Communication Networks

Spring 2018

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Slides from

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Materials inspired from Scott Shenker & Jennifer Rexford

Last week on

Communication Networks

Communication Networks

Part 1: General overview

#1 What is a network made of?

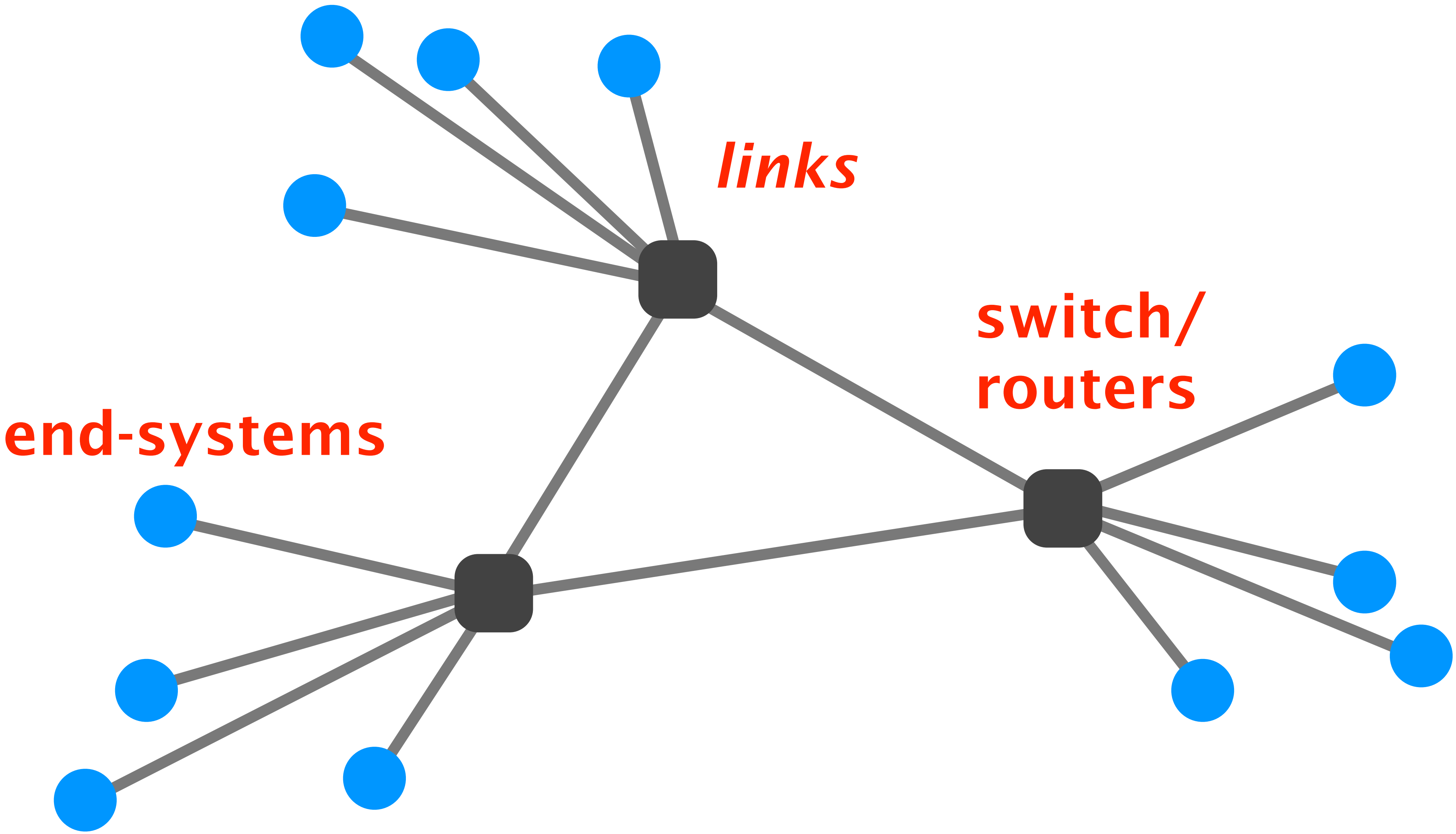
How is it shared?

How is it organized?

How does communication happen?

How do we characterize it?

Networks are composed of three basic components



Communication Networks

Part 1: General overview

What is a network made of?

#2 How is it shared?

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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

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

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

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

Pros and cons of packet switching

advantages

- efficient use of resources
- simpler to implement than circuit switching
- route around trouble

disadvantages

- unpredictable performance
- requires buffer management and congestion control

Communication Networks

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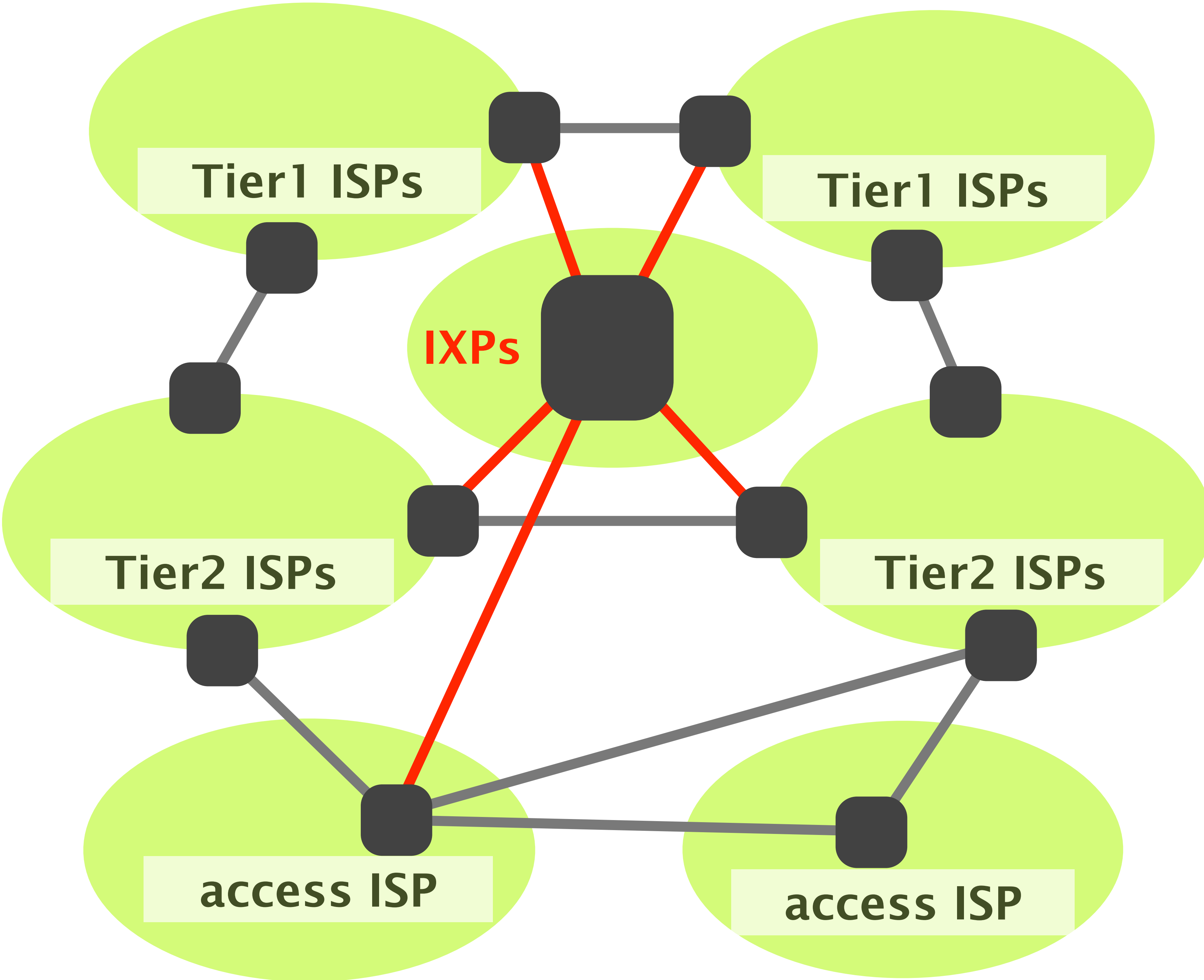
How do we characterize it?


Tier1 ISPs
Tier1 ISPs
IXPs
Tier2 ISPs
Tier2 ISPs
access ISP
access ISP

This week on

Communication Networks

Communication Networks

Part 1: General overview

What is a network made of?

How is it shared?

How is it organized?

#4 How does communication happen?

#5 How do we characterize it?

Communication Networks

Part 1: General overview

What is a network made of?

How is it shared?

How is it organized?

#4 **How does communication happen?**

How do we characterize it?

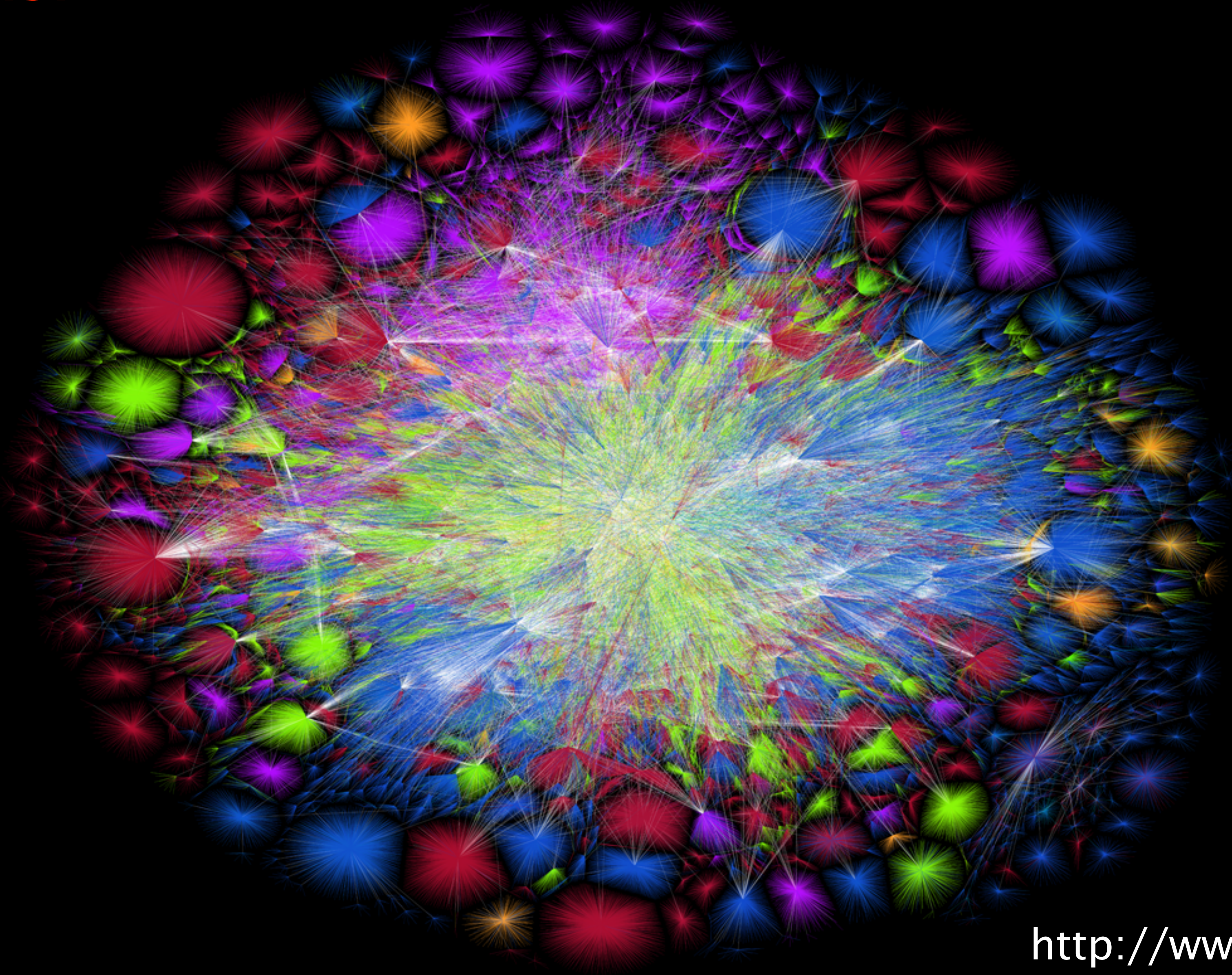
The Internet should allow

processes on different hosts

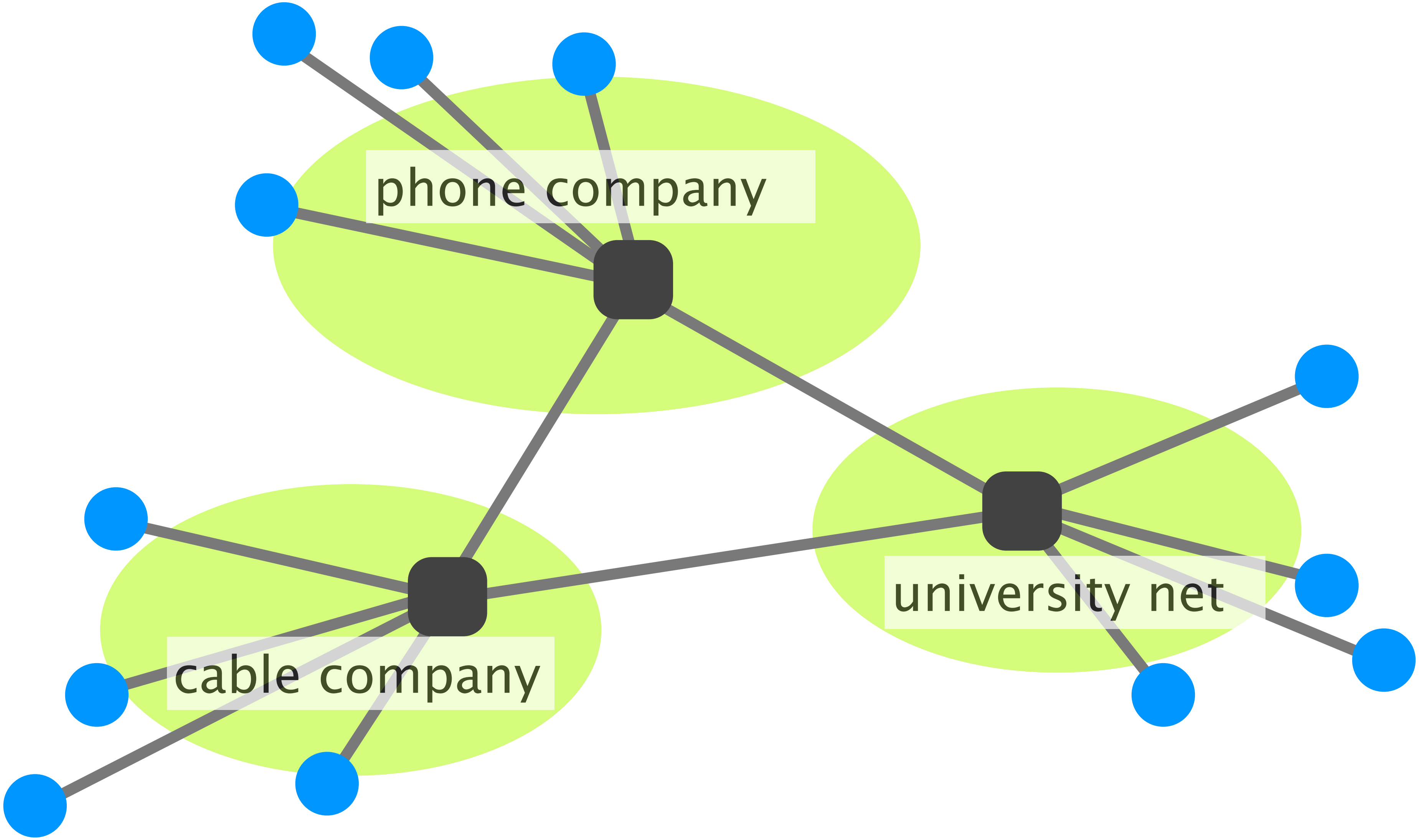
to exchange data

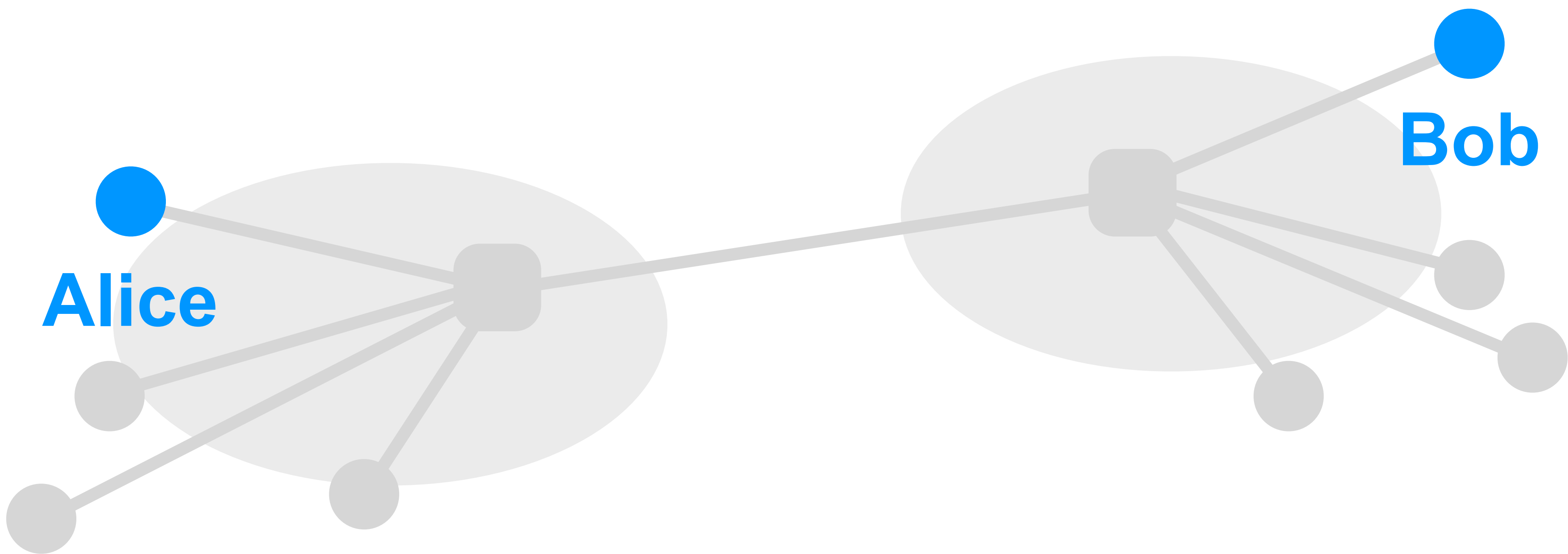
everything else is just commentary…

How do you exchange data in a network as complex as **this?**



http://www.opte.org

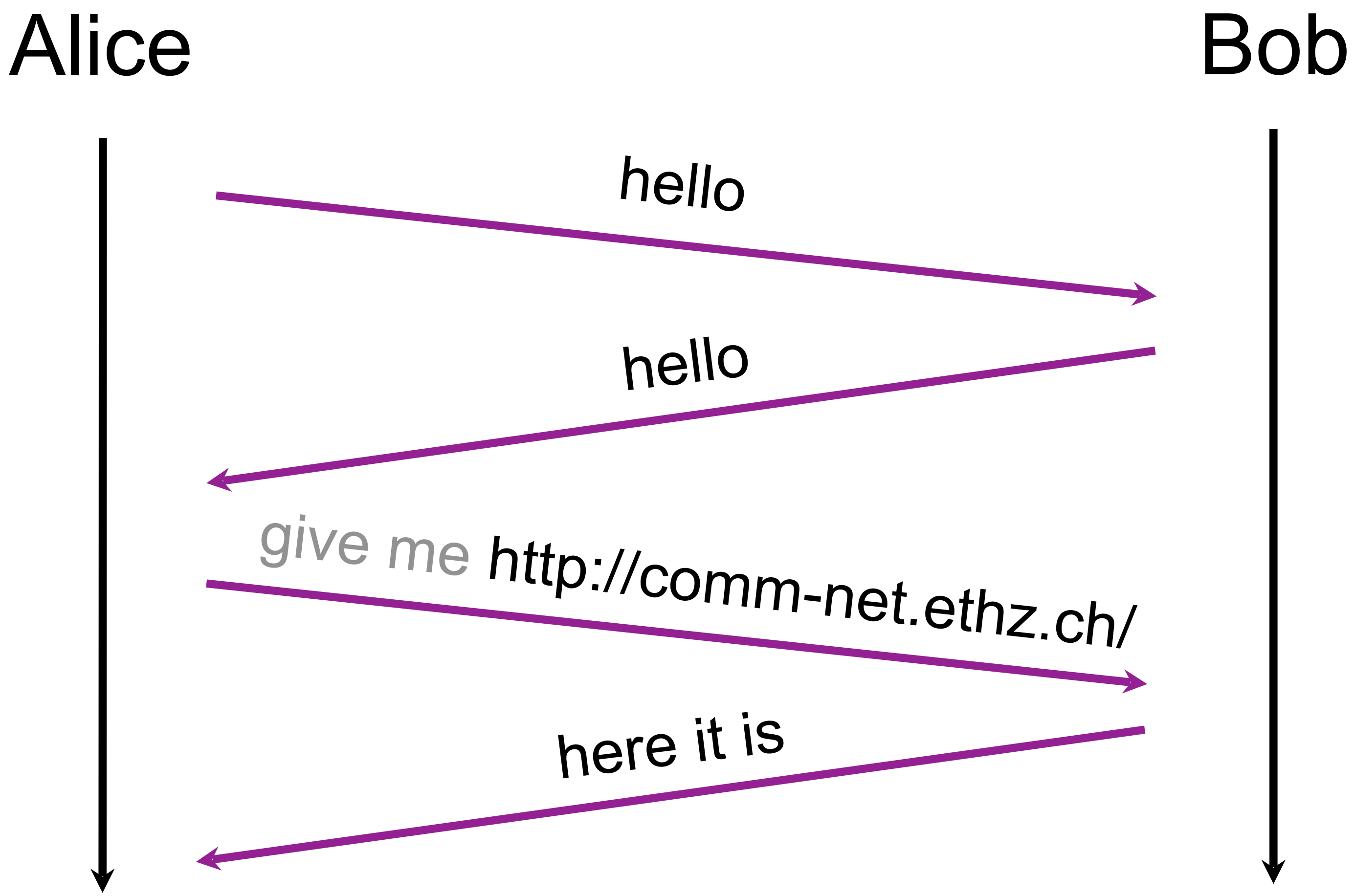

phone company
cable company
university net


Alice
Bob

To exchange data, Alice and Bob use
a set of network protocols

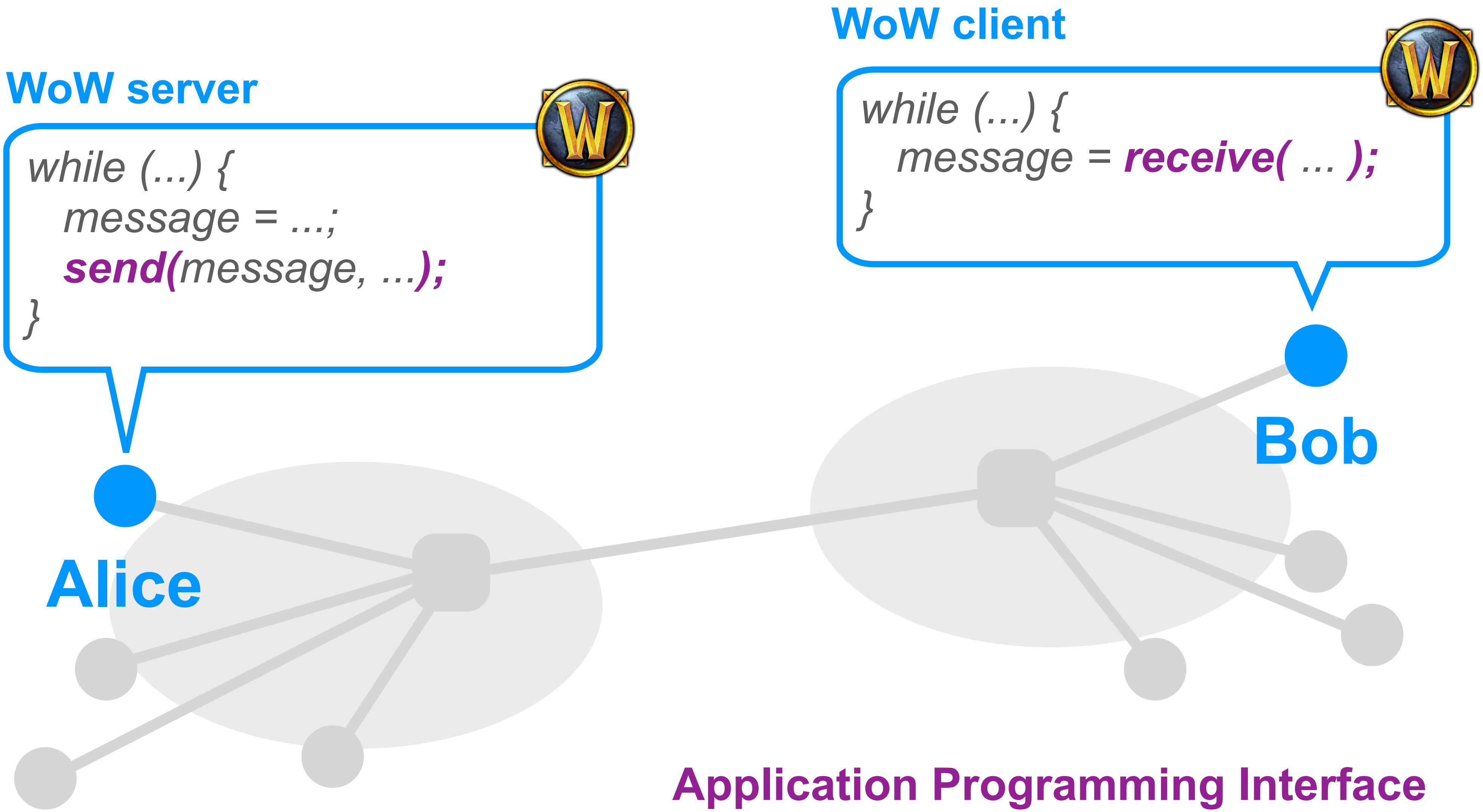
A protocol is like a conversational convention:

who should talk next and how they should respond



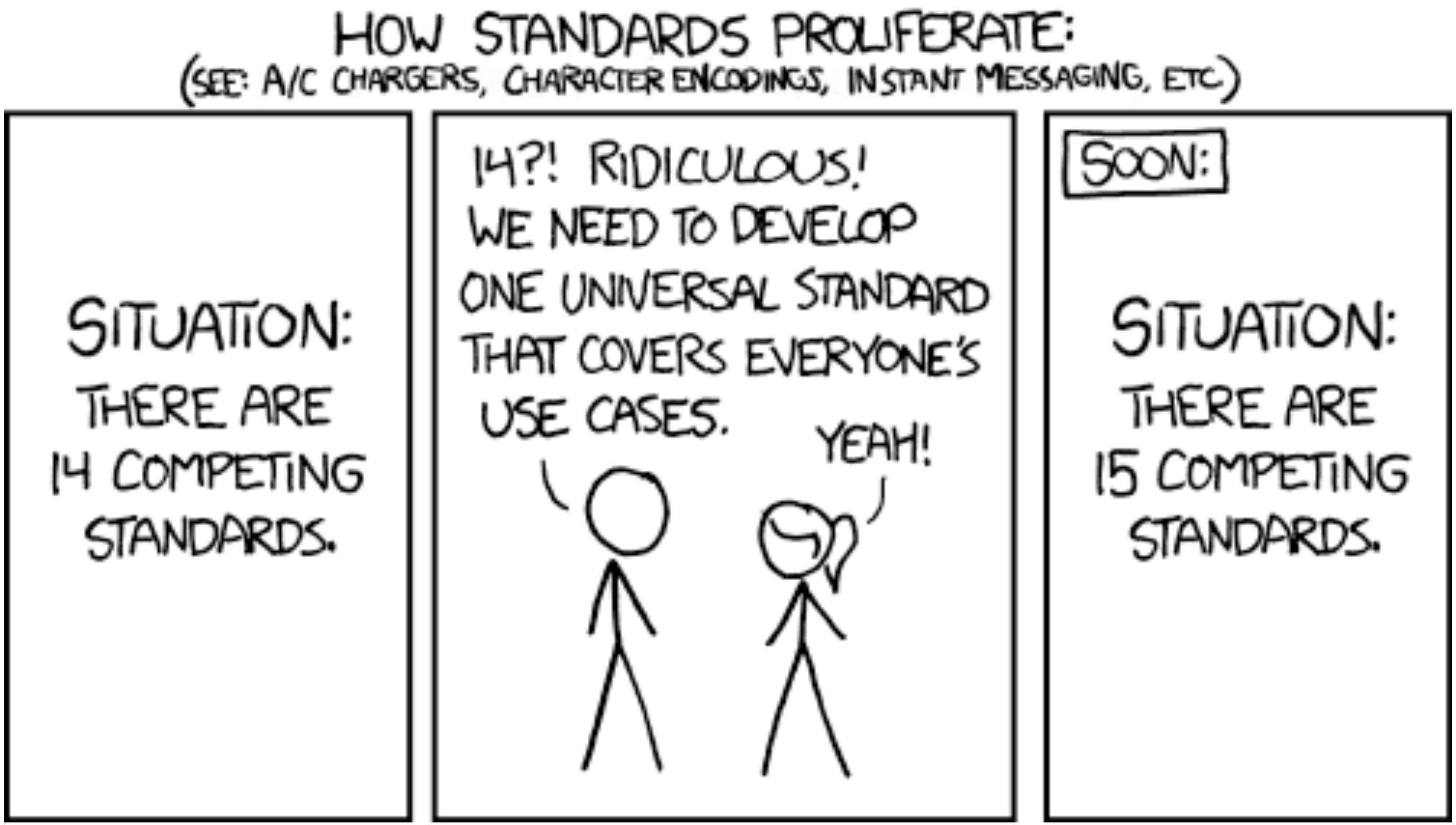
Sometimes implementations are not compliant...

Each protocol is governed by a specific interface



In practice, there exists **a lot** of network protocols.

How does the Internet organize **this?**



https://xkcd.com/927/

Modularity is a key component of any good system

Problem

can’t build large systems out of spaghetti code

hard (if not, impossible) to understand, debug, update

need to bound the scope of changes

evolve the system without rewriting it from scratch

Solution

Modularity is how we do it

…and understand the system at a higher-level

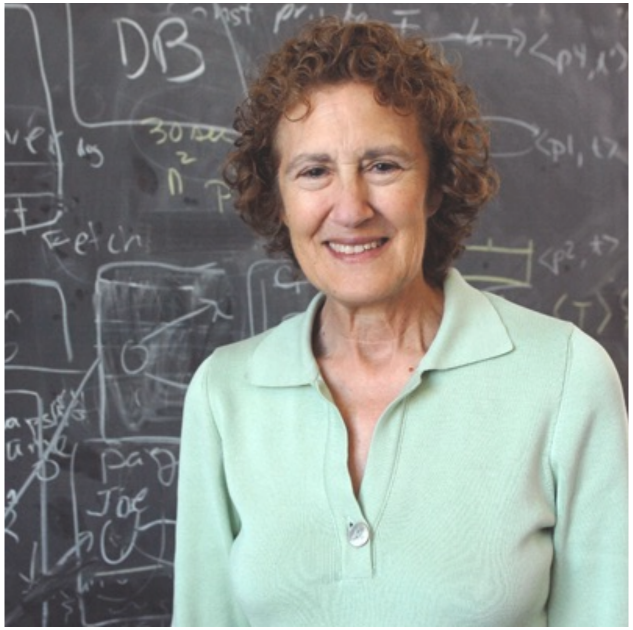


Photo: Donna Coveney

Modularity,
based on abstraction,
is *the* way things get done

— *Barbara Liskov*, MIT

To provide structure to the design of network protocols, network designers organize protocols in layers

and the network hardware/software that implement them

Internet communication can be decomposed in 5 independent layers (or 7 layers for the OSI model)

	layer
L5	Application
L4	Transport
L3	Network
L2	Link
L1	Physical

Each layer provides a service to the layer above

	layer	service provided:
L5	Application	network access
L4	Transport	end-to-end delivery (reliable or not)
L3	Network	global best-effort delivery
L2	Link	local best-effort delivery
L1	Physical	physical transfer of bits

Each layer provides a service to the layer above

by using the services of the layer directly below it

Applications

...built on...

Reliable (or unreliable) transport

...built on...

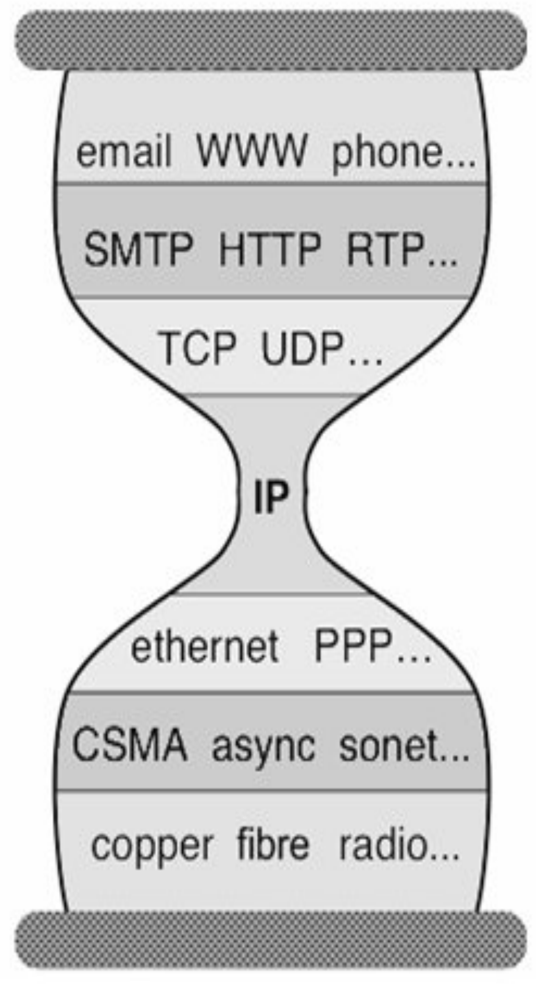
Best-effort global packet delivery

...built on...

Best-effort local packet delivery

...built on...

Physical transfer of bits



Each layer has a unit of data

	layer	role
L5	Application	exchanges messages between processes
L4	Transport	transports segments between end-systems
L3	Network	moves packets around the network
L2	Link	moves frames across a link
L1	Physical	moves bits across a physical medium

Each layer (except for L3) is implemented with different protocols

	layer	protocol
L5	Application	HTTP, SMTP, FTP, SIP, …
L4	Transport	TCP, UDP, SCTP
L3	Network	IP
L2	Link	Ethernet, Wifi, (A/V)DSL, WiMAX, LTE, …
L1	Physical	Twisted pair, fiber, coaxial cable, …

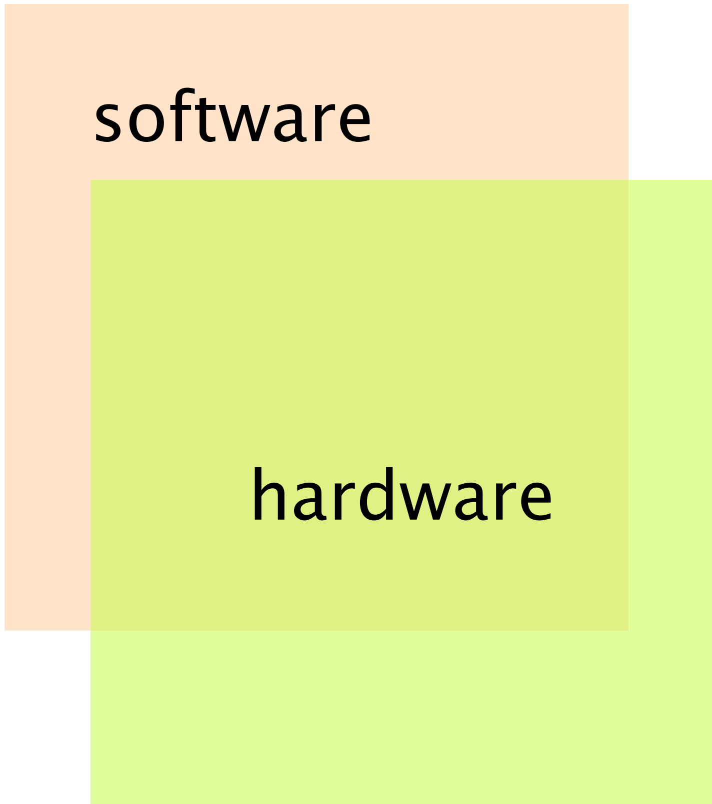
The Internet Protocol (IP) acts as an unifying, network, layer

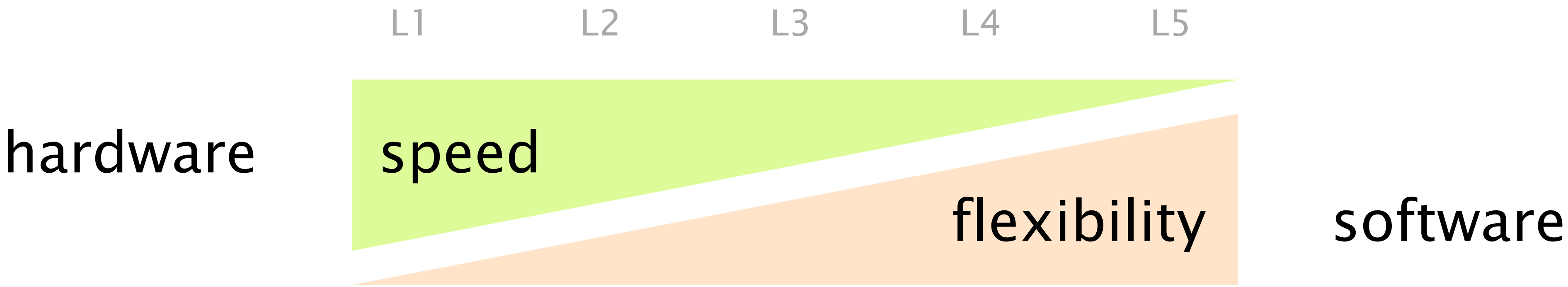
	layer	protocol
L5	Application	HTTP, SMTP, FTP, SIP, …
L4	Transport	TCP, UDP, SCTP
L3	Network	IP
L2	Link	Ethernet, Wifi, (A/V)DSL, Cable, LTE, …
L1	Physical	Twisted pair, fiber, coaxial cable, …

Each layer is implemented with different protocols and technologies

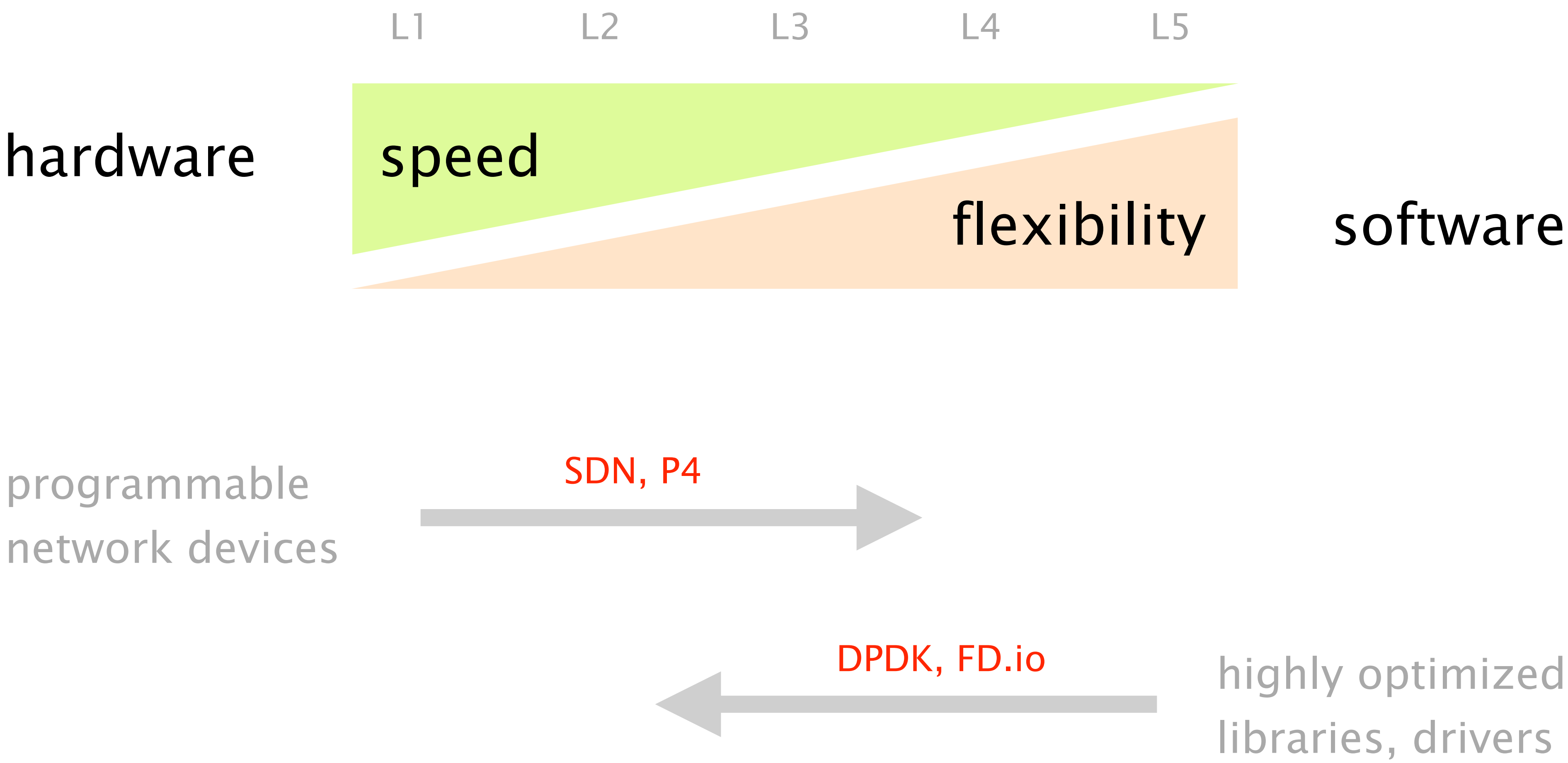
	layer
L5	Application
L4	Transport
L3	Network
L2	Link
L1	Physical

technology




L1
L2
L3
L4
L5
hardware
speed
flexibility
software

Software and hardware advancements



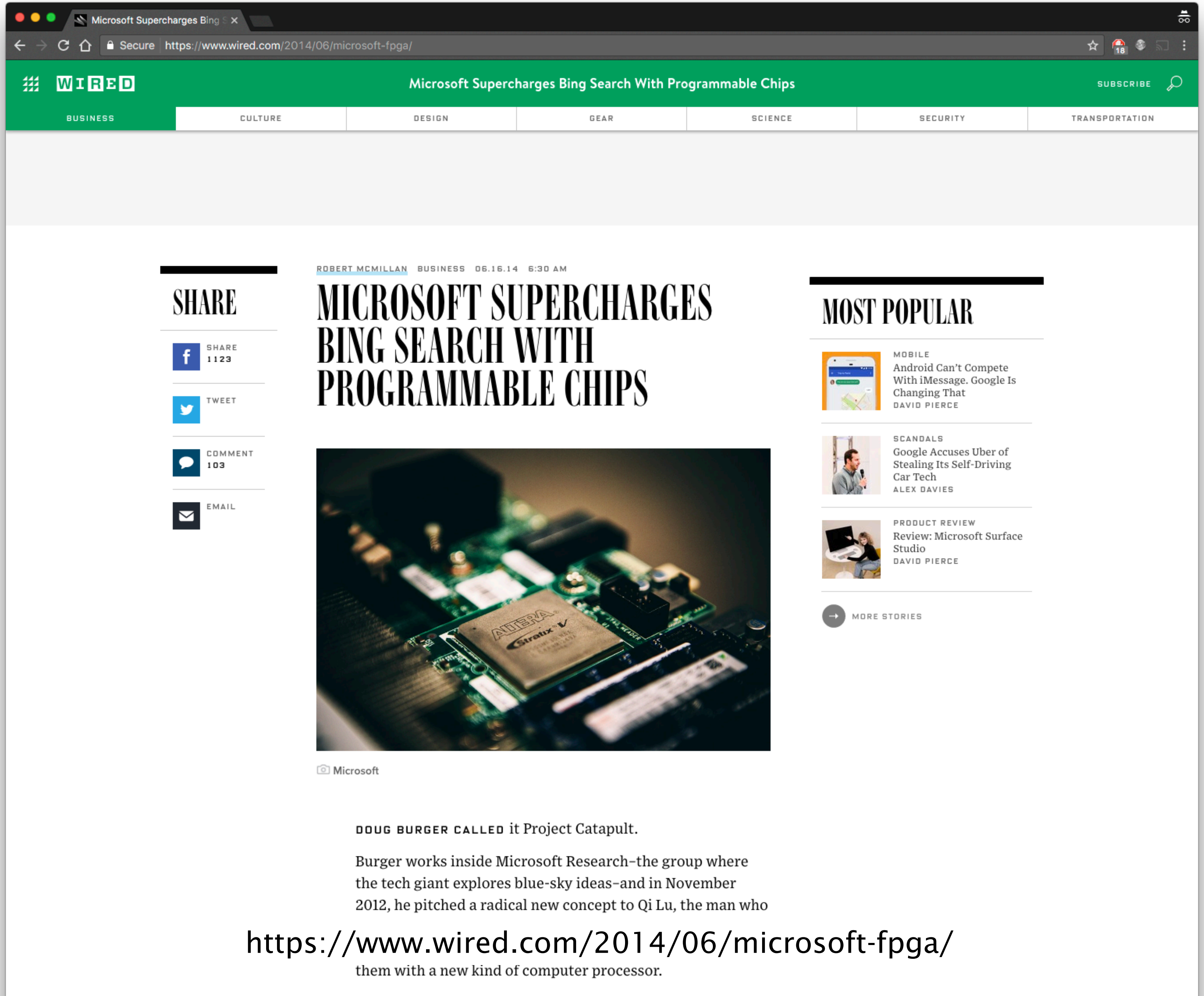
Network stack challenges at increasing speeds

The 100Gbit/s challenge

Jesper Dangaard Brouer
Red Hat inc.

Linux Conf Au, New Zealand, January 2015

http://people.netfilter.org/hawk/presentations/LCA2015/net_stack_challenges_100G_LCA2015.pdf



Microsoft Supercharges Bing Search With Programmable Chips

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ROBERT MCMILLAN BUSINESS 06.16.14 6:30 AM

MICROSOFT SUPERCHARGES BING SEARCH WITH PROGRAMMABLE CHIPS

Microsoft

DOUG BURGER CALLED it Project Catapult.

Burger works inside Microsoft Research–the group where the tech giant explores blue-sky ideas–and in November 2012, he pitched a radical new concept to Qi Lu, the man who

them with a new kind of computer processor.

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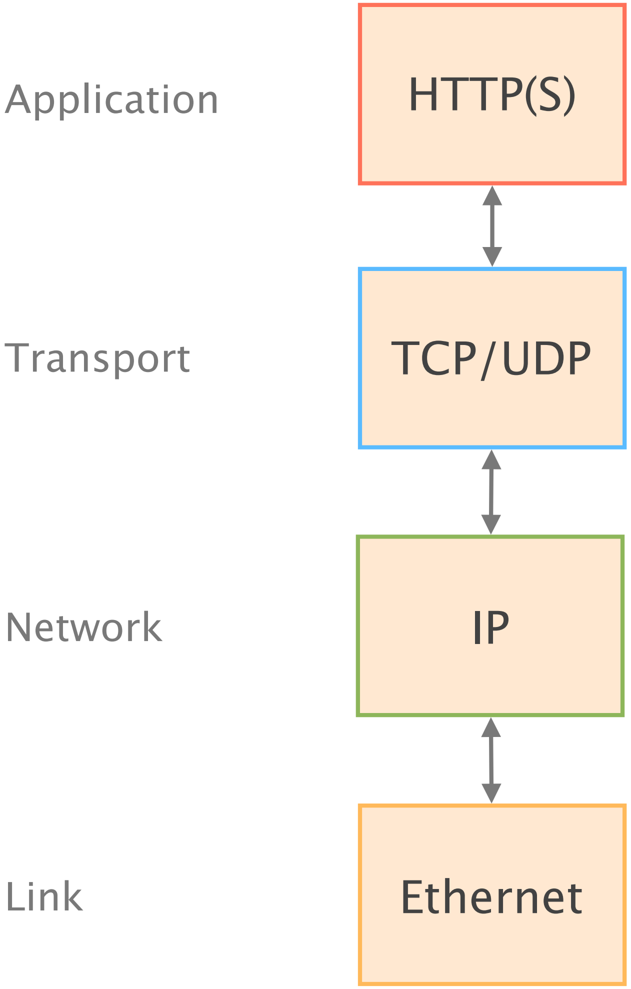
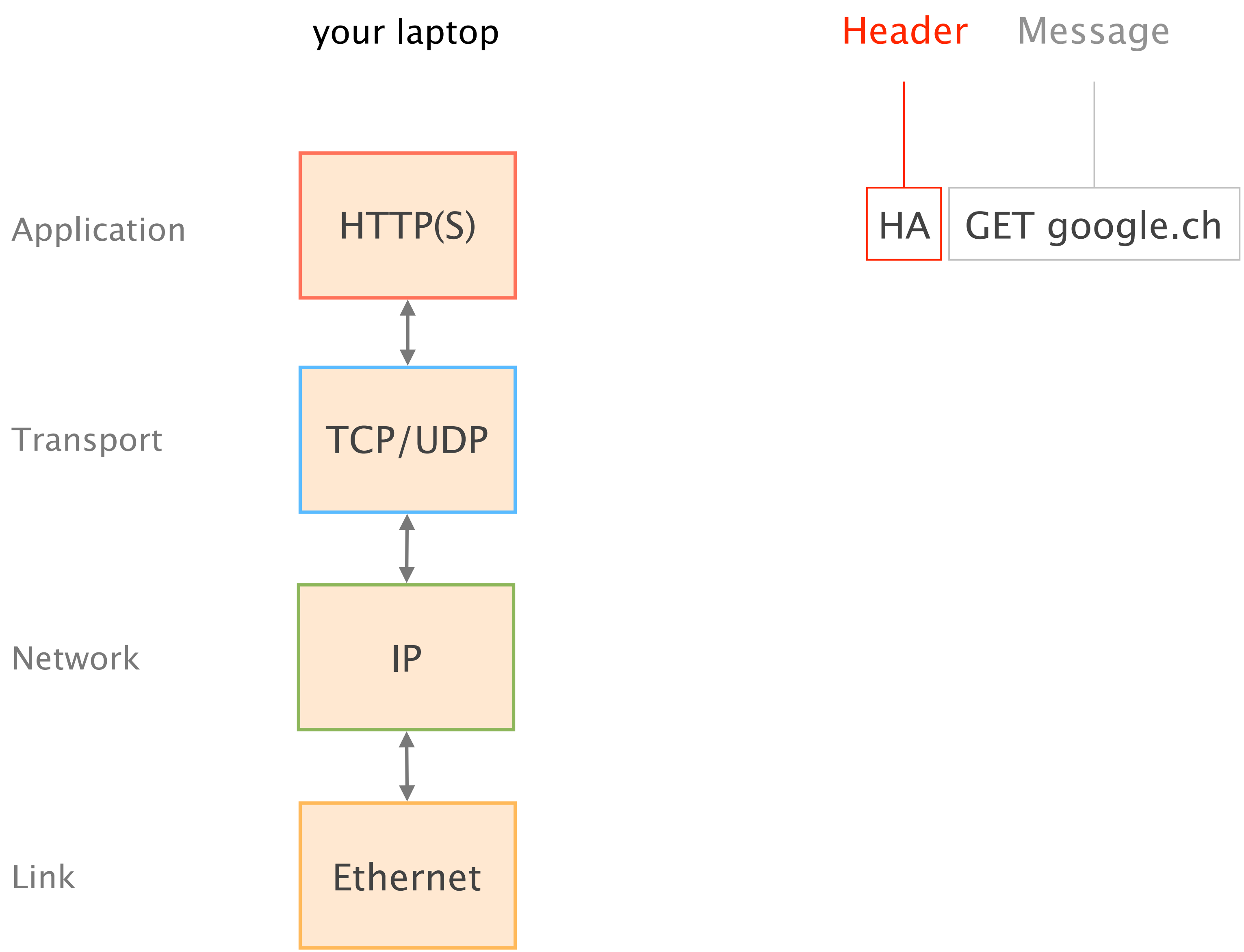
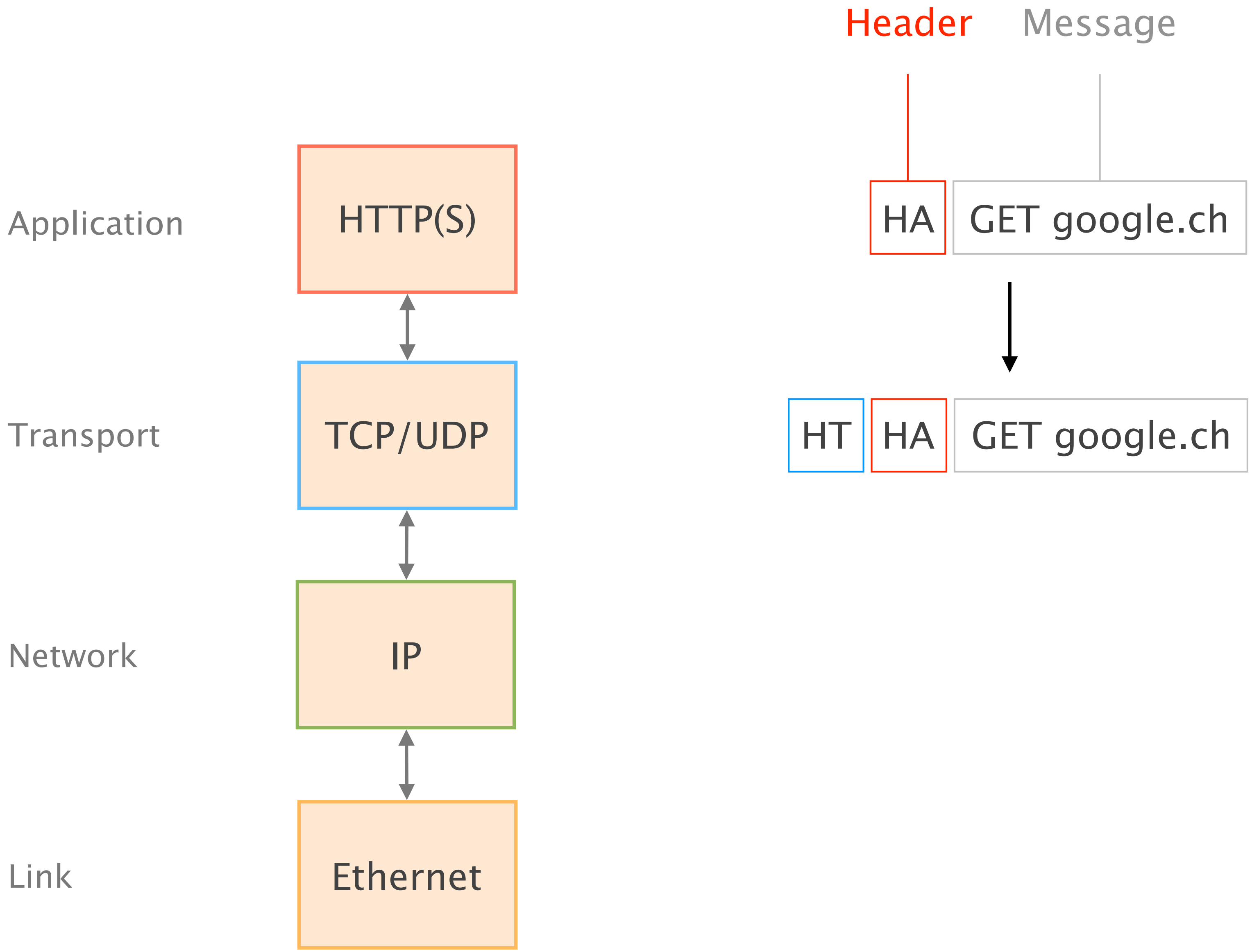
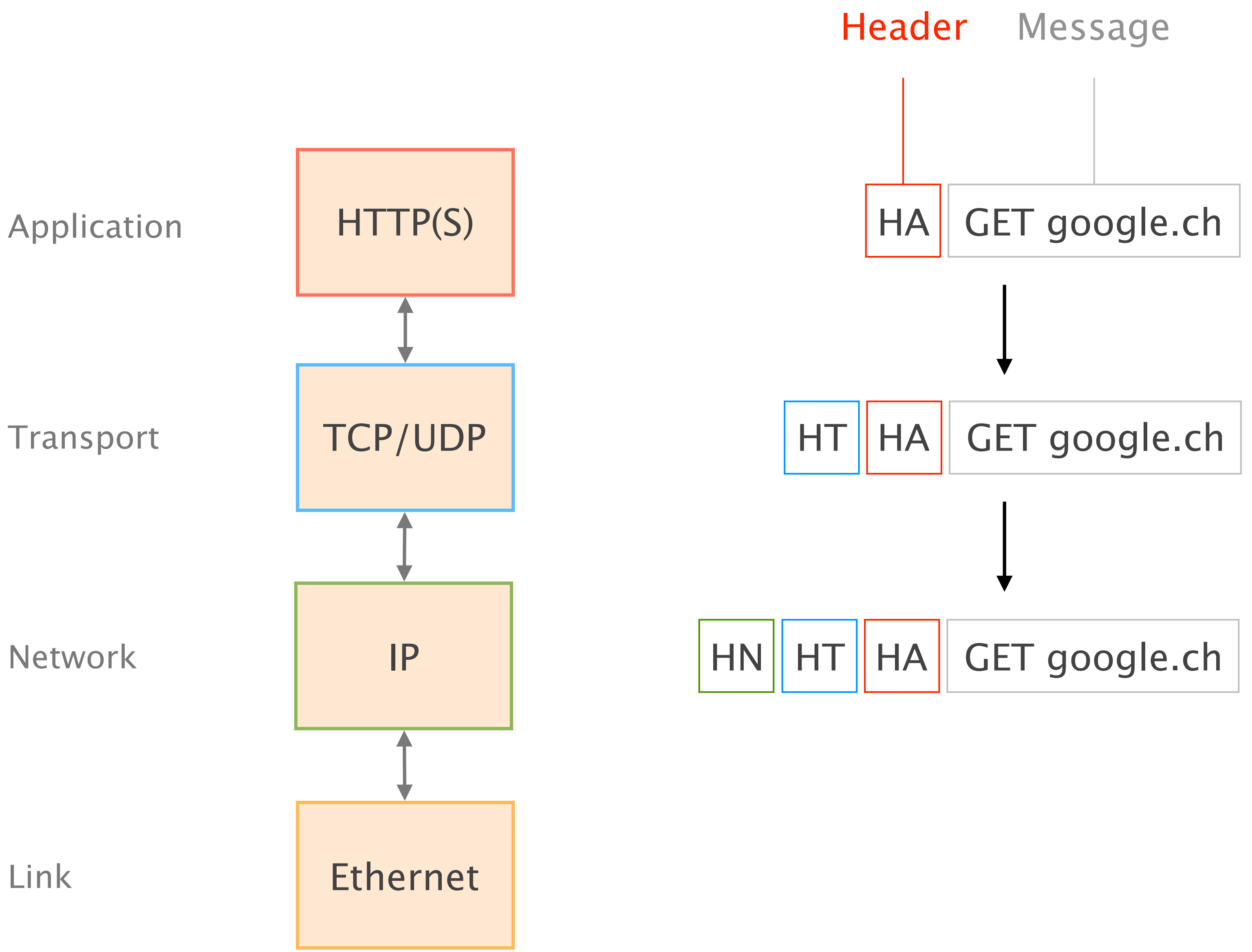
https://www.wired.com/2014/06/microsoft-fpga/

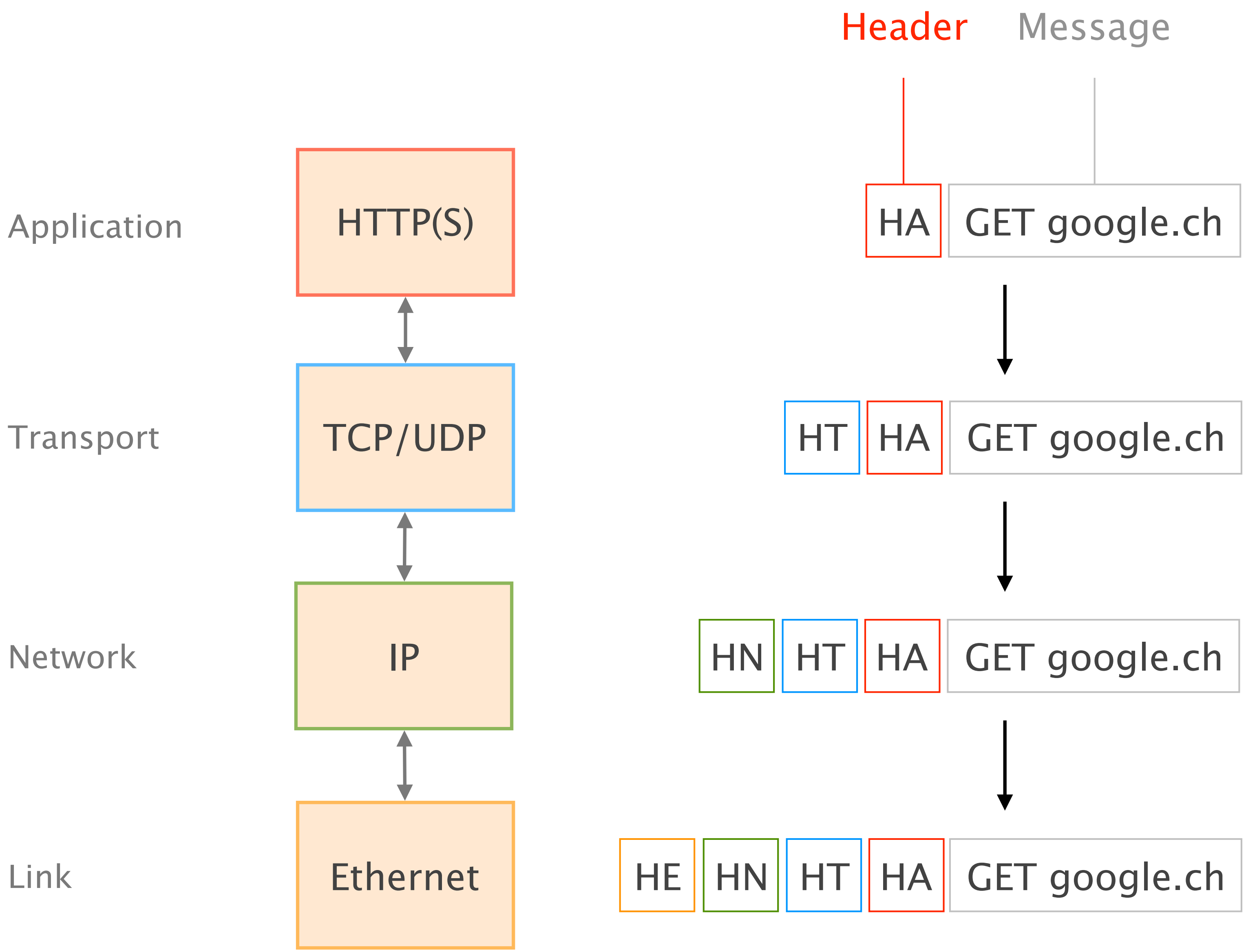
Each layer takes messages from the layer above, and *encapsulates* with its own header and/or trailer



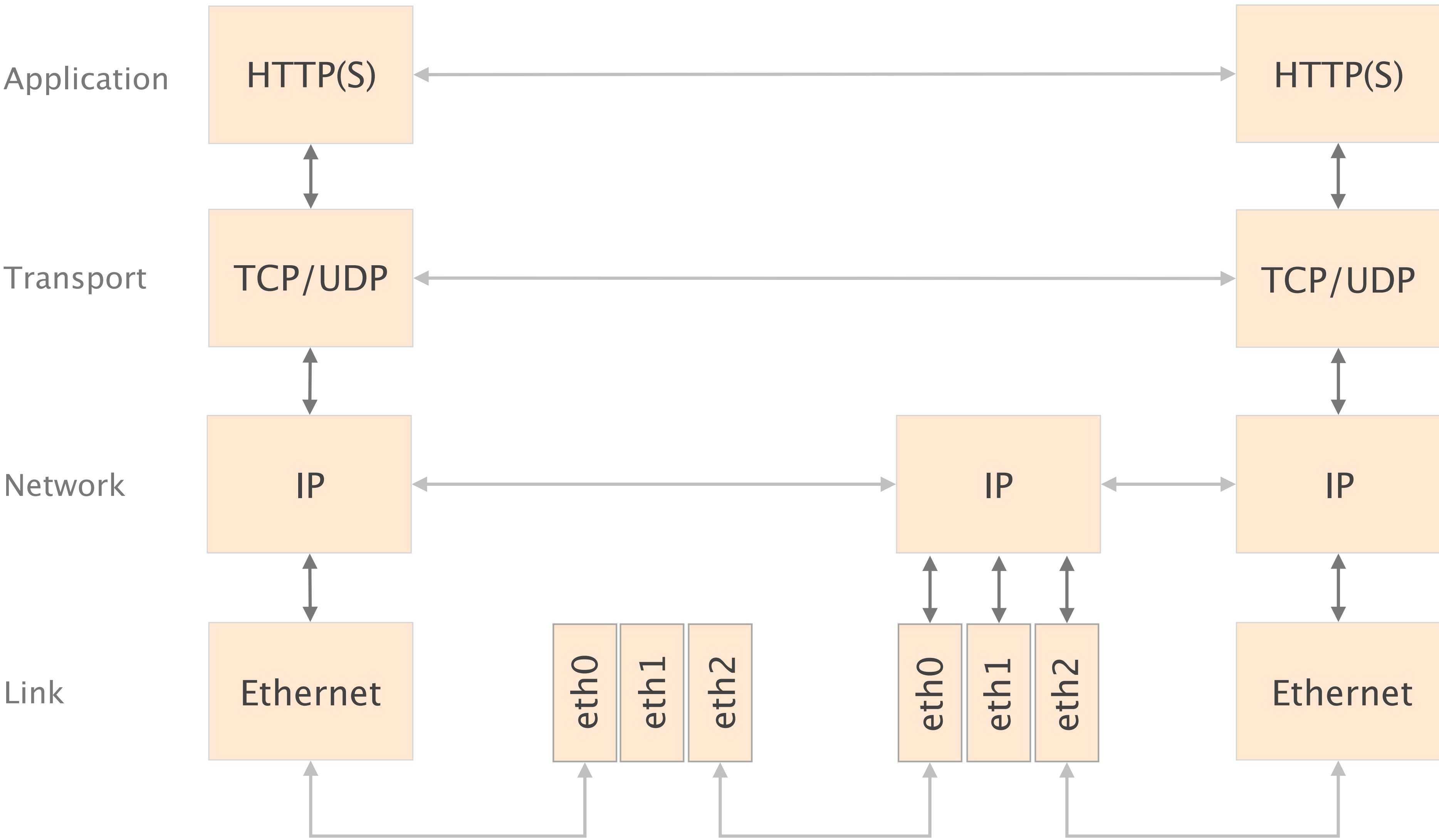

your laptop
Application
HTTP(S)
Transport
TCP/UDP
Network
IP
Link
Ethernet
Header
Message
HA
GET google.ch


Application
HTTP(S)
Transport
TCP/UDP
Network
IP
Link
Ethernet
Header
Message
HA
GET google.ch
HT
HA
GET google.ch

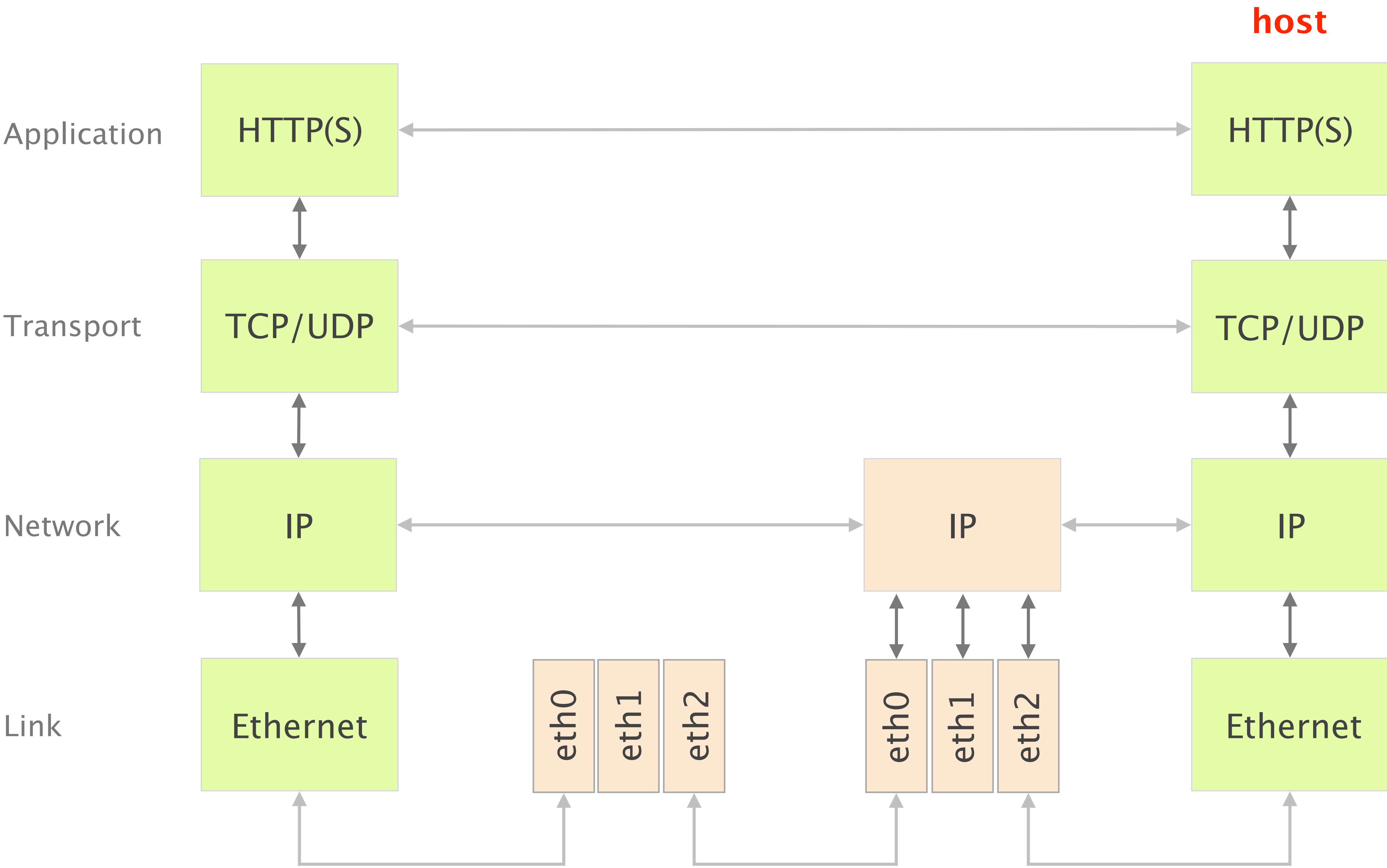

Header
Message
Application
HTTP(S)
HA
GET google.ch
Transport
TCP/UDP
HT
HA
GET google.ch
Network
IP
HN
HT
HA
GET google.ch
Link
Ethernet


Header
Message
Application
HTTP(S)
HA
GET google.ch
Transport
TCP/UDP
HT
HA
GET google.ch
Network
IP
HN
HT
HA
GET google.ch
Link
Ethernet
HE
HN
HT
HA
GET google.ch

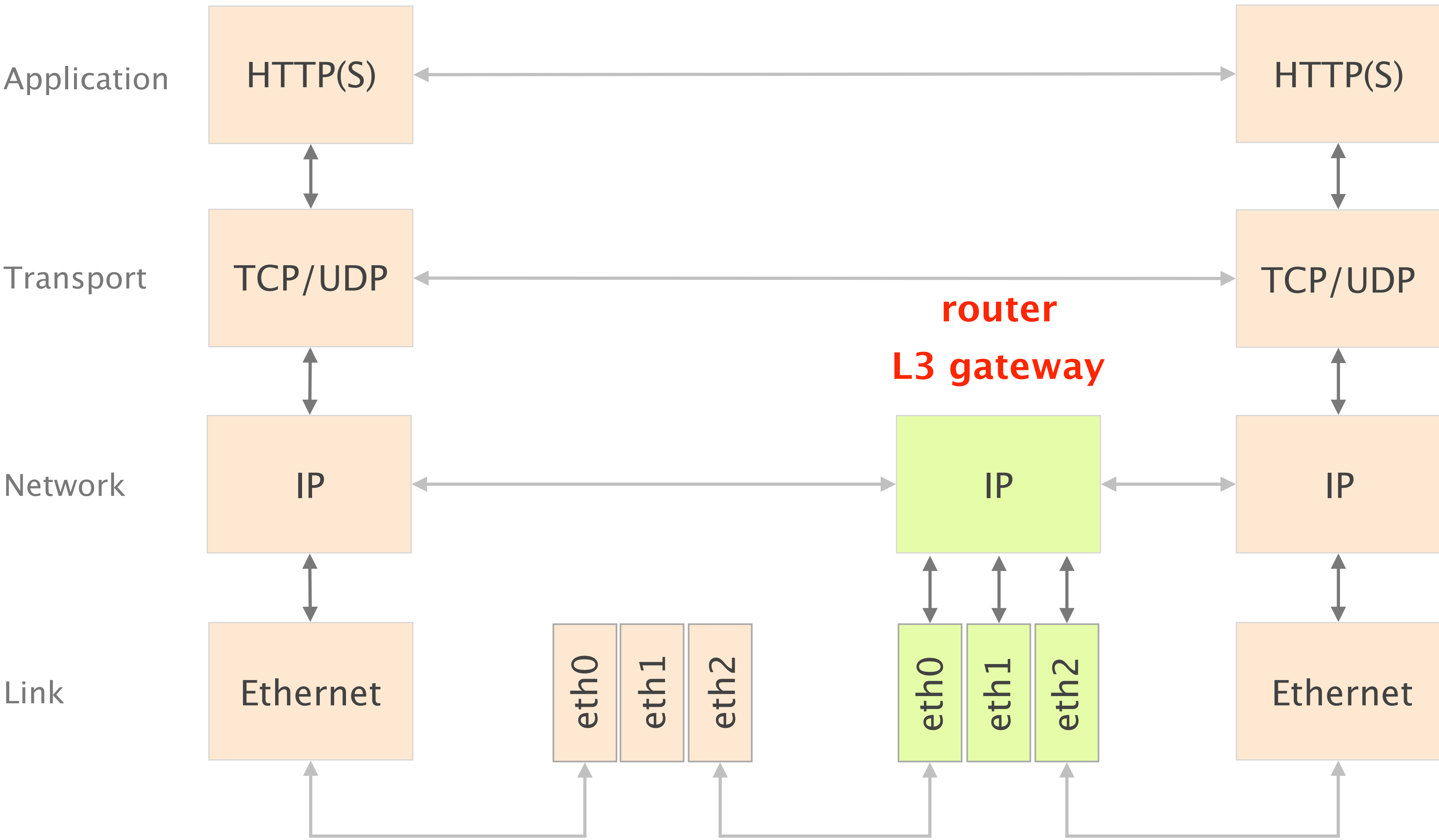
In practice, layers are distributed on every network device



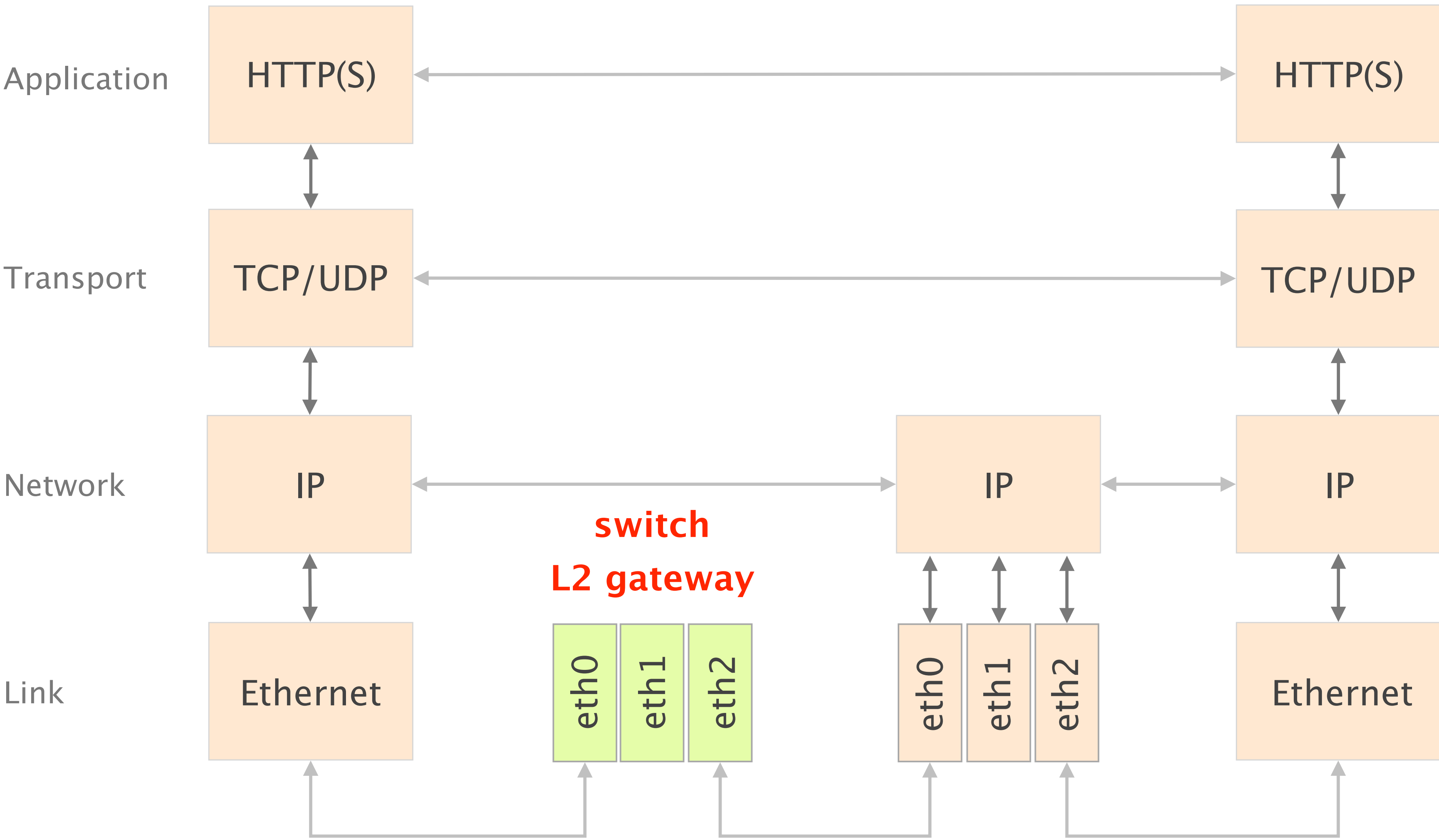
Since when bits arrive they must make it to the application, all the layers exist on a host



Routers act as L3 gateway
as such they implement L2 and L3



Switches act as L2 gateway
as such they only implement L2



Let’s see how it looks like in practice

on a host, using Wireshark

https://www.wireshark.org

Communication Networks

Part 1: General overview

What is a network made of?

How is it shared?

How is it organized?

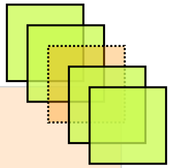
How does communication happen?

#5 **How do we characterize it?**

A network *connection* is characterized by its delay, loss rate and throughput

delay

loss



throughput

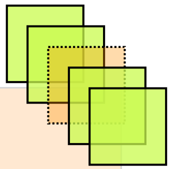
How long does it take for a packet to reach the destination

What fraction of packets sent to a destination are dropped?

At what rate is the destination receiving data from the source?

A network *connection* is characterized by its delay, loss rate and throughput

delay



loss

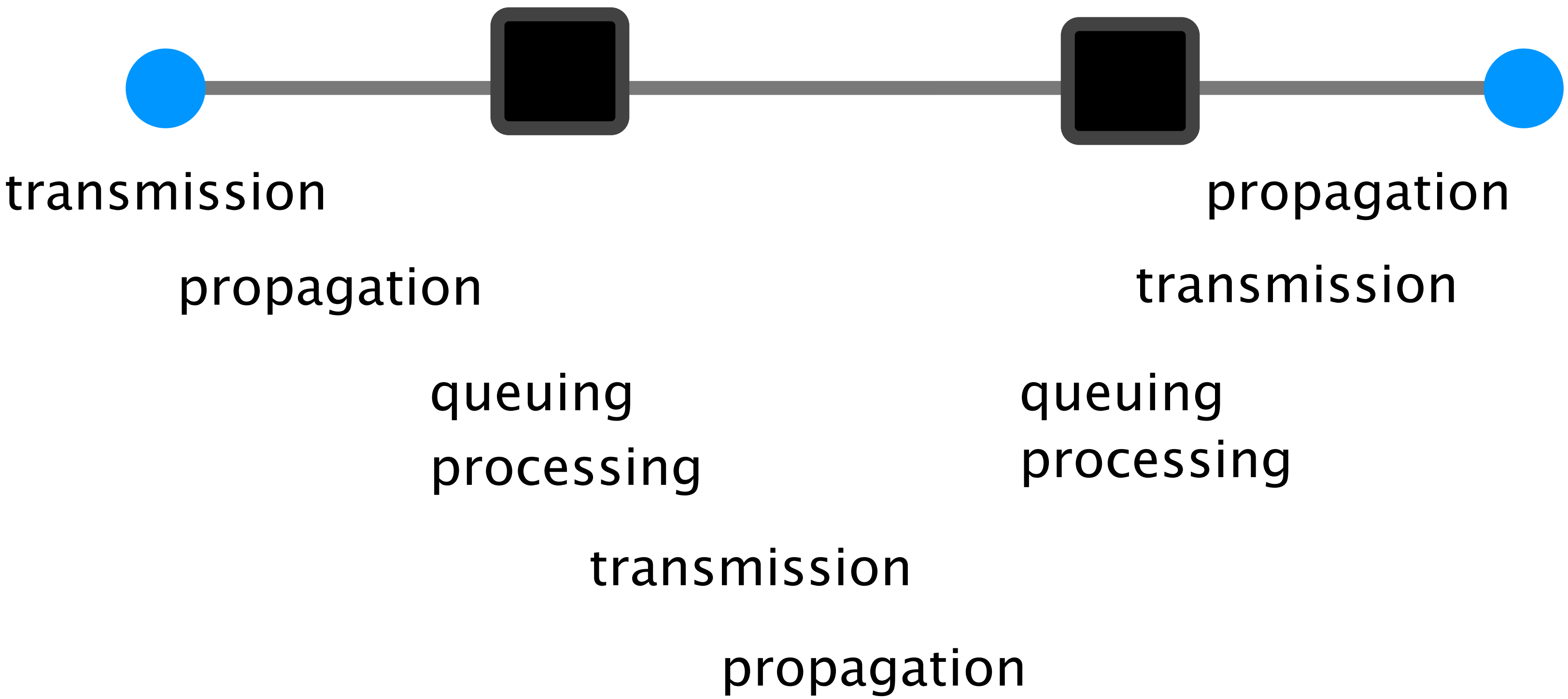
throughput

Each packet suffers from several types of delays at *each node* along the path

	transmission	delay	↕	due to link properties
⊕	propagation	delay		
⊕	processing	delay	↕	due to traffic mix & switch internals
⊕	queuing	delay		
=	total	delay		

Overall, the main culprits for the overall delay are the transmission, propagation and queuing delays

	transmission	delay	
⊕	propagation	delay	
⊕	processing	delay	*tend to be tiny*
⊕	queuing	delay	
=	total	delay	


transmission
propagation
queuing
processing
transmission
propagation
queuing
processing
transmission
propagation

The transmission delay is the amount of time required to push all of the bits onto the link

$$\text{Transmission delay [sec]} = \frac{\text{packet size [\#bits]}}{\text{link bandwidth [\#bits/sec]}}$$

Example

$$\frac{1000 \text{ bits}}{100 \text{ Mbps}} \quad 10\ \mu\text{sec}$$

The propagation delay is the amount of time required for a bit to travel to the end of the link

$$\text{Propagation delay [sec]} = \frac{\text{link length [m]}}{\text{propagation speed [m/sec]}}$$

(fraction of speed of light)

Example

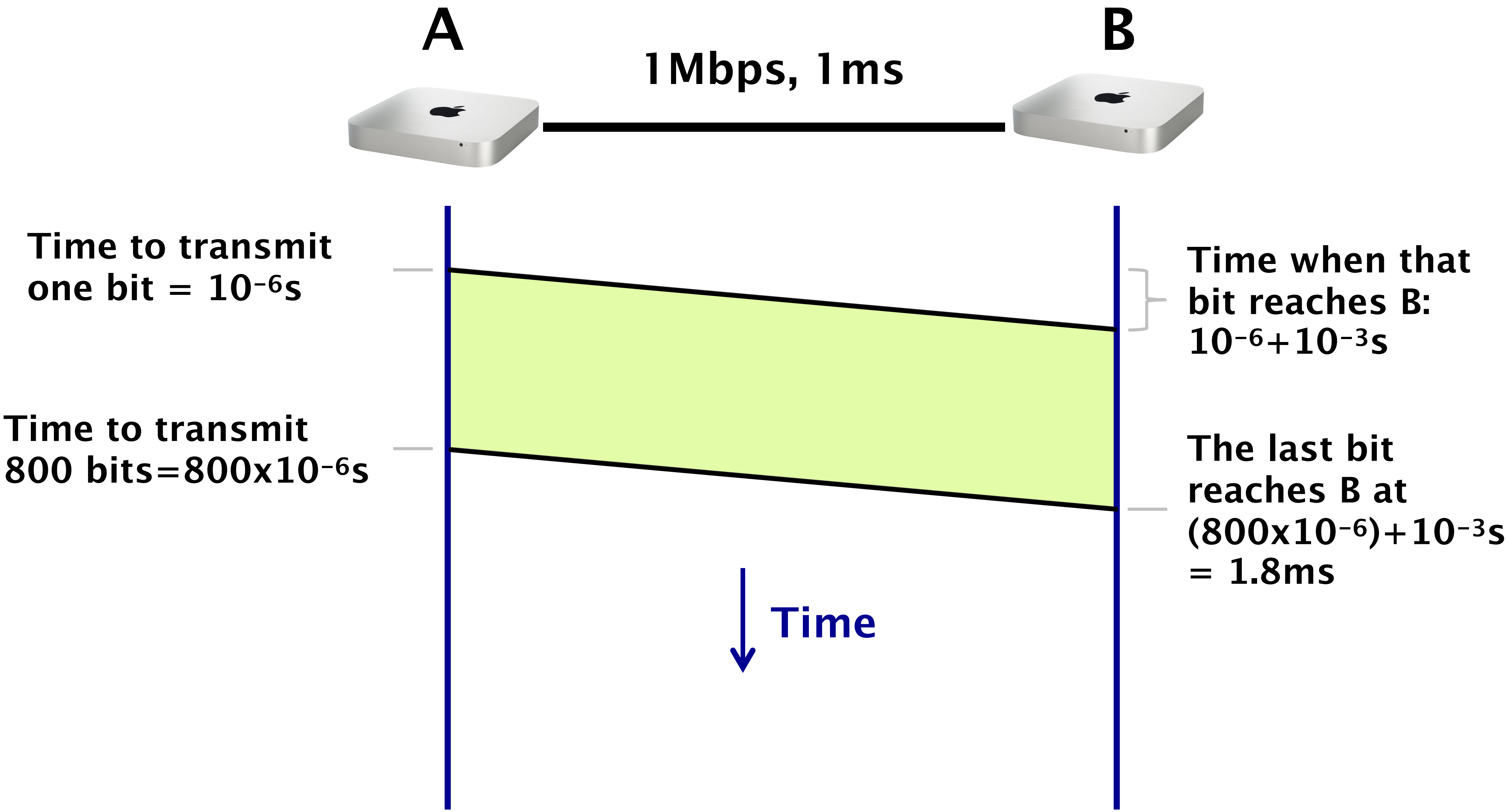
$$\frac{30\,000 \text{ m}}{2\times10^{8} \text{ m/sec}} \quad 150\ \mu\text{sec}$$

(speed of light in fiber)

How long does it take for a packet to travel from A to B?

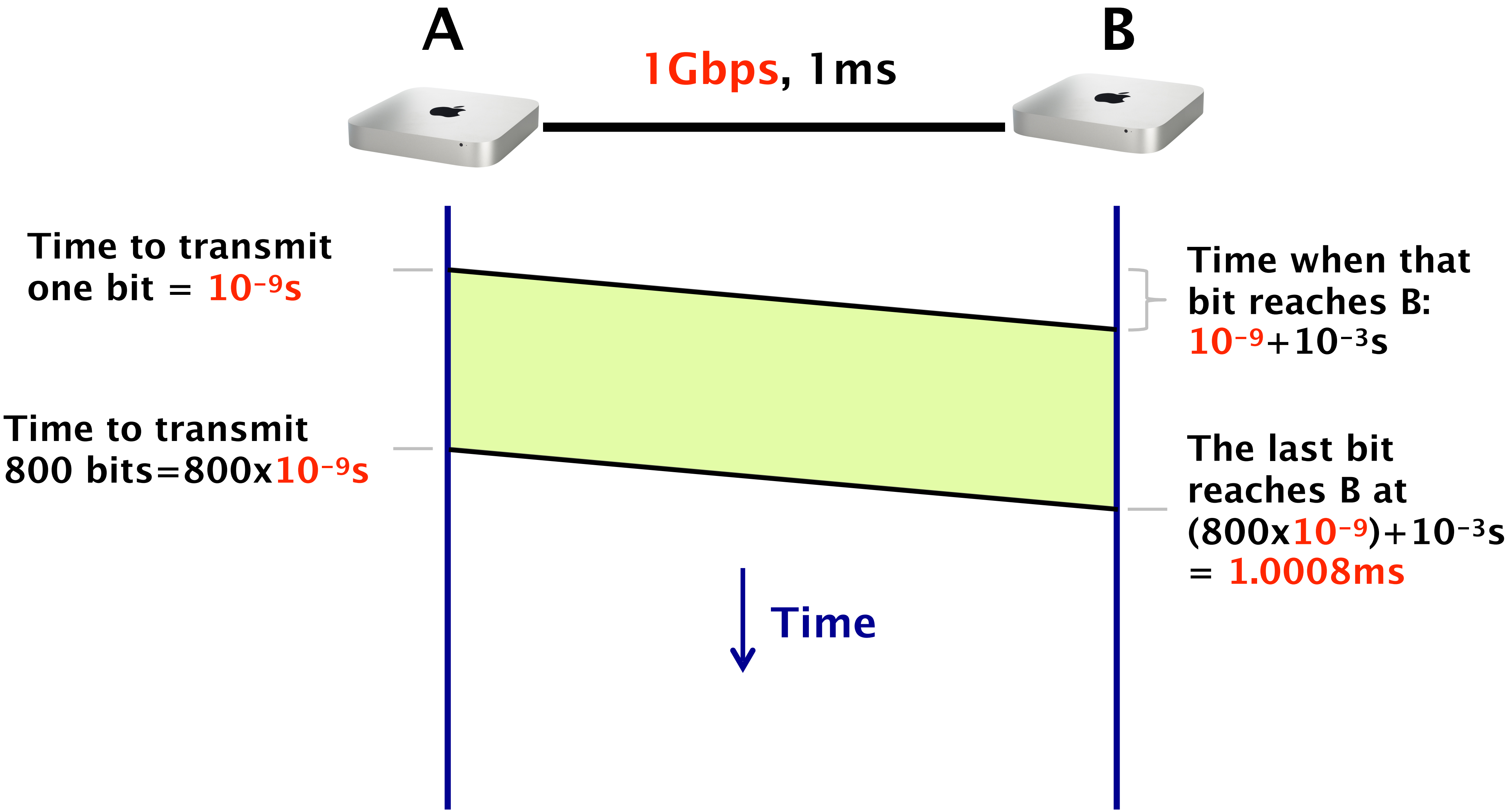
(not considering queuing for now)

How long does it take to exchange 100 Bytes packet?

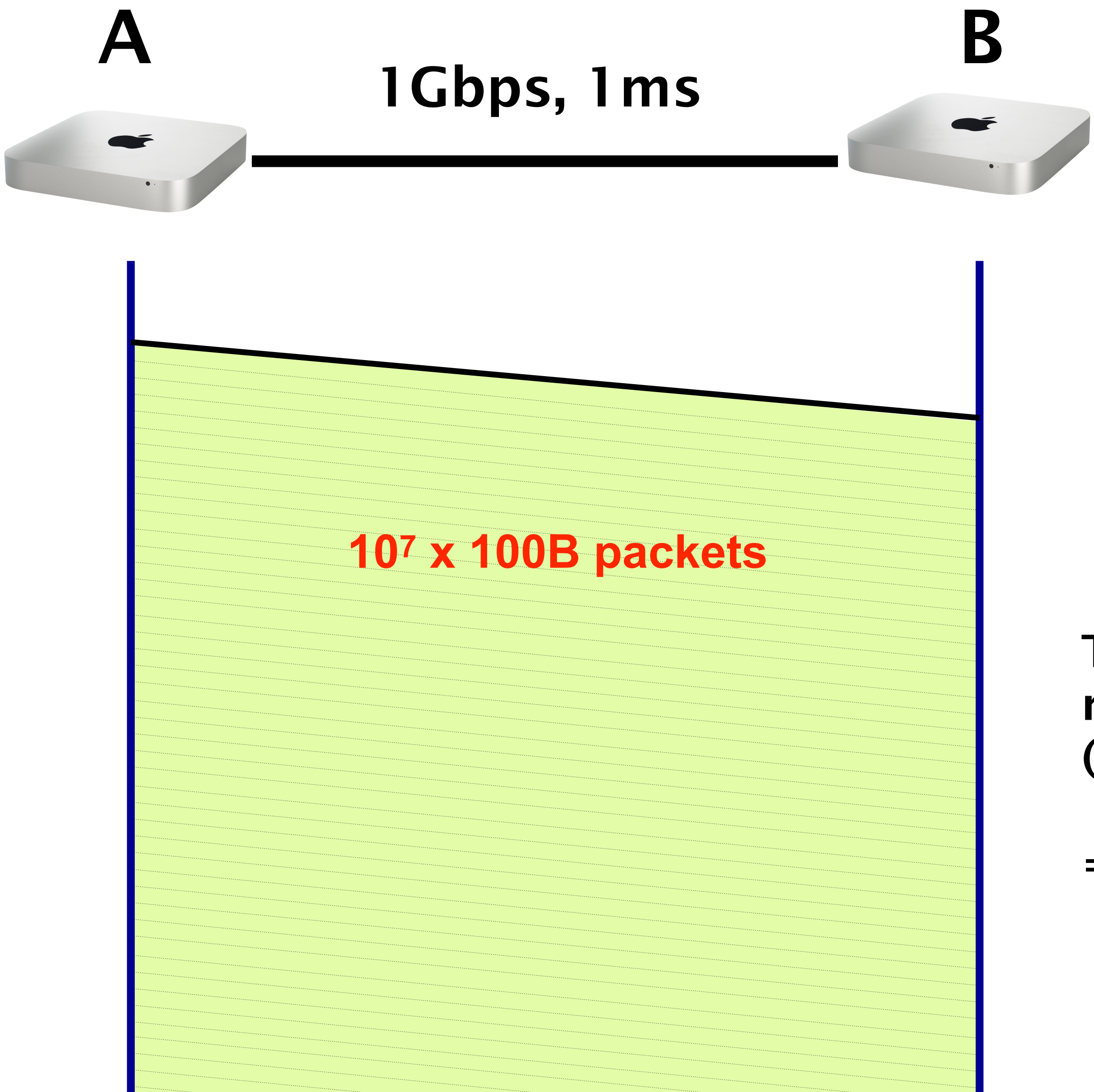


If we have a 1 Gbps link,

the total time decreases to 1.0008ms



If we now exchange a 1GB file
split in 100B packets



The last bit reaches B at
$(10^7 \times 800 \times 10^{-9}) + 10^{-3}$s
= 8001ms

Different transmission characteristics imply different tradeoffs in terms of which delay dominates

10^7x100B	pkt	1Gbps link	transmission delay dominates
1x100B	pkt	1Gbps link	propagation delay dominates
1x100B	pkt	1Mbps link	both matter

In the Internet, we **can't know** in advance which one matters!

The queuing delay is the amount of time a packet waits (in a buffer) to be transmitted on a link

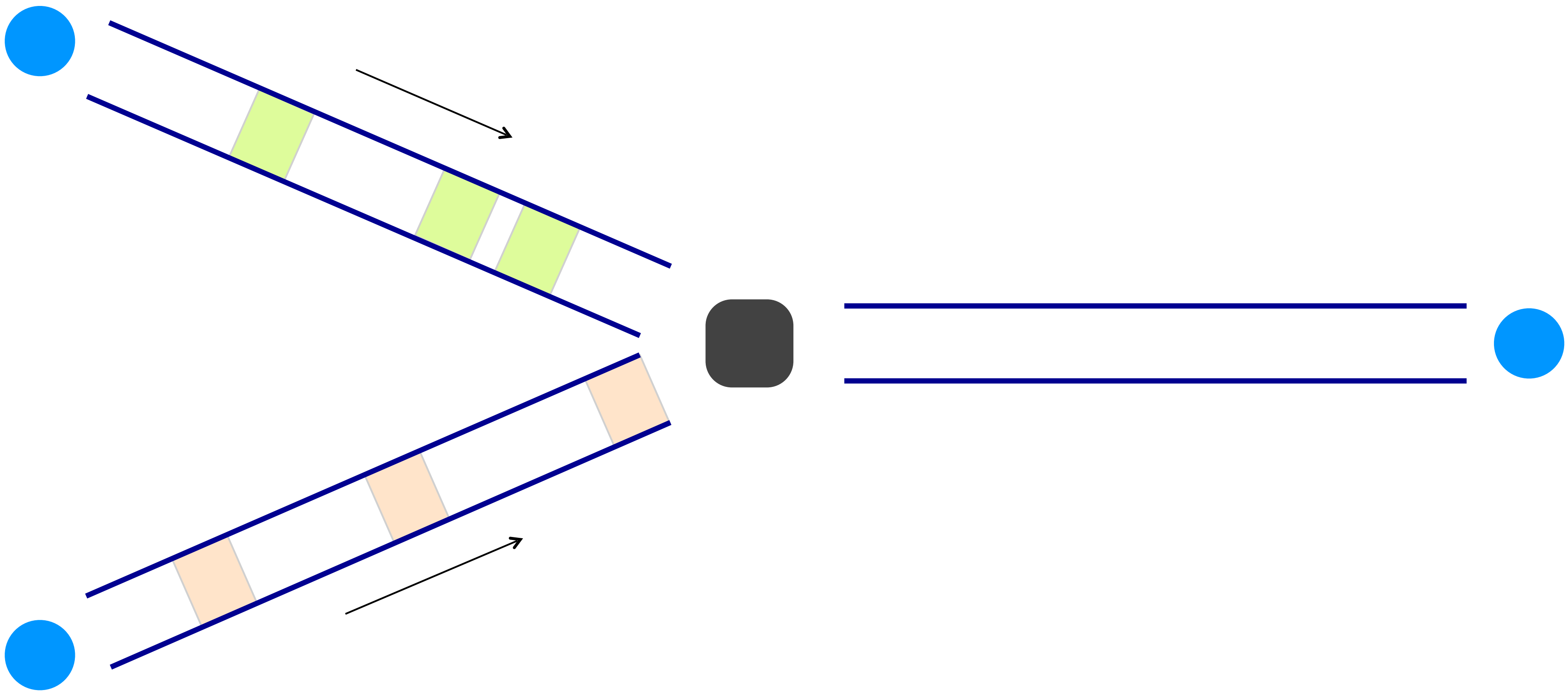
Queuing delay is the hardest to evaluate

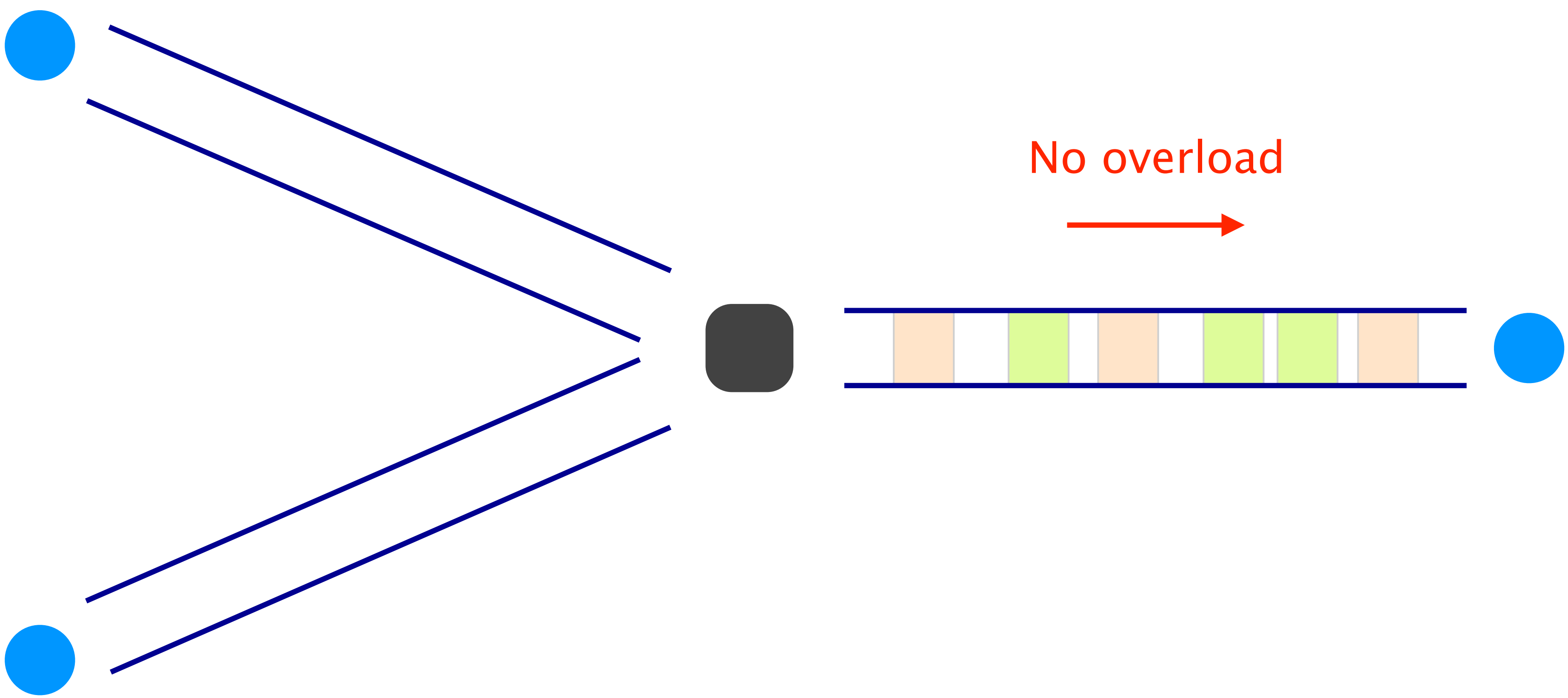
as it varies from packet to packet

It is characterized with statistical measures

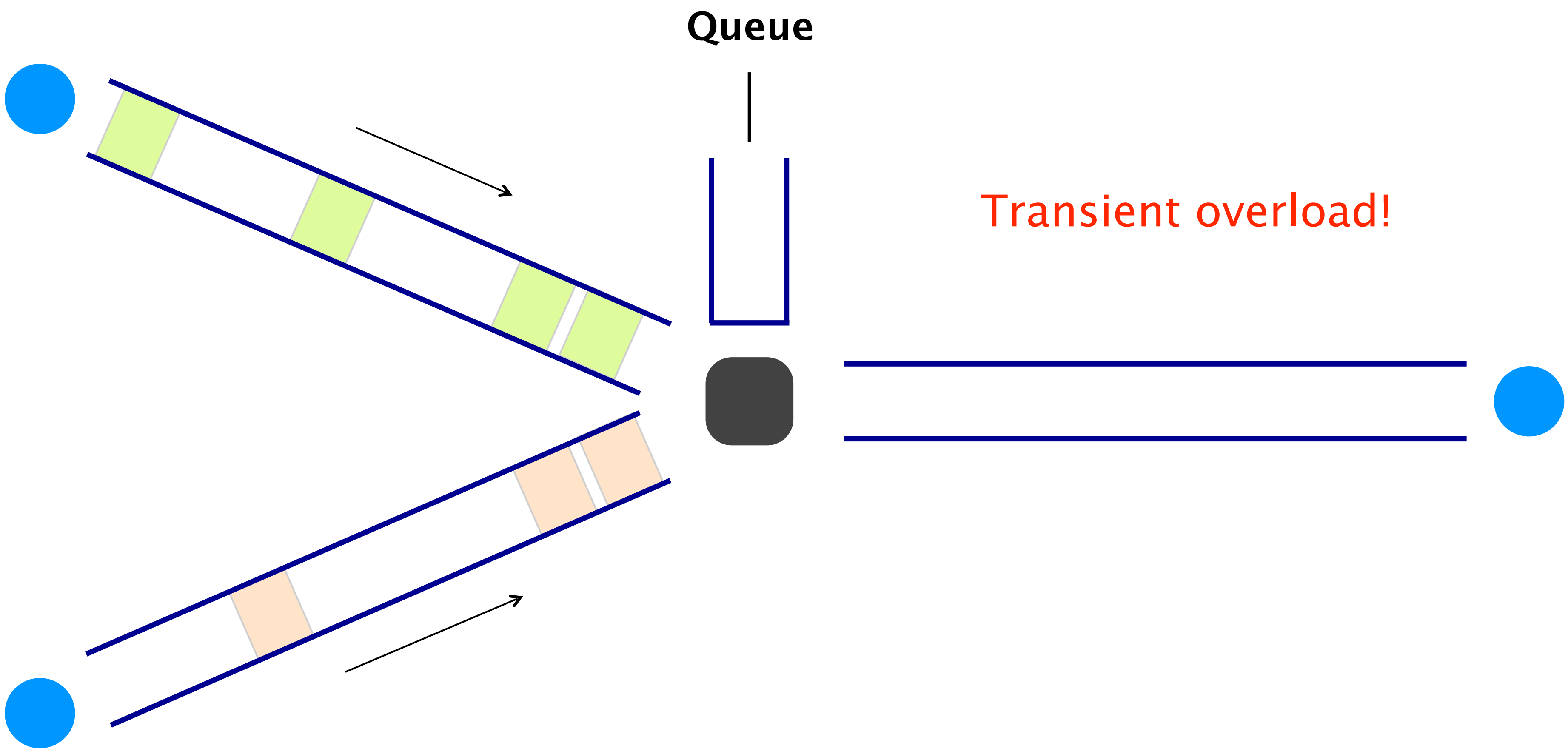
e.g., average delay & variance, probability of exceeding *x*

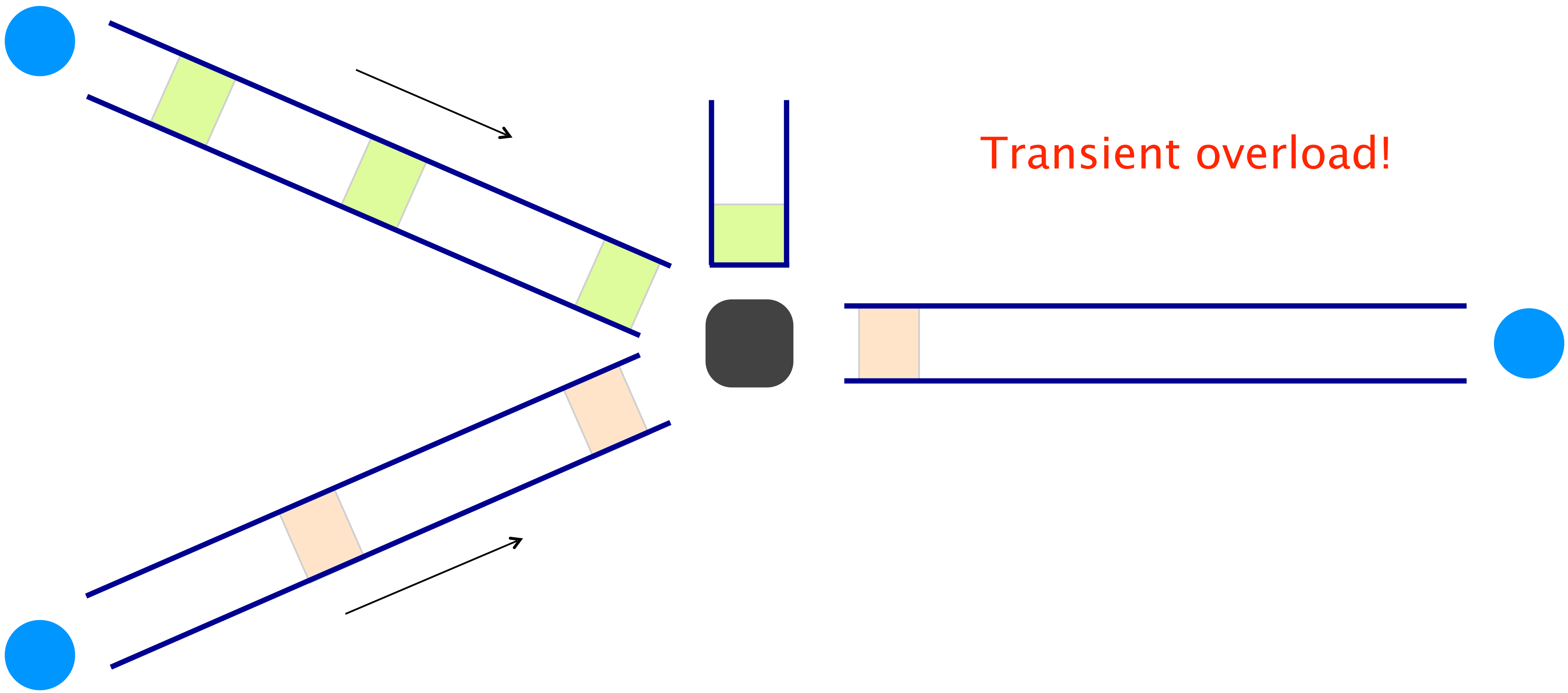
Queuing delay depends on the traffic pattern

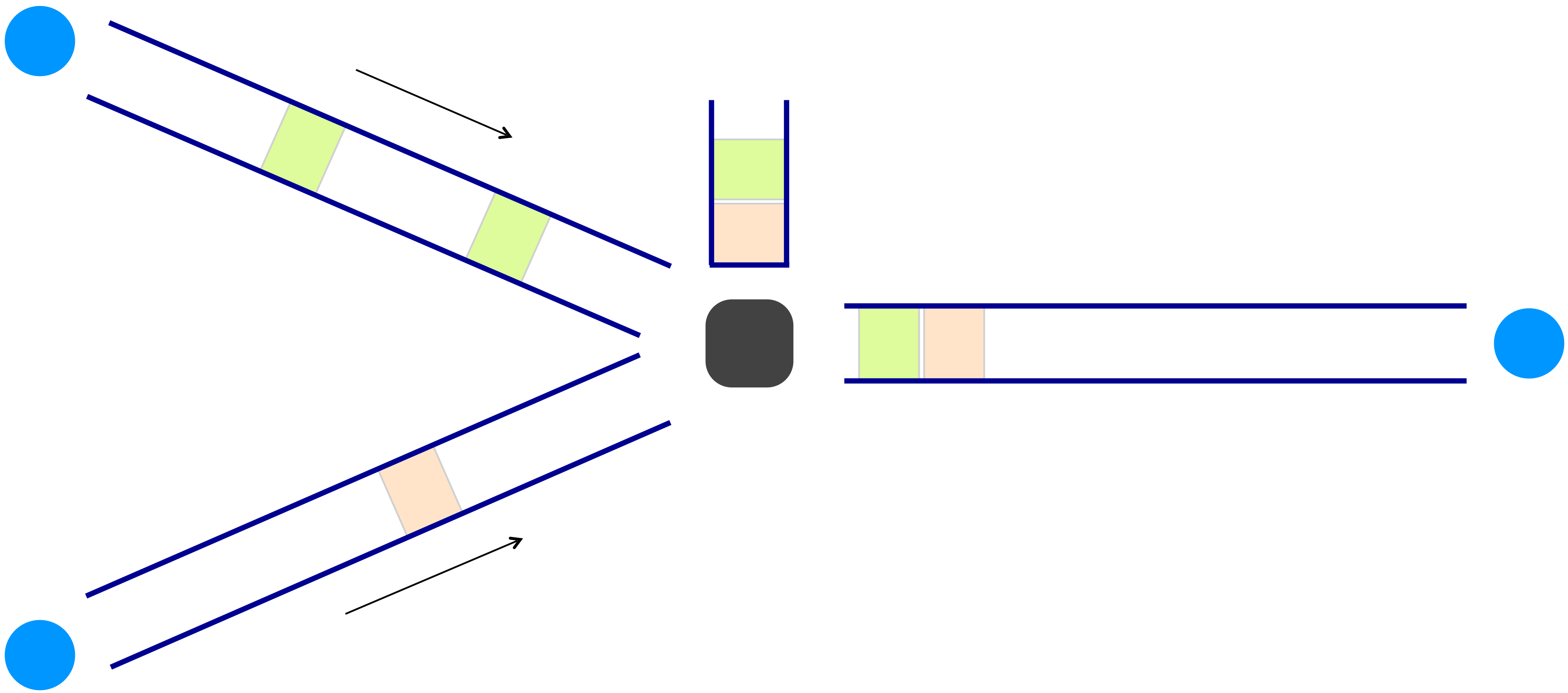


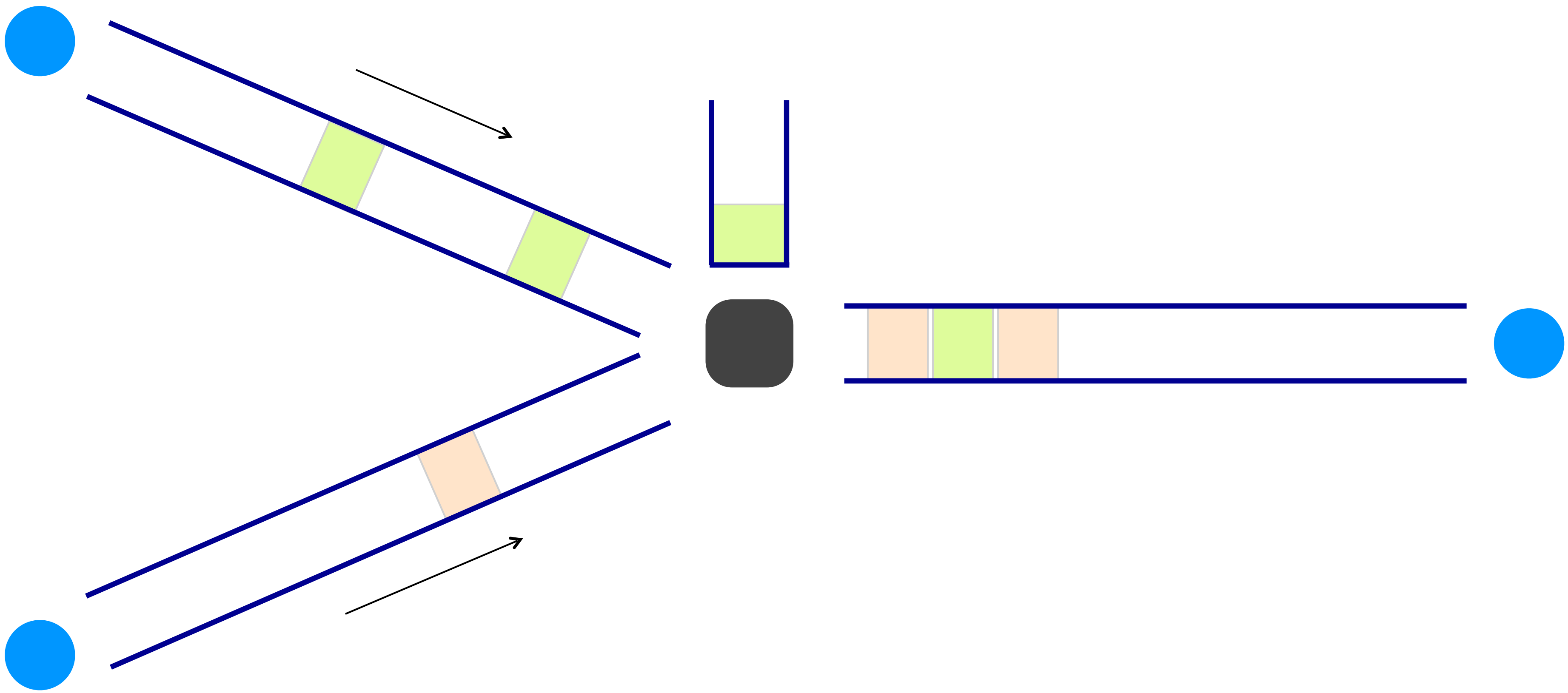

No overload

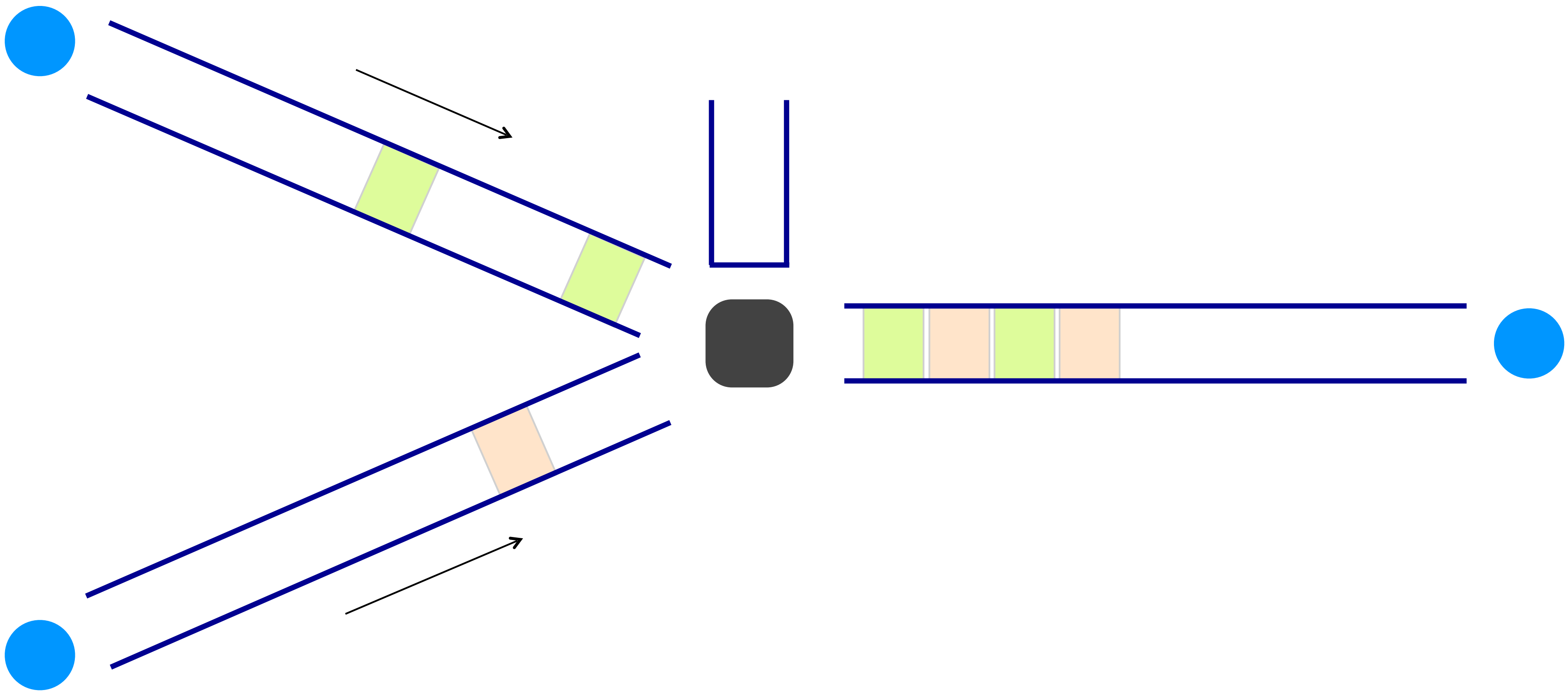
Queuing delay depends on the traffic pattern



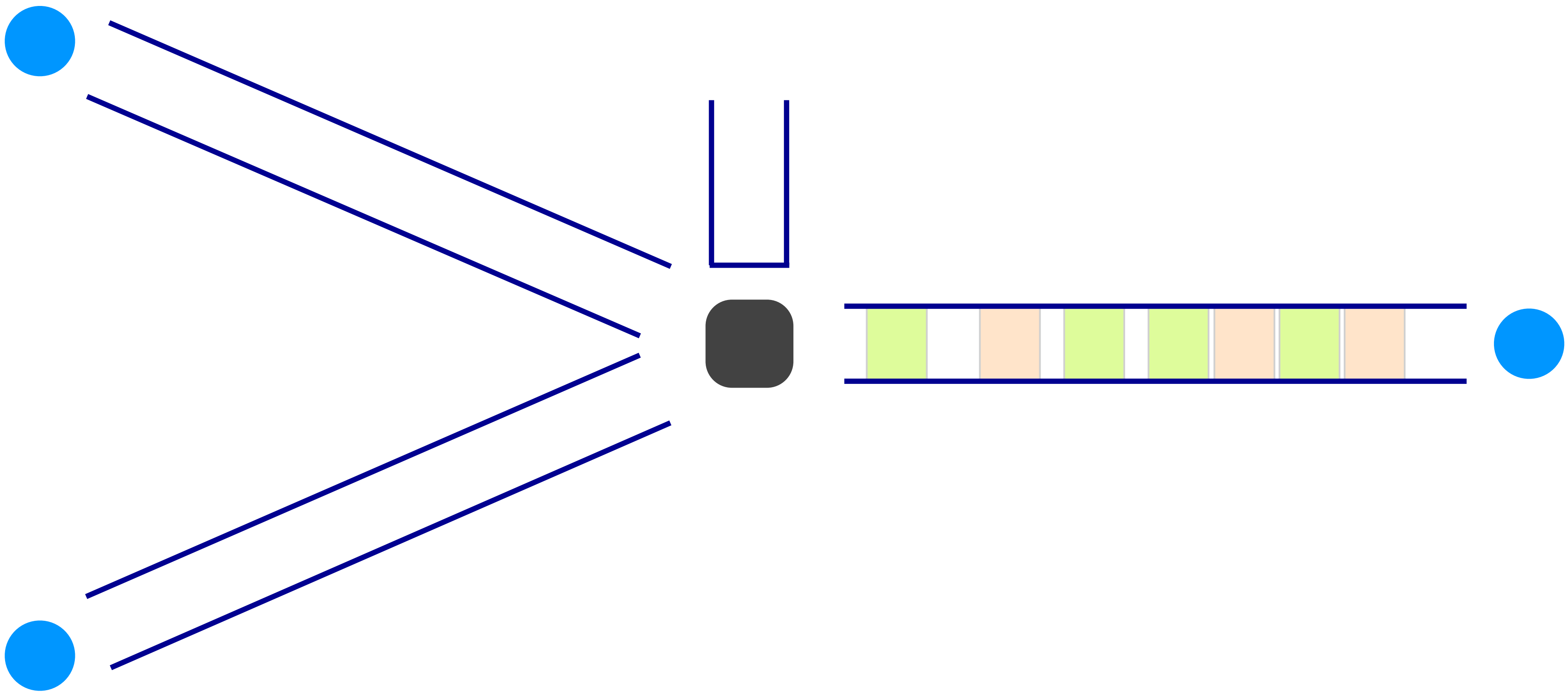

Transient overload!







Queues absorb transient bursts,
but introduce queueing delays



The time a packet has to sit in a buffer before being processed depends on the traffic pattern

Queueing delay depends on:

- arrival rate at the queue
- transmission rate of the outgoing link
- traffic burstiness

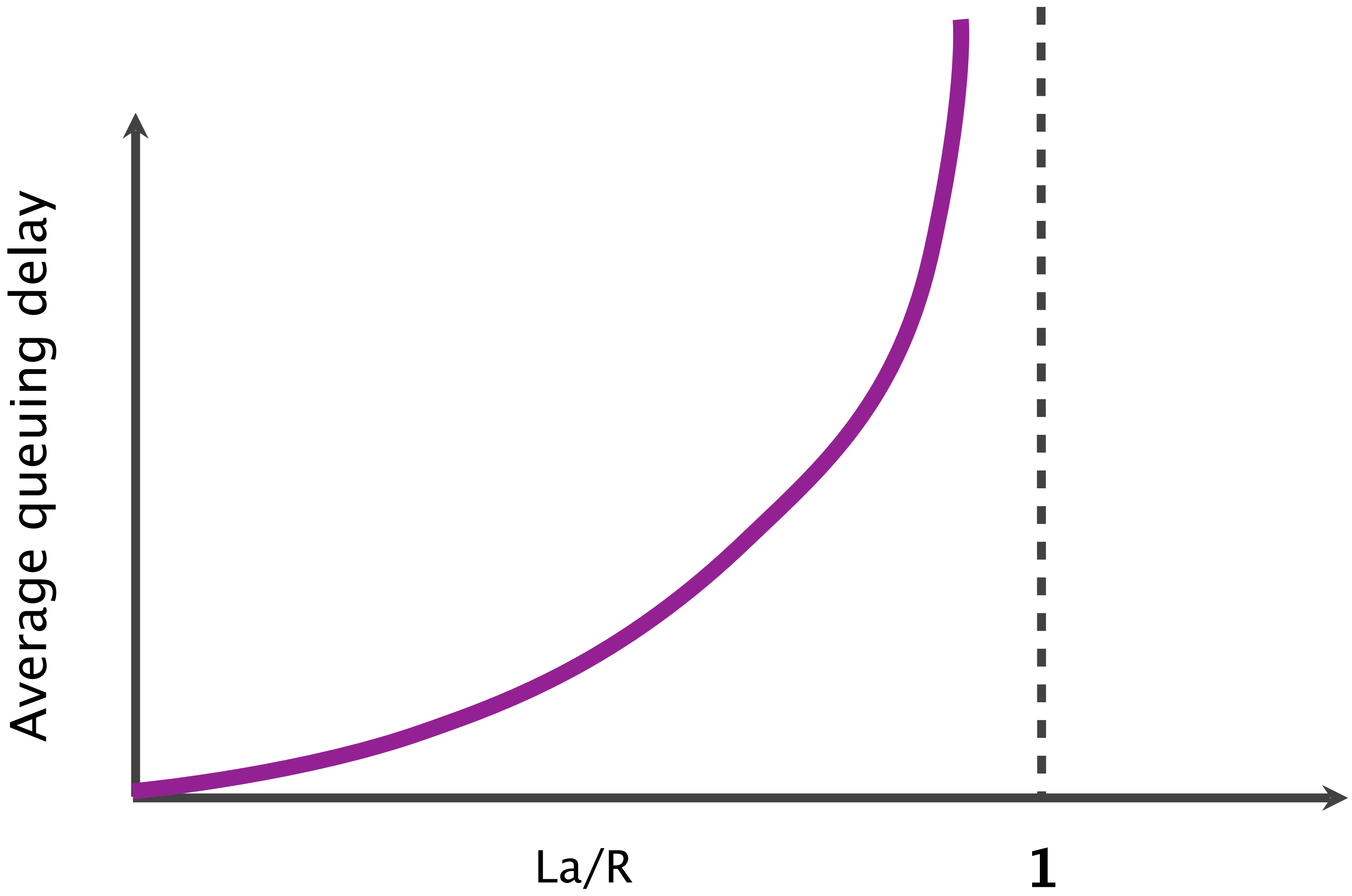
average packet arrival rate	a	[packet/sec]
transmission rate of outgoing link	R	[bit/sec]
fixed packets length	L	[bit]
average bits arrival rate	La	[bit/sec]
traffic intensity	La/R	

When the traffic intensity is >1, the queue will increase without bound, and so does the queuing delay

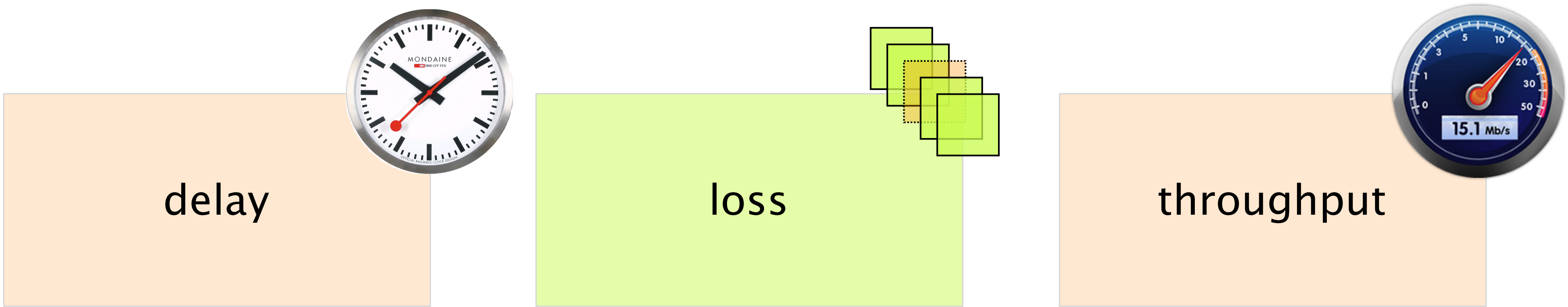
Golden rule

Design your queuing system,
so that it operates far from that point

When the traffic intensity is <=1,
queueing delay depends on the burst size

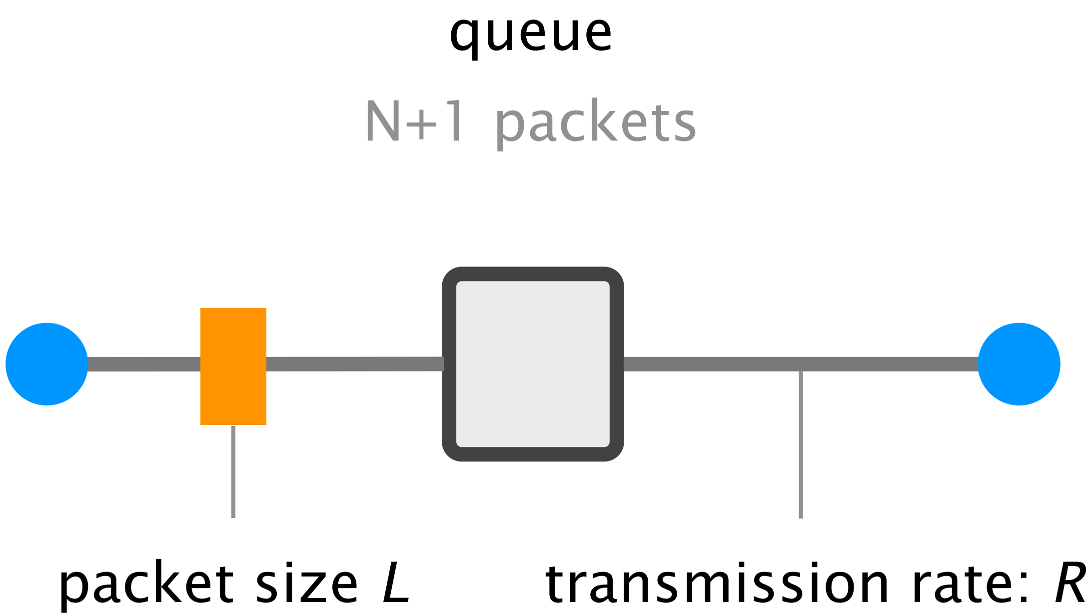


A network *connection* is characterized by its delay, loss rate and throughput



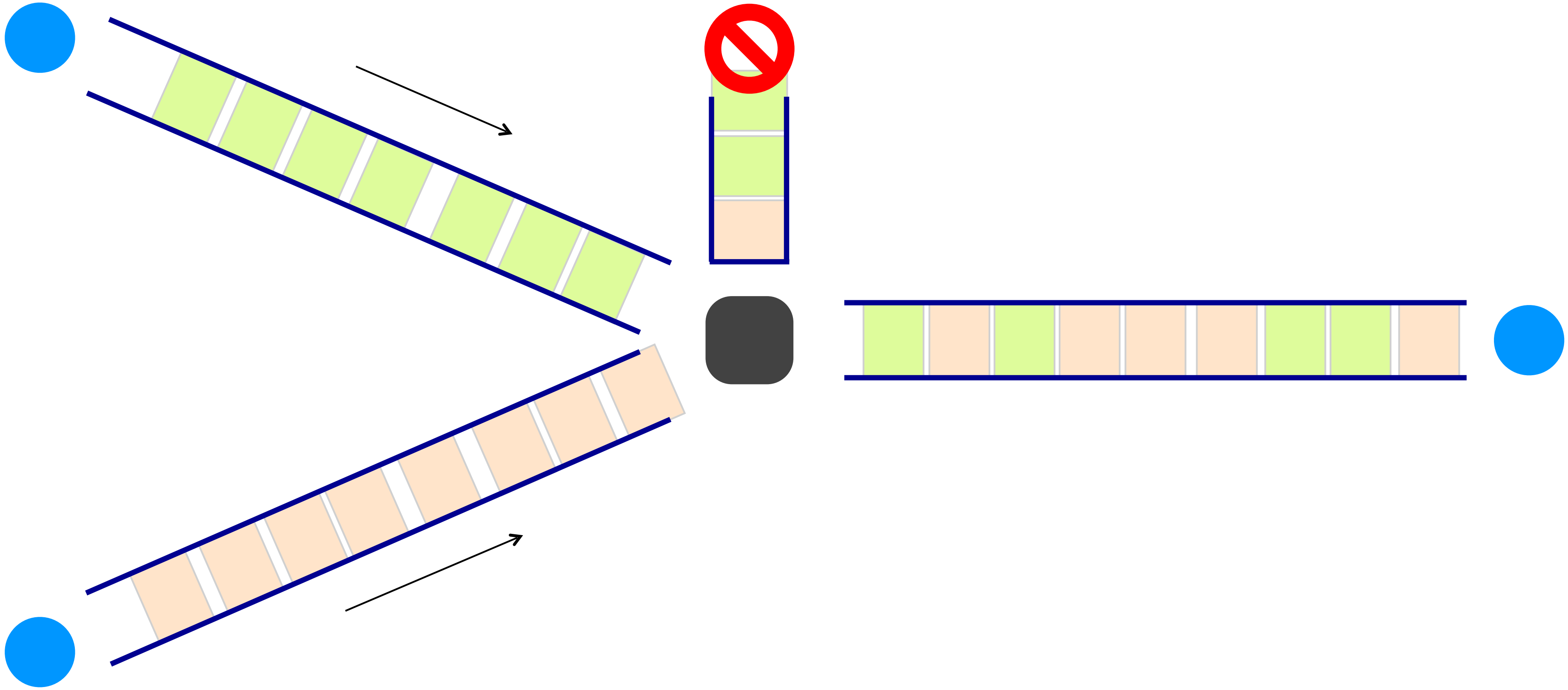
In practice, queues are not infinite.

There is an upper bound on queuing delay.



queuing delay upper bound: N*L/R

If the queue is persistently overloaded,
it will eventually drop packets (loss)



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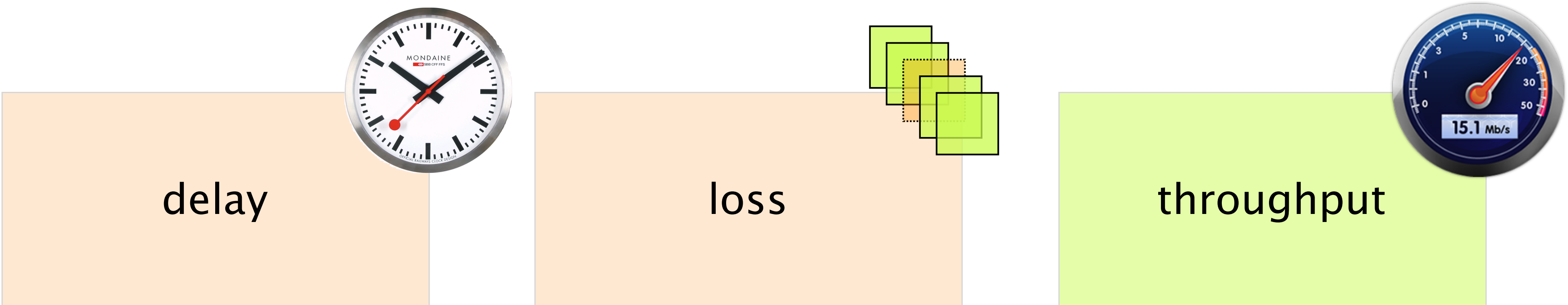
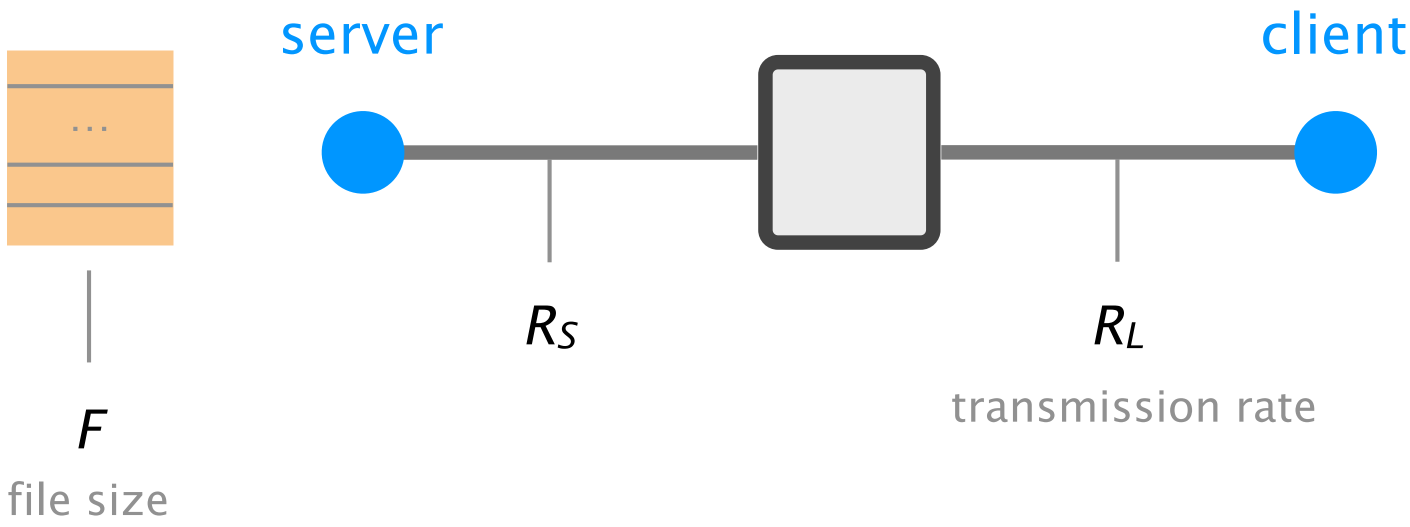


The throughput is the instantaneous rate at which a host receives data

$$\underset{[\#bits/sec]}{\text{Average throughput}} = \frac{\text{data size} \quad [\#bits]}{\text{transfer time} \quad [sec]}$$

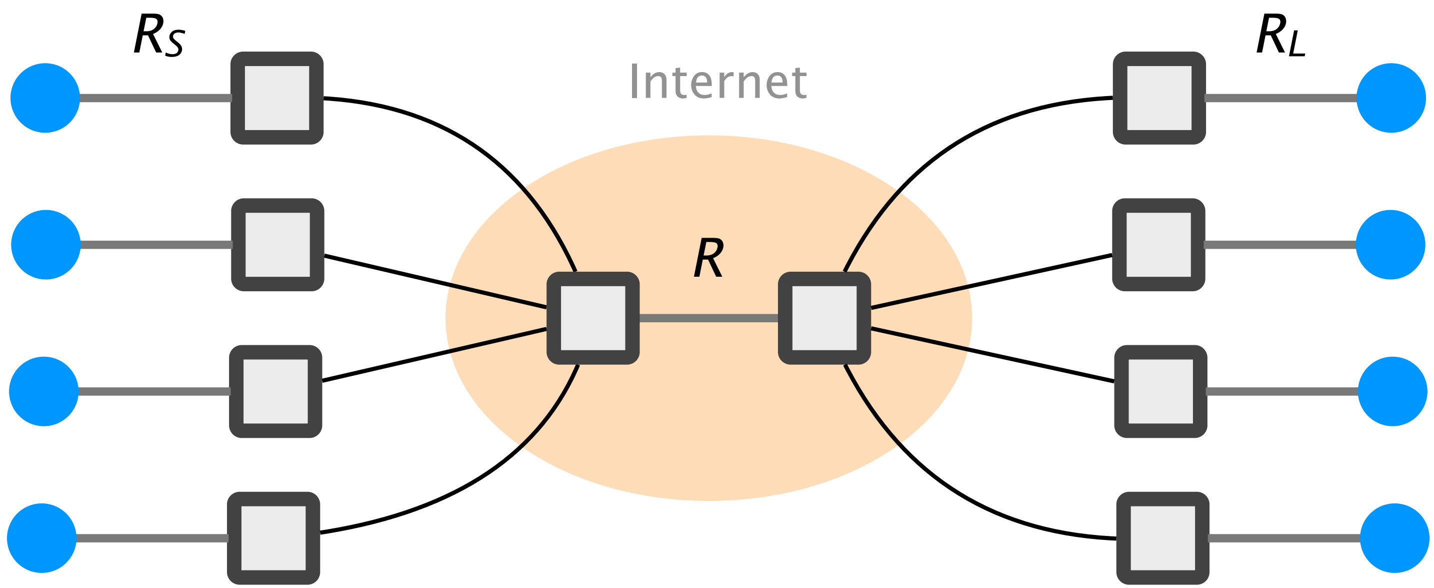
To compute throughput, one has to consider the bottleneck link



Average throughput $\min(R_S, R_L)$

= transmission rate of the bottleneck link

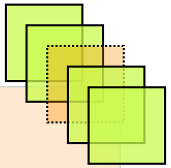
To compute throughput, one has to consider the bottleneck link… and the intervening traffic



if $4*\min(R_S,R_L) > R$ the bottleneck is now in the core, providing each download R/4 of throughput

A network *connection* is characterized by its delay, loss rate and throughput

delay



loss

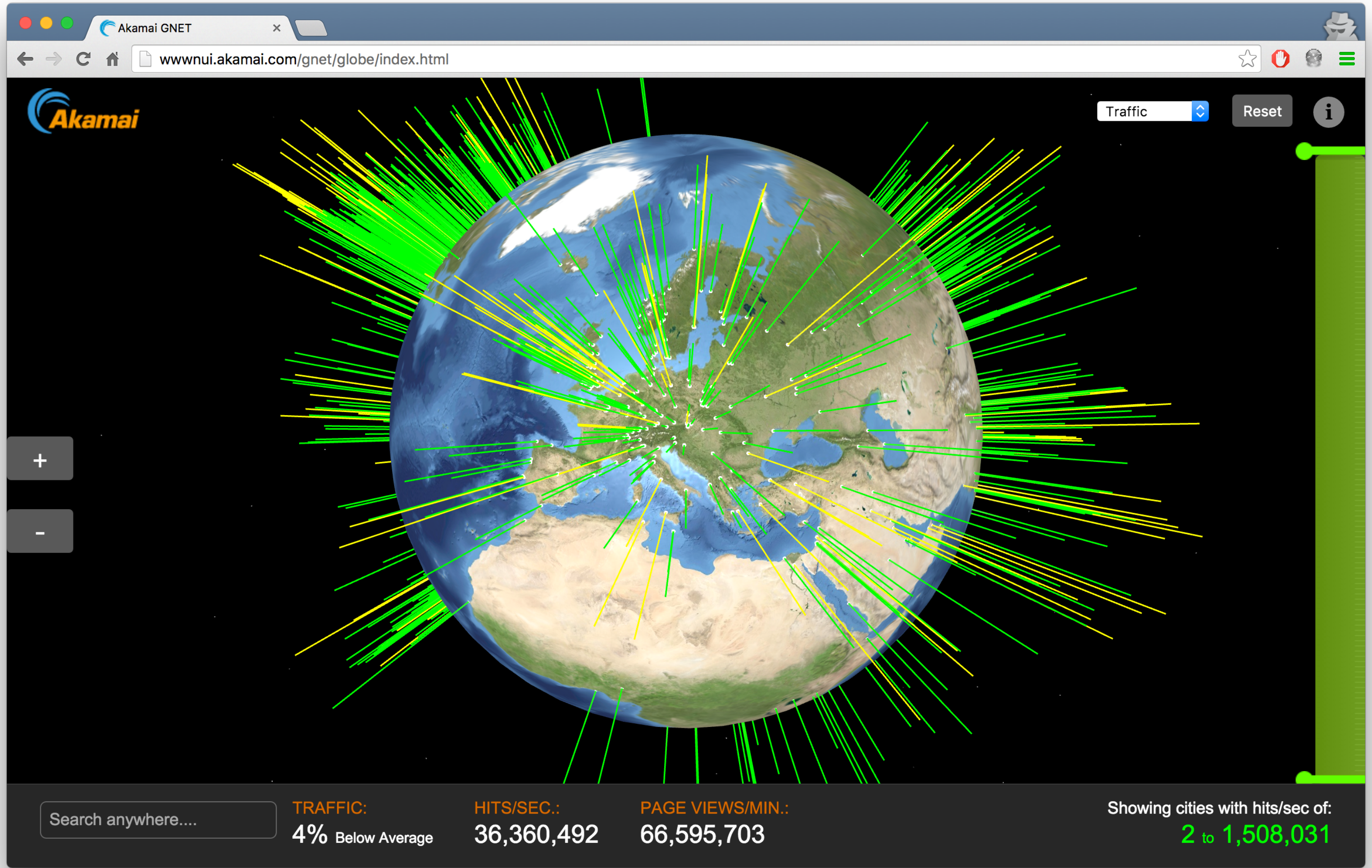
throughput

As technology improves, throughput increase & delays are getting lower except for propagation

(speed of light)

Because of propagation delays,

Content Delivery Networks move content closer to you



http://wwwnui.akamai.com/gnet/globe/index.html

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, …

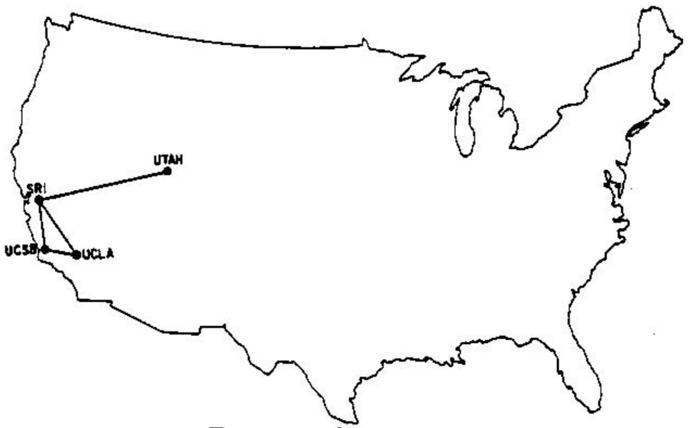
… but knew that circuit-switching will not make it

too inefficient for bursty loads and not resilient

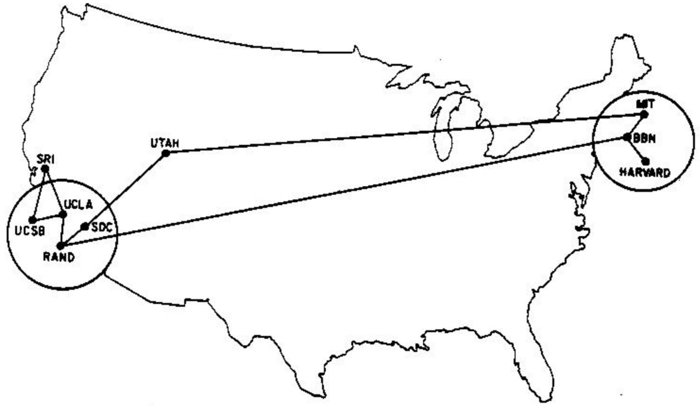
From this wish arose three crucial questions

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

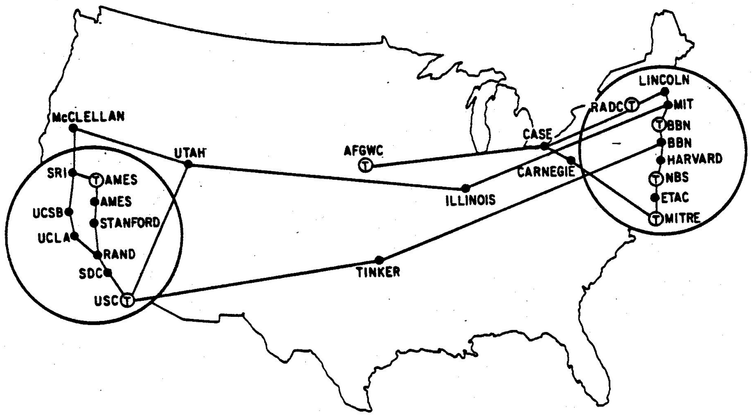
The 60s saw the creation of packet switching and the Advanced Research Projects Agency Network



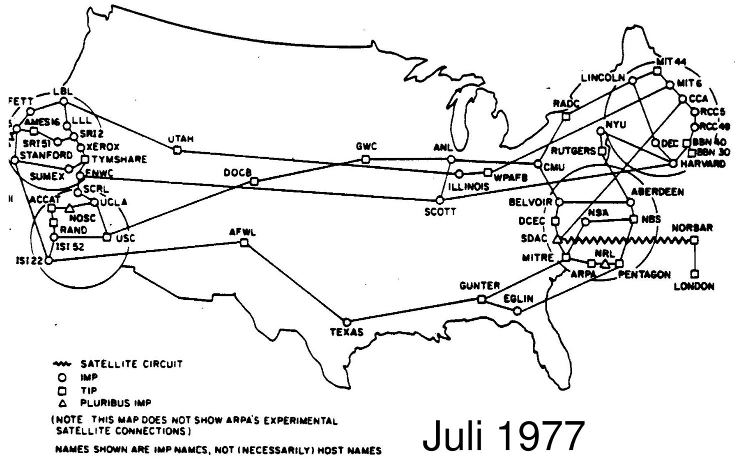
Dezember 1969



Juni 1970



März 1972



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

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

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

1971	Network Control Program predecessor of TCP/IP
1972	Email & Telnet
1973	Ethernet
1974	TCP/IP paper by Vint Cerf & Bob Kahn

In the 80s, TCP/IP went mainstream

1983	NCP to TCP/IP Flag day Domain Name Service (DNS)
1985	NSFNet (TCP/IP) succeeds to ARPANET
198x	Internet meltdowns due to congestion
1986	Van Jacobson saves the Internet (with congestion control)

The 90s saw the creation of the Web as well as the Internet going commercial

1989	Arpanet is decommissioned
	Birth of the Web Tim Berners Lee (CERN)
1993	Search engines invented (Excite)
1995	NSFNet is decommissioned
1998	Google reinvents search

Swiss made

The new millennium brings the Web 2.0, focus on user-generated content

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

Fast Internet access everywhere, every device needs an Internet connection

2009 — Mining of the Bitcoin genesis block

Fast mobile Internet access: 4G/LTE

Internet of Things (IoT) boom
Cars & refrigerators in the Internet

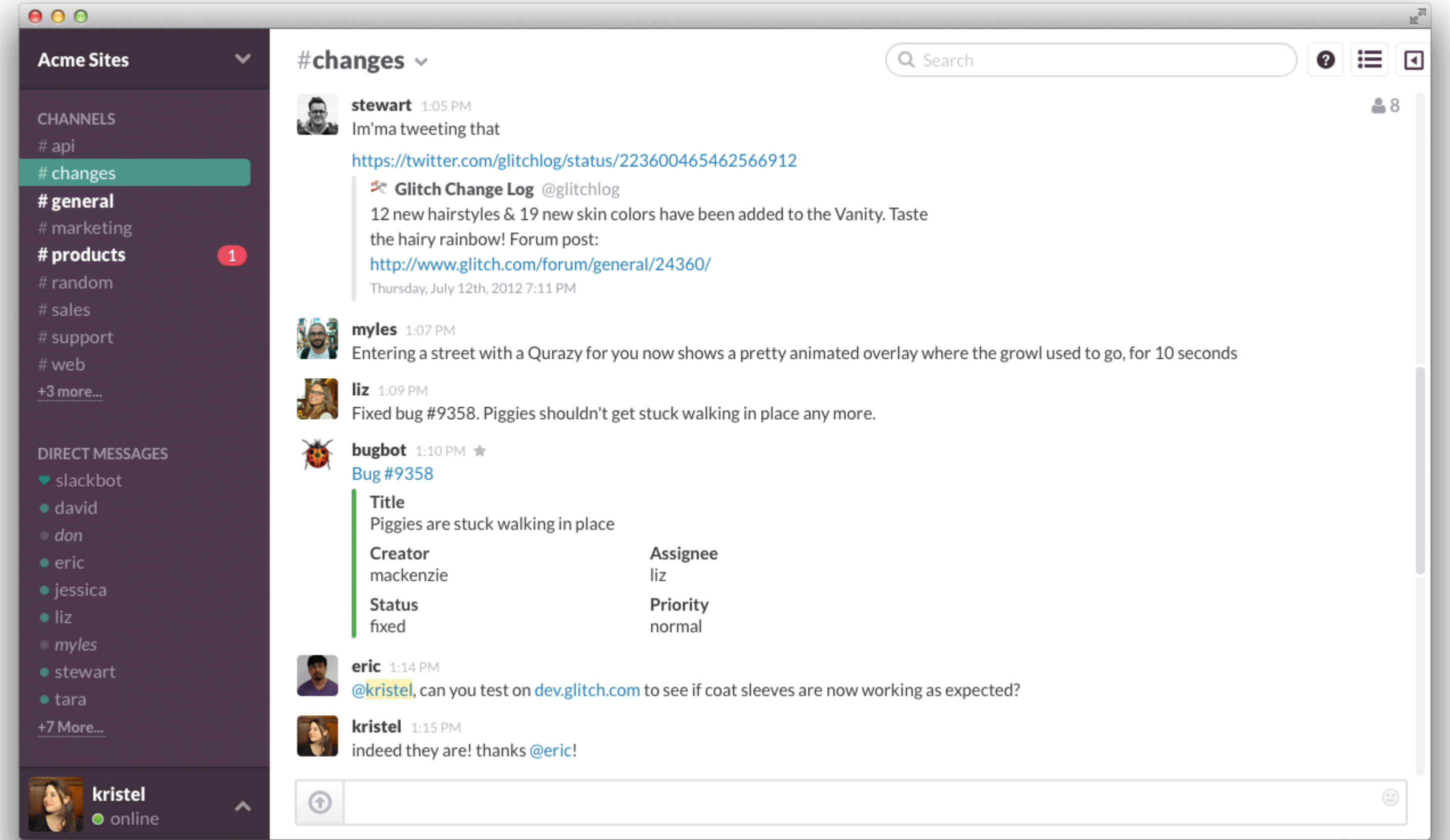
2018 — Only 26% of the Alexa Top 1000 websites reachable over IPv6
http://www.worldipv6launch.org/measurements/

Soon? — Encrypted transport protocols
For example QUIC

Communication Networks

Course organization

Please join the Slack workspace



Web, smartphone and desktop clients available

Please join the Slack workspace

Ask questions and receive important notifications

E.g. related to the theoretical exercises

Create a (private) channel for your group

During the practical assignments

Contribute to public channels in Englisch

You can contact me in German (@buehlert)

Two practical assignments in the second half of the semester

Group of maximum three students

Registration will open soon

Internet Hackathon in week 9 (~ 6-10pm)

More information follow shortly

This Thursday

First Exercise Session (IFW A 36)

Next Monday on

Communication Networks

Routing!