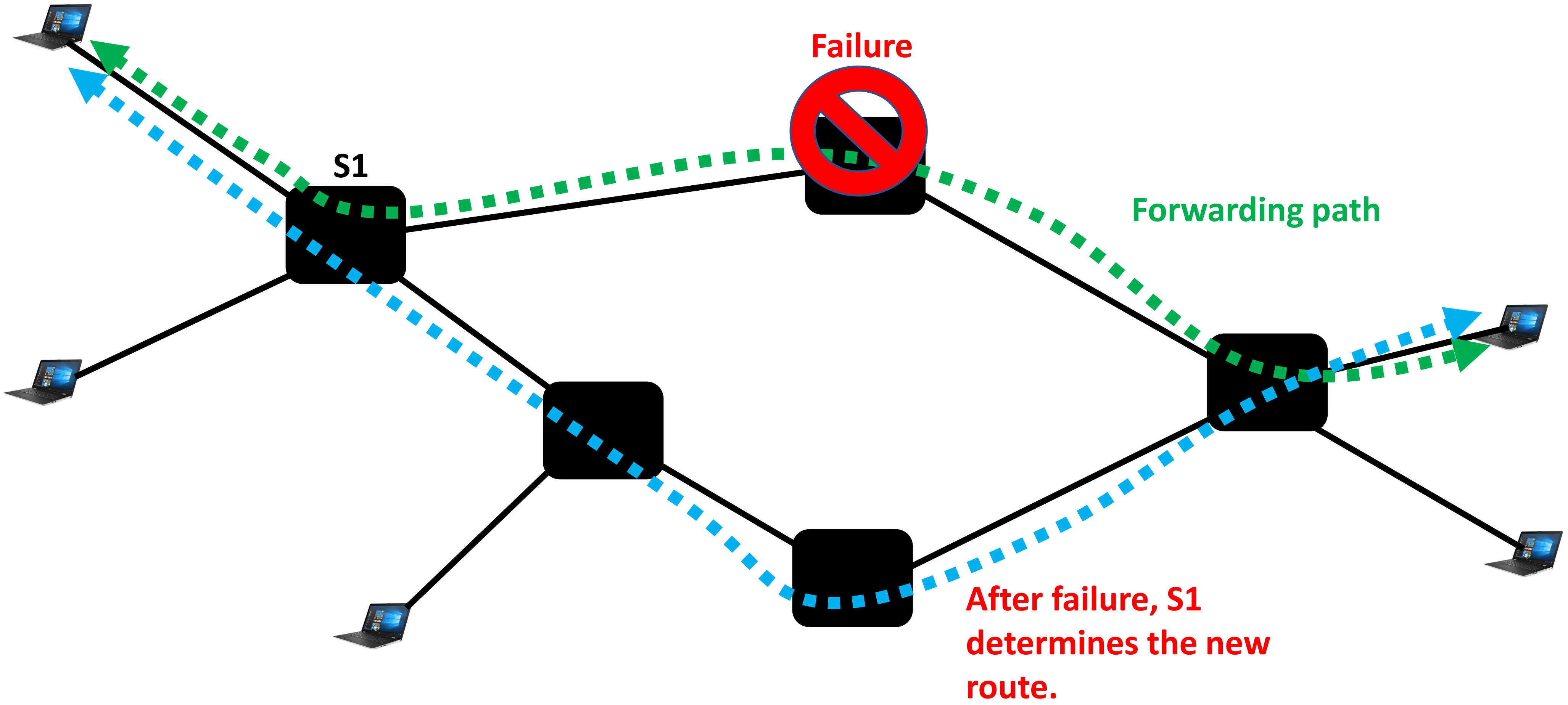


Packet-switching

Buffering to handle temporal overloads



Failure tolerance



Pros & Cons

Pros

Efficient resource management

Simple implementation

Failure tolerance

Cons

Unpredictable performance

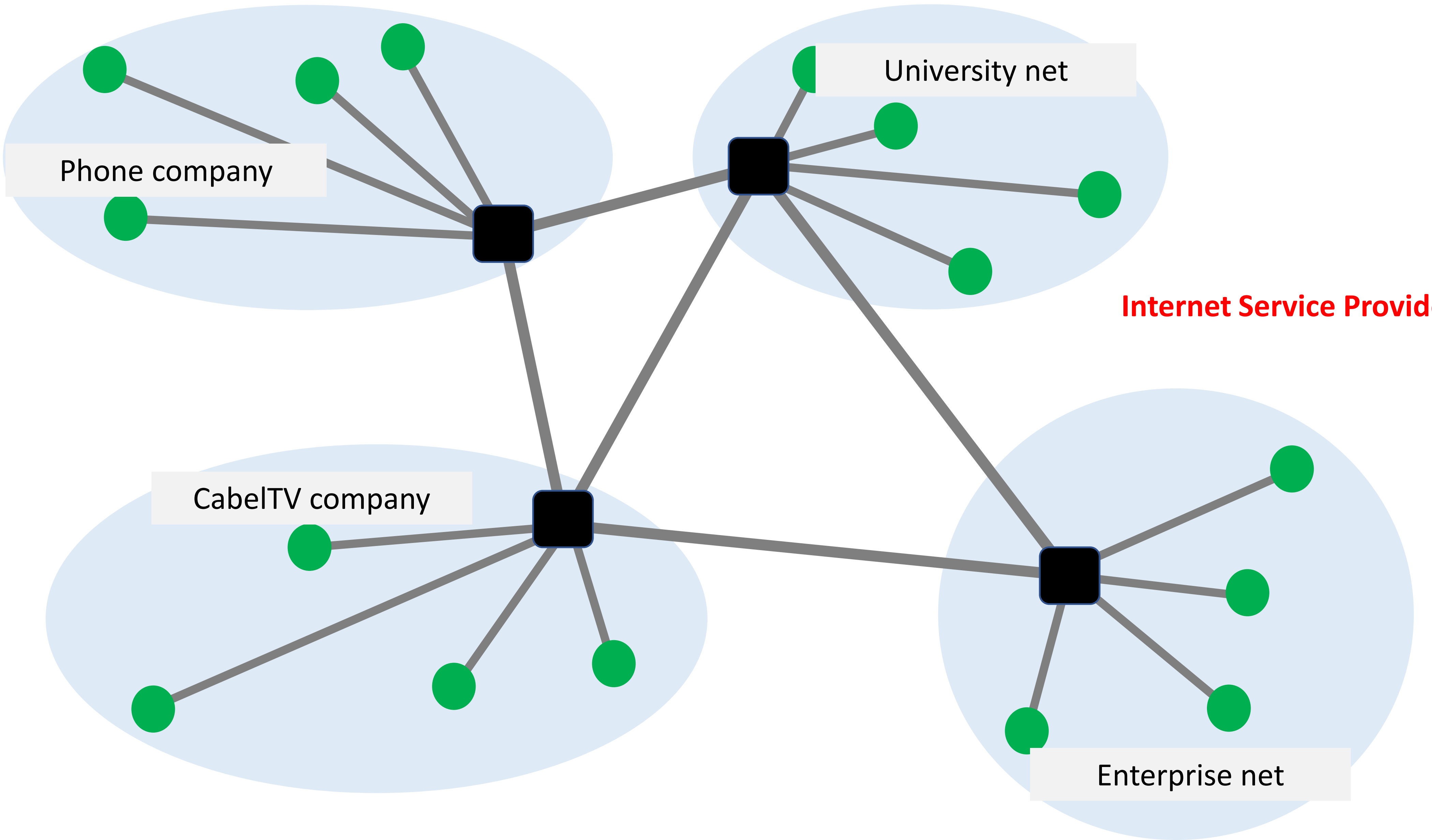
Buffer management and congestion control is needed

Internet is packet-switched

Overview

How to organize the network?

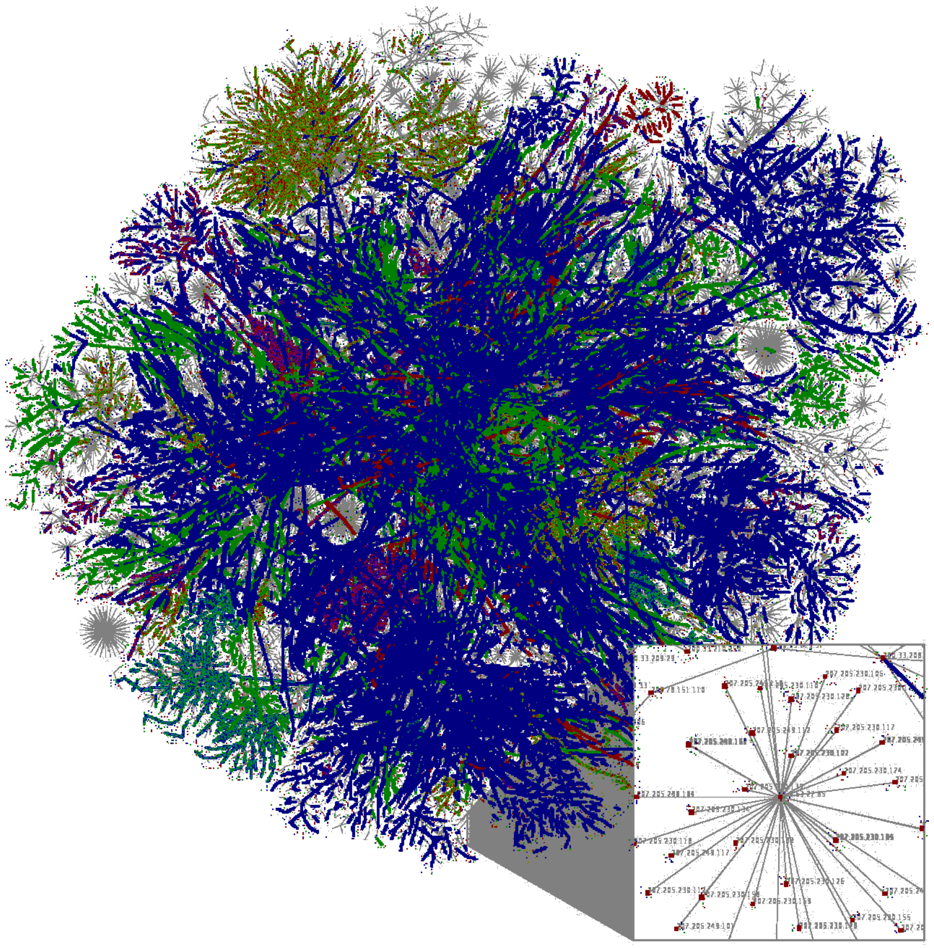
Internet = Network of networks



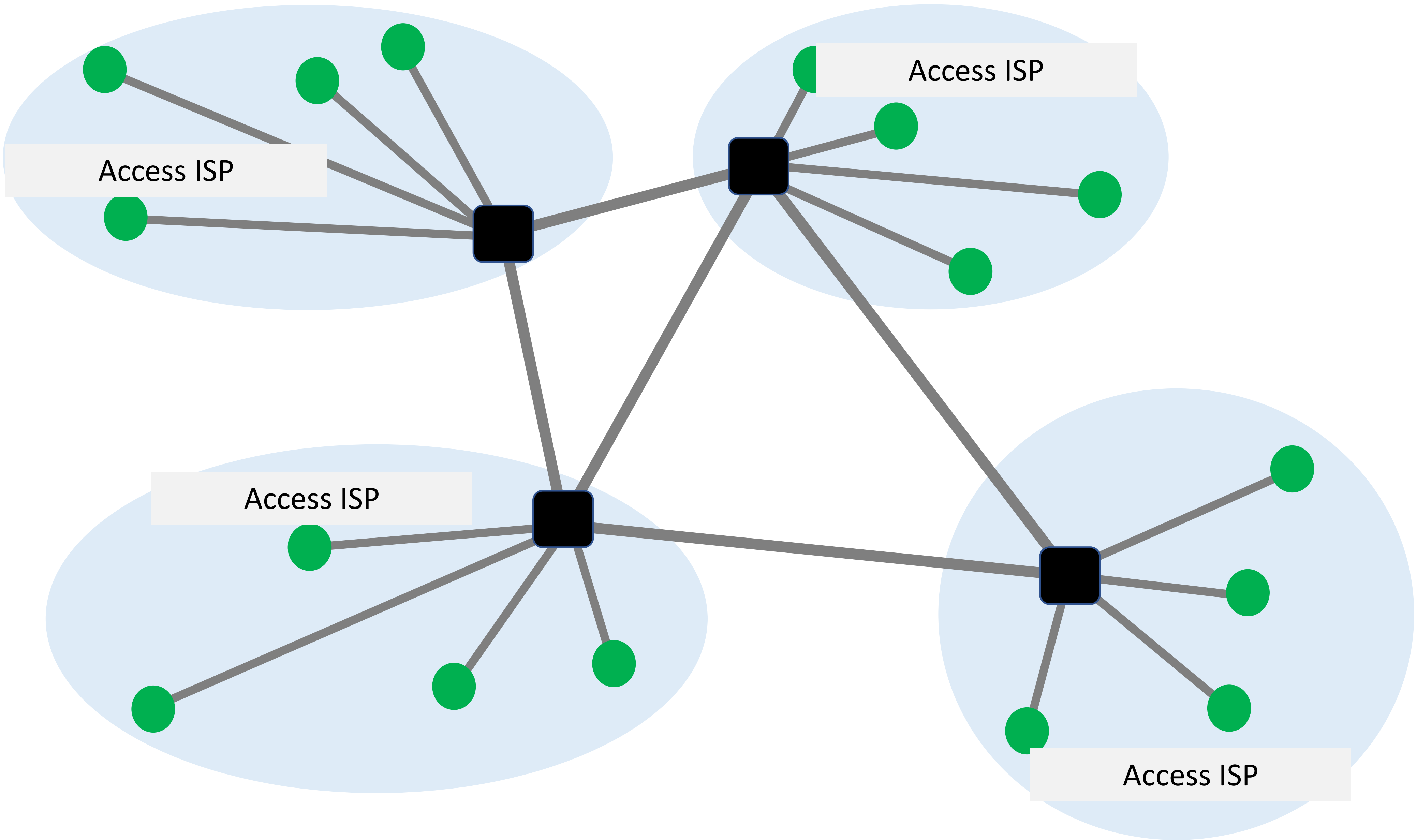
Internet Service Providers = ISPs

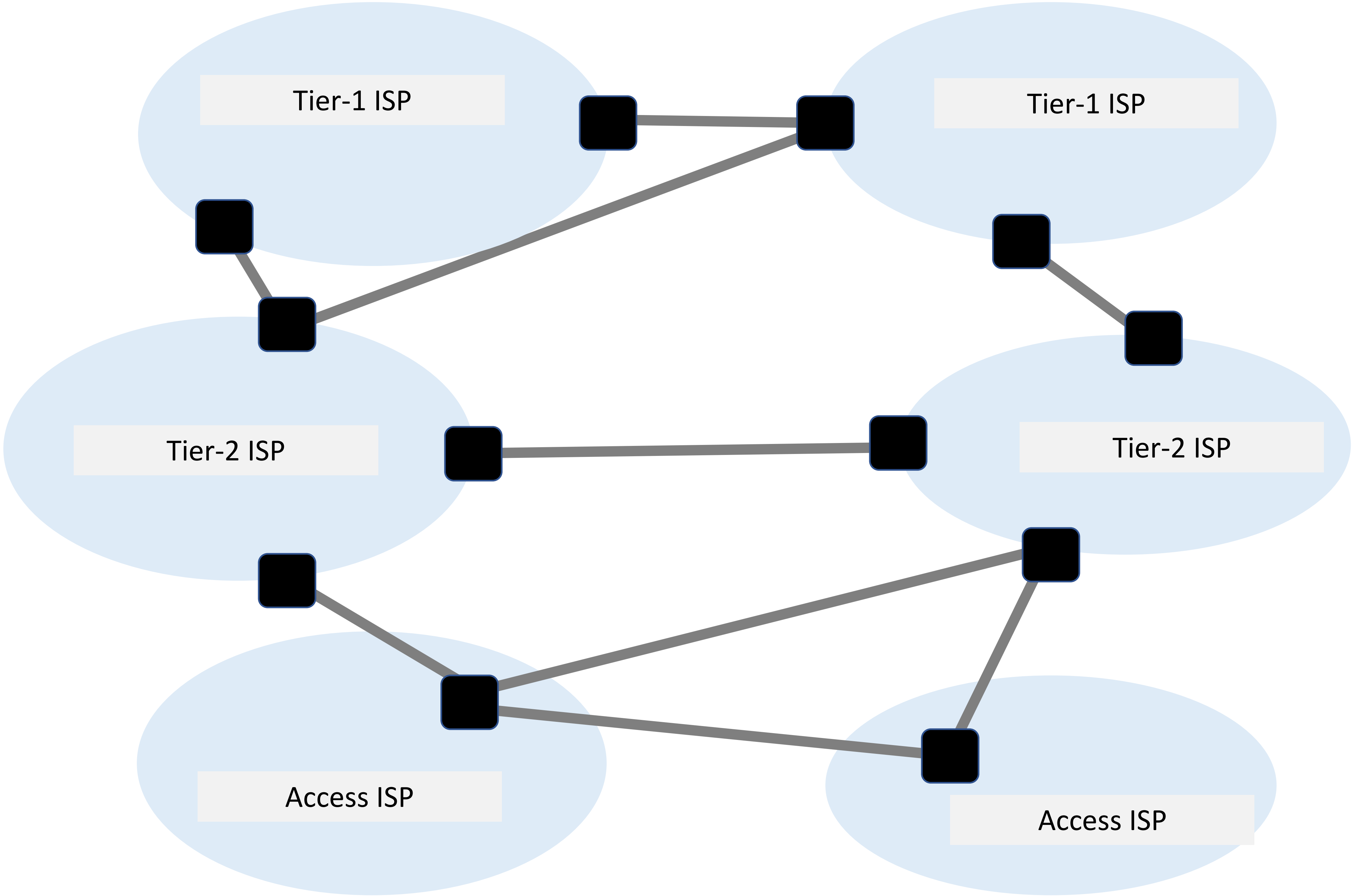
What is Internet?

- Network of networks
- Largest Wide Area Network
- Properties
  - System independent
  - No central control
  - Built from LANs
  - Global
  - Enables services like WEB, file transfer, etc.



ISP – Internet Service Provider

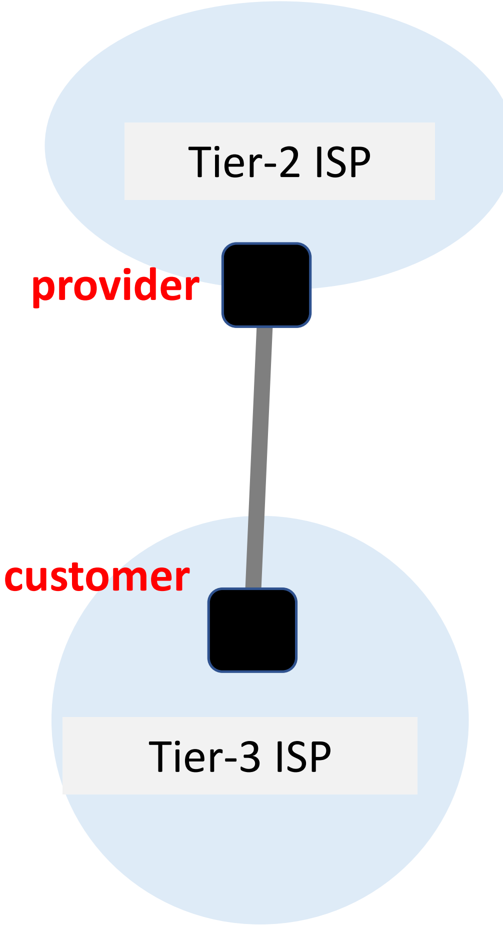


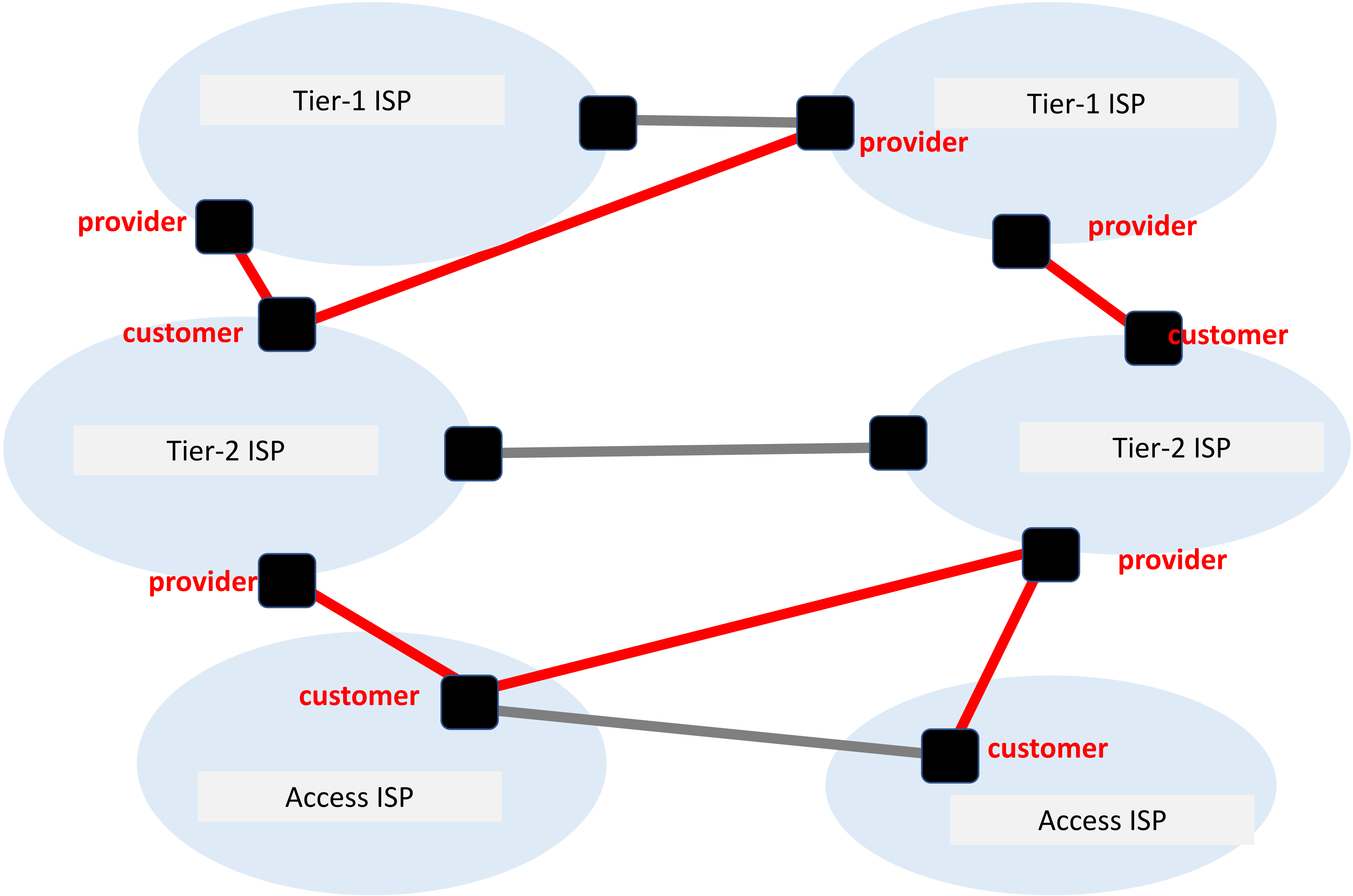

Tier-1 ISP
Tier-1 ISP
Tier-2 ISP
Tier-2 ISP
Access ISP
Access ISP

Hierarchical structure of Internet

provider-customer relations

Tier-1	has no provider
international	
Tier-2	provides transit to Tier-3s átjárást
national	Have at least one provider
Tier-3	do not provide any transit
local	Have at least one provider





Tier-1 ISP
Tier-1 ISP
provider
provider
provider
customer
customer
Tier-2 ISP
Tier-2 ISP
provider
provider
customer
customer
Access ISP
Access ISP

Hierarchical structure of Internet

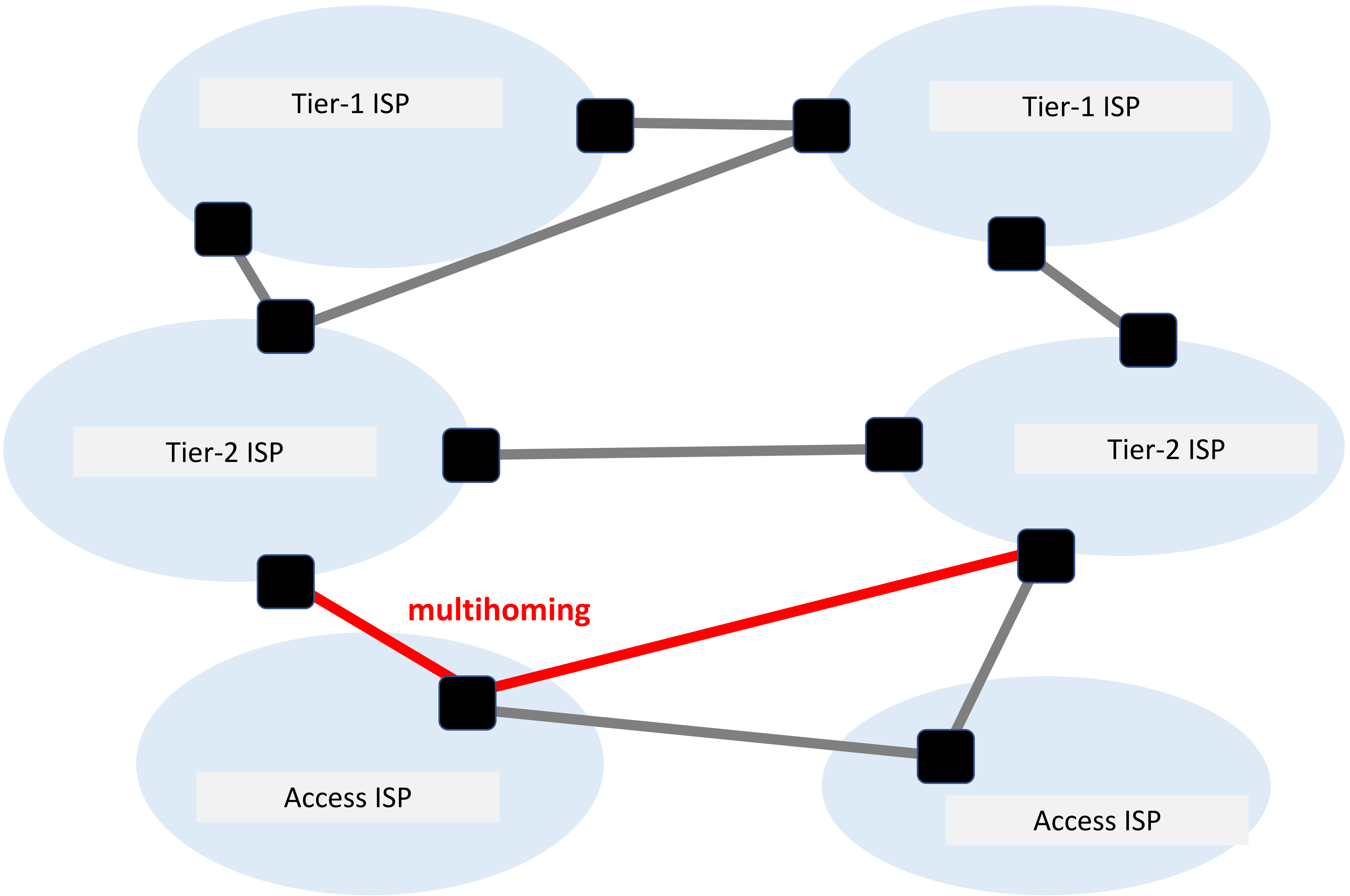
provider-customer relations

~50.000 networks

Few docents

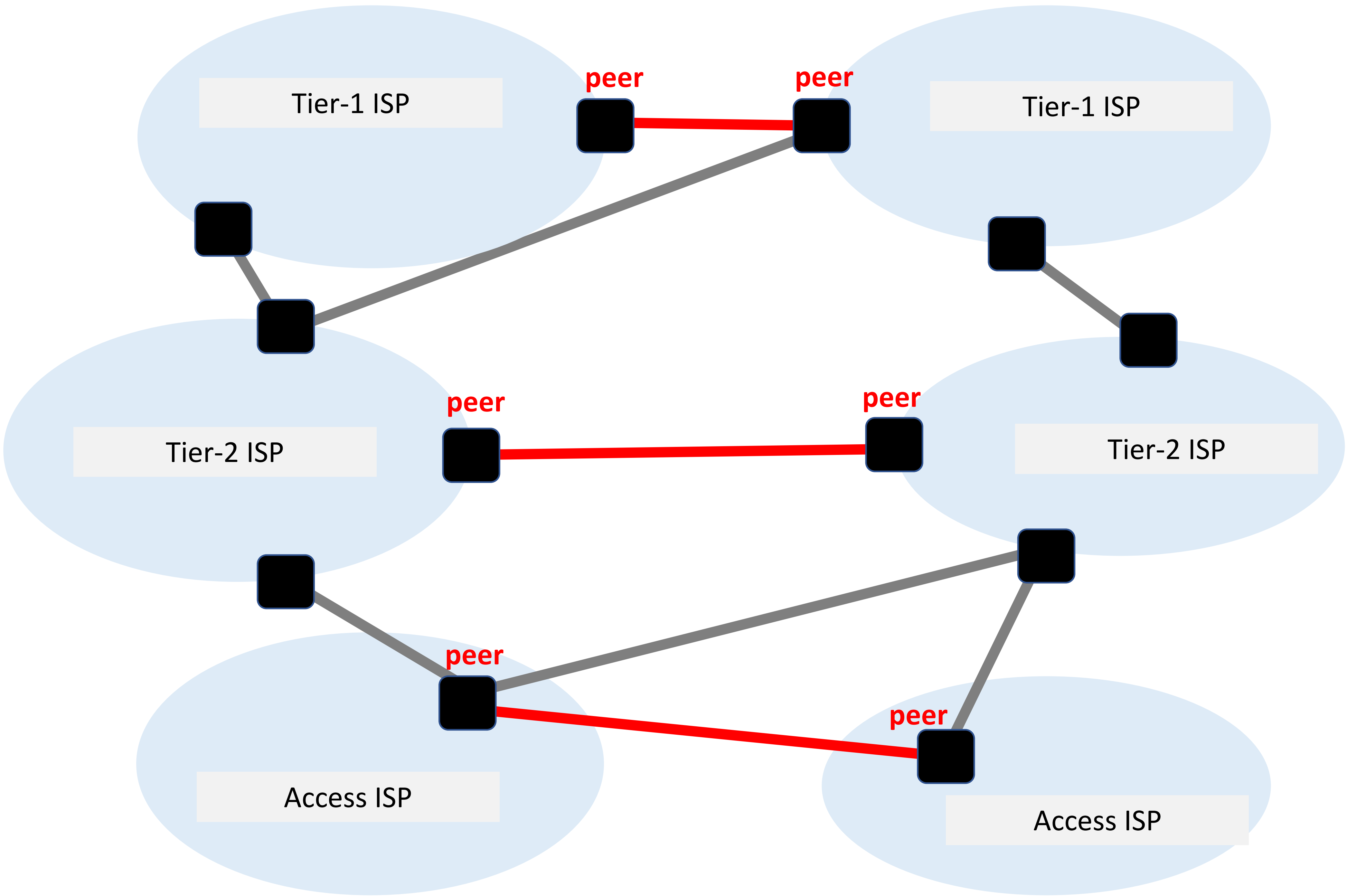
Few thousands

85-90%


Tier-1 ISP
Tier-1 ISP
Tier-2 ISP
Tier-2 ISP
multihoming
Access ISP
Access ISP

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

This is known as “peering”


Tier-1 ISP
peer
peer
Tier-1 ISP
Tier-2 ISP
peer
peer
Tier-2 ISP
peer
peer
Access ISP
Access ISP

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

Infrastructure/physical costs

of provisioning or renting physical links

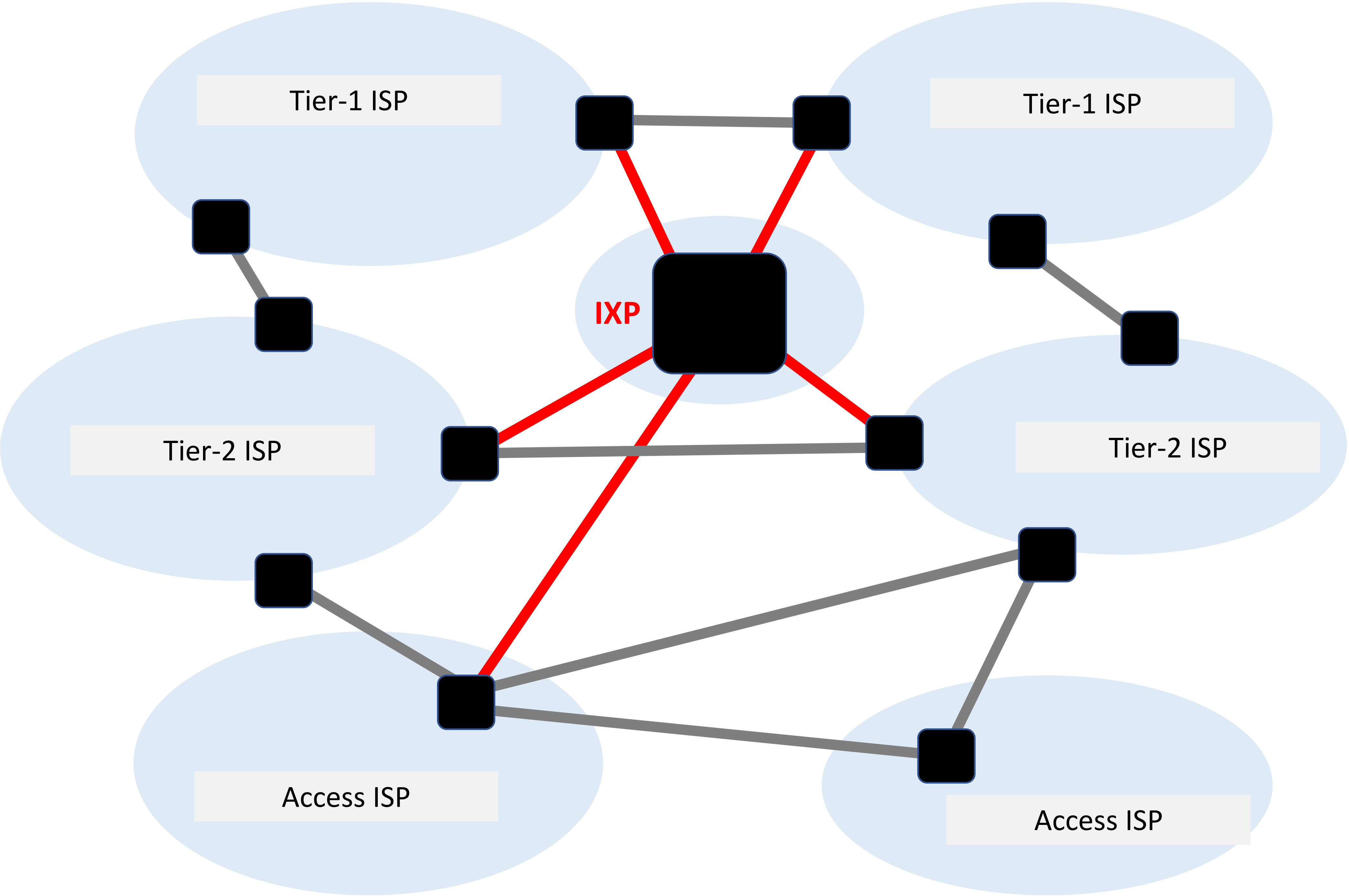
Bandwidth costs

a lot of links are not necessarily fully utilized

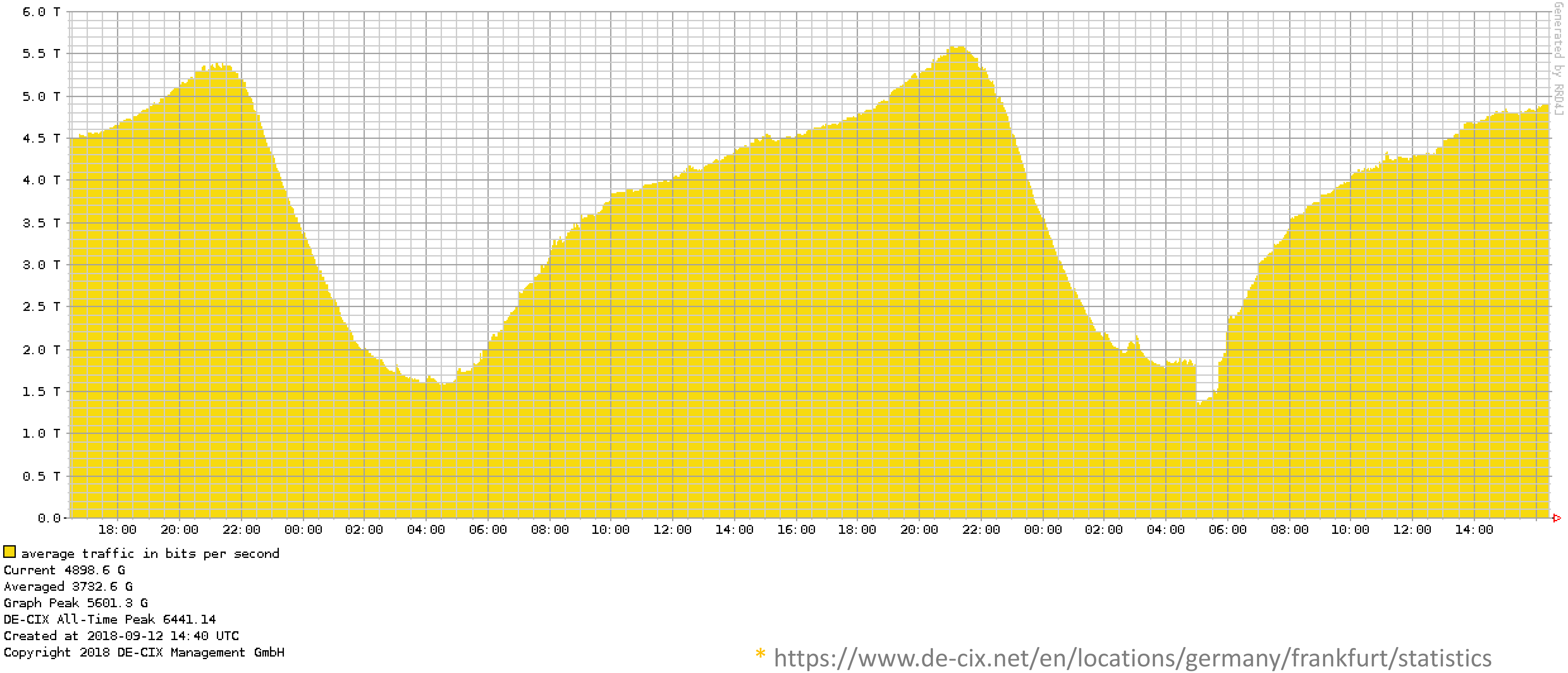
Human costs

to manage each connection individually

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


Tier-1 ISP
Tier-1 ISP
IXP
Tier-2 ISP
Tier-2 ISP
Access ISP
Access ISP

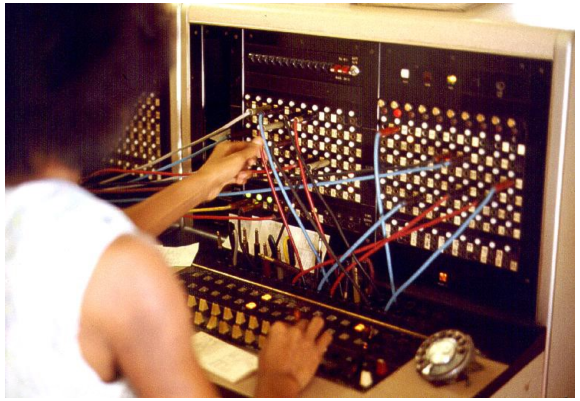
Two days of an IXP – DE-CIX Frankfurt



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

Brief history of Internet

The Internet history starts in the late 50's…



Phone networks = the communication network

fully circuit-switched

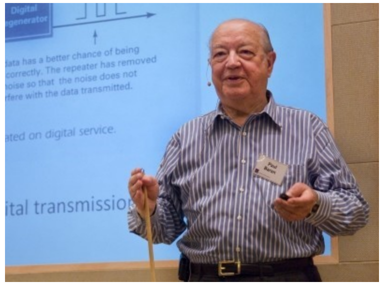
People wanted to use networks for other things

defense, computers, etc.

circuit-switching does not fit to these new requirements…

inefficient for bursty loads and not resilient

Three main questions



Paul Baran RAND

How can we design a more resilient network?

… led to the invention of packet switching

Leonard Kleinrock
UCLA

How can we design a more efficient network?

… also led to the invention of packet switching

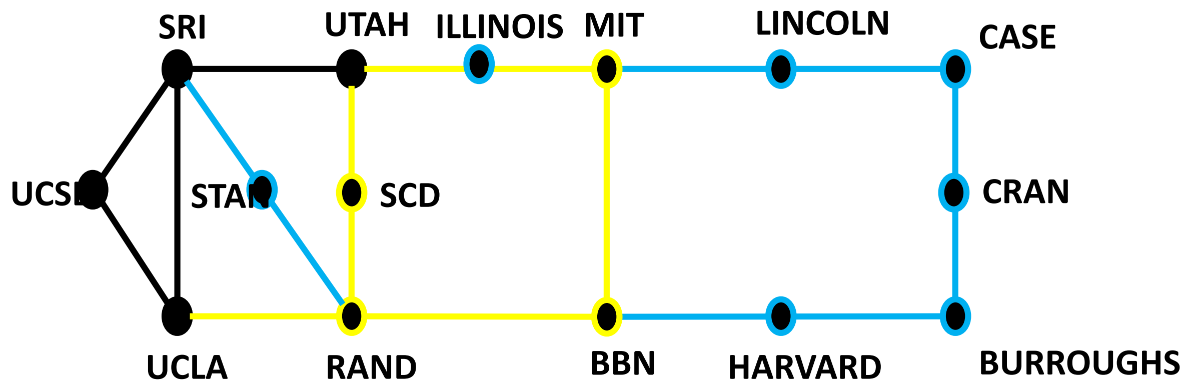
Vint Cerf & Bob Kahn
DARPA

How can we connect all these networks together?

… the invention of Internet as we know it

The 60’s was all about packet switching…

Advanced Research Projects Agency NETwork (ARPANET)



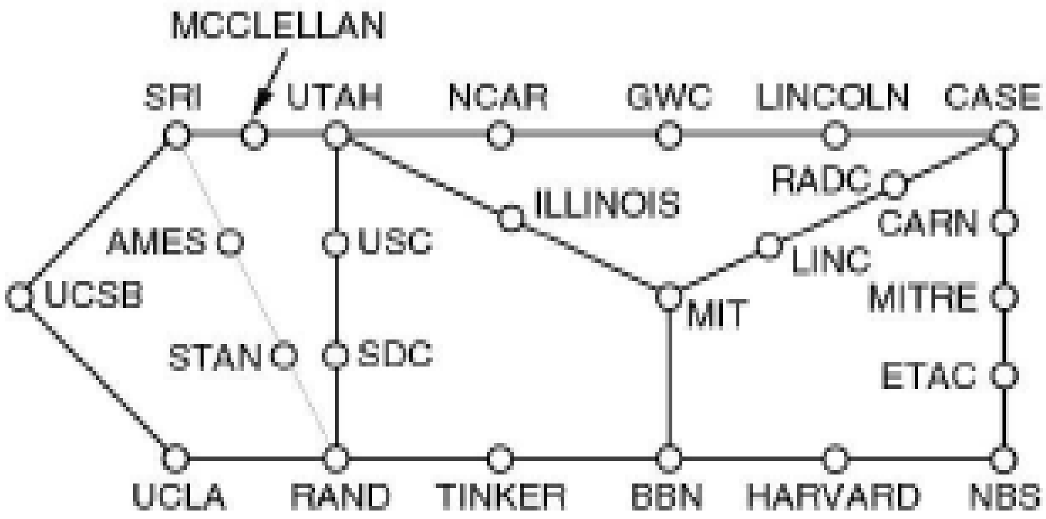
1969 december

1970 july

1971 march

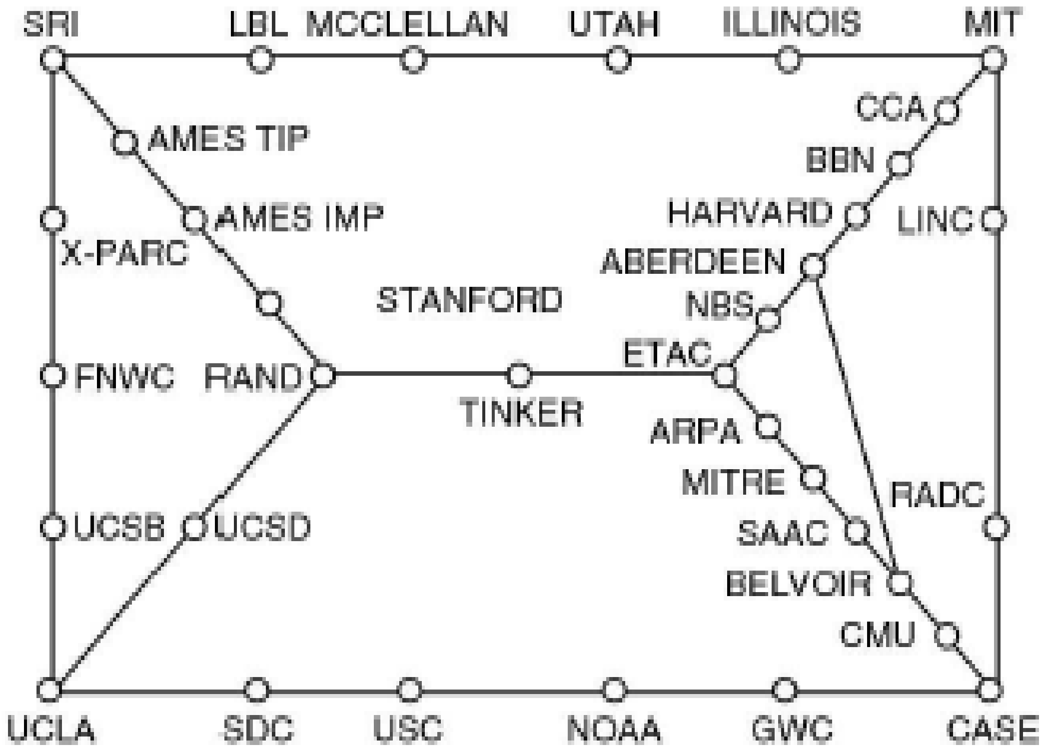
ARPANET

April 1972

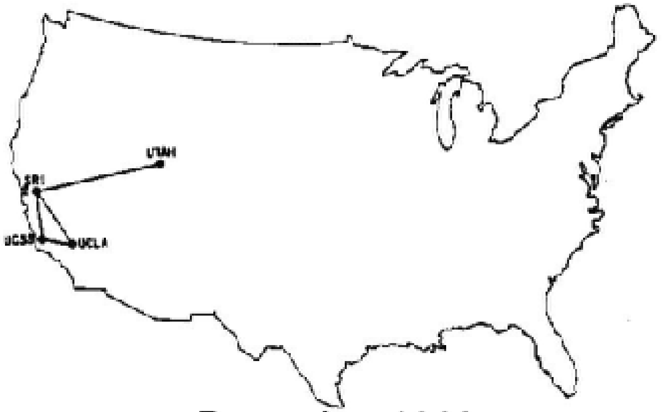


ARPANET

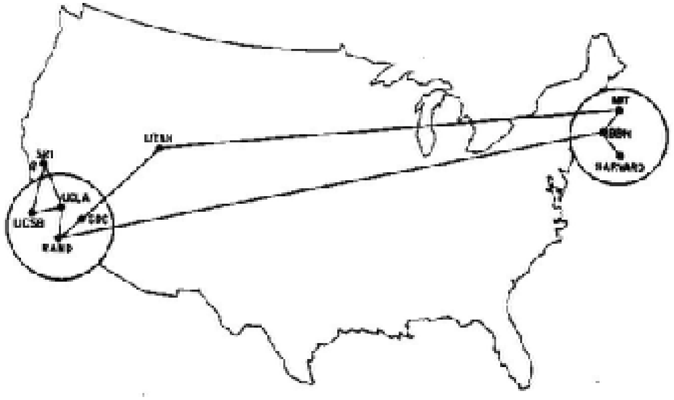
September 1972



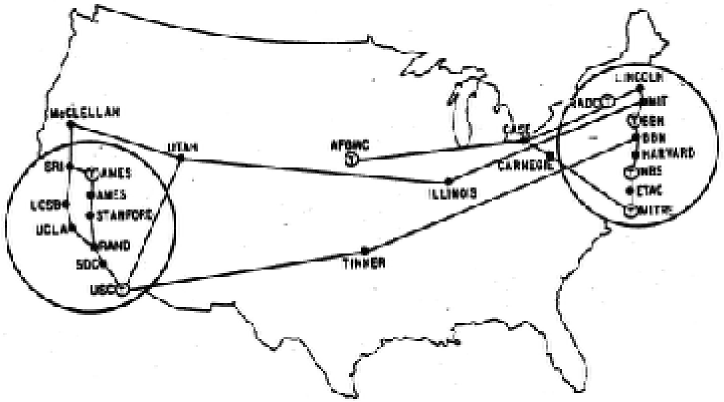
ARPANET



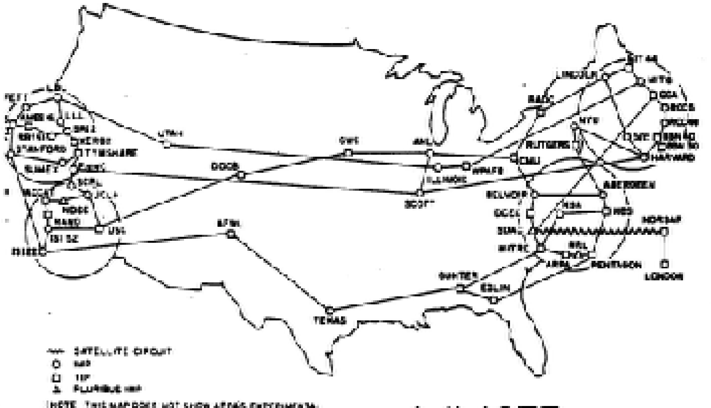
Dezember 1969



Juni 1970



März 1972



Juli 1977

The first message over the Internet : „LO”

29. Oct. 1969

Leonard Kleinrock from 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.

… and the system crashed …

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

The 70’s about Ethernet, TCP/IP and email…

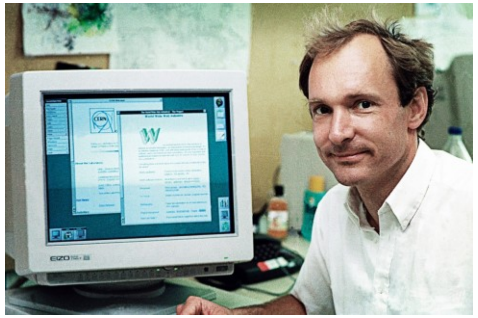
1971	**Network Control Program (NCP)** Predecessor of TCP/IP
1972	**Email and Telnet**
1973	**Ethernet**
1974	**TCP/IP** Paper of Vint Cerf and Bob Kahn

80’s when TCP/IP went mainstream

1983	**NCP to TCP/IP**
	Domain Name Service (DNS)
1985	**NSFNet (TCP/IP)**
198x	**First Internet crashes caused by congestion**
1986	**Van Jacobson saves the Internet**
	congestion control

Van Jacobson

90's – the Internet going commercial…



1989 **ARPANET closed**

Birth of the WEB

Tim Berners Lee (CERN)

1993 **First search engine (Excite)**

1995 **NSFNet closed**

1998 **Google reinvents searching**

To be continued…