Computer Networks and Internet Technology

2021W703033 VO Rechnernetze und Internettechnik
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With materials and inspiration from Scott Shenker, Jennifer Rexford, Phil Levis, Adrian Perrig and Laurent Vanbever

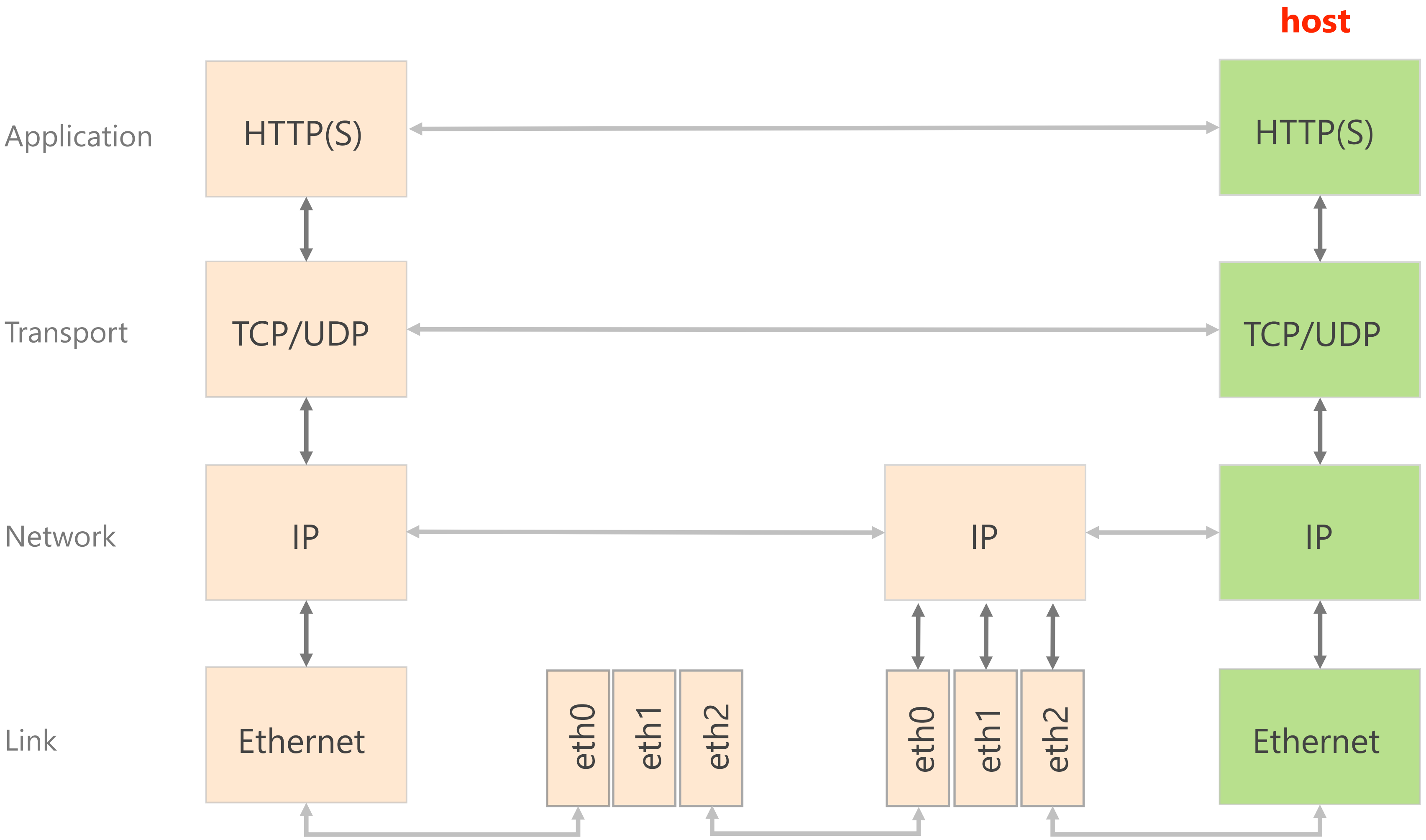
Communication Networks and Internet Technology

Recap of this weeks lecture

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

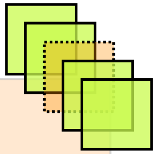
Since when bits arrive they must make it to the application, all the layers exist on a host



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

delay

loss



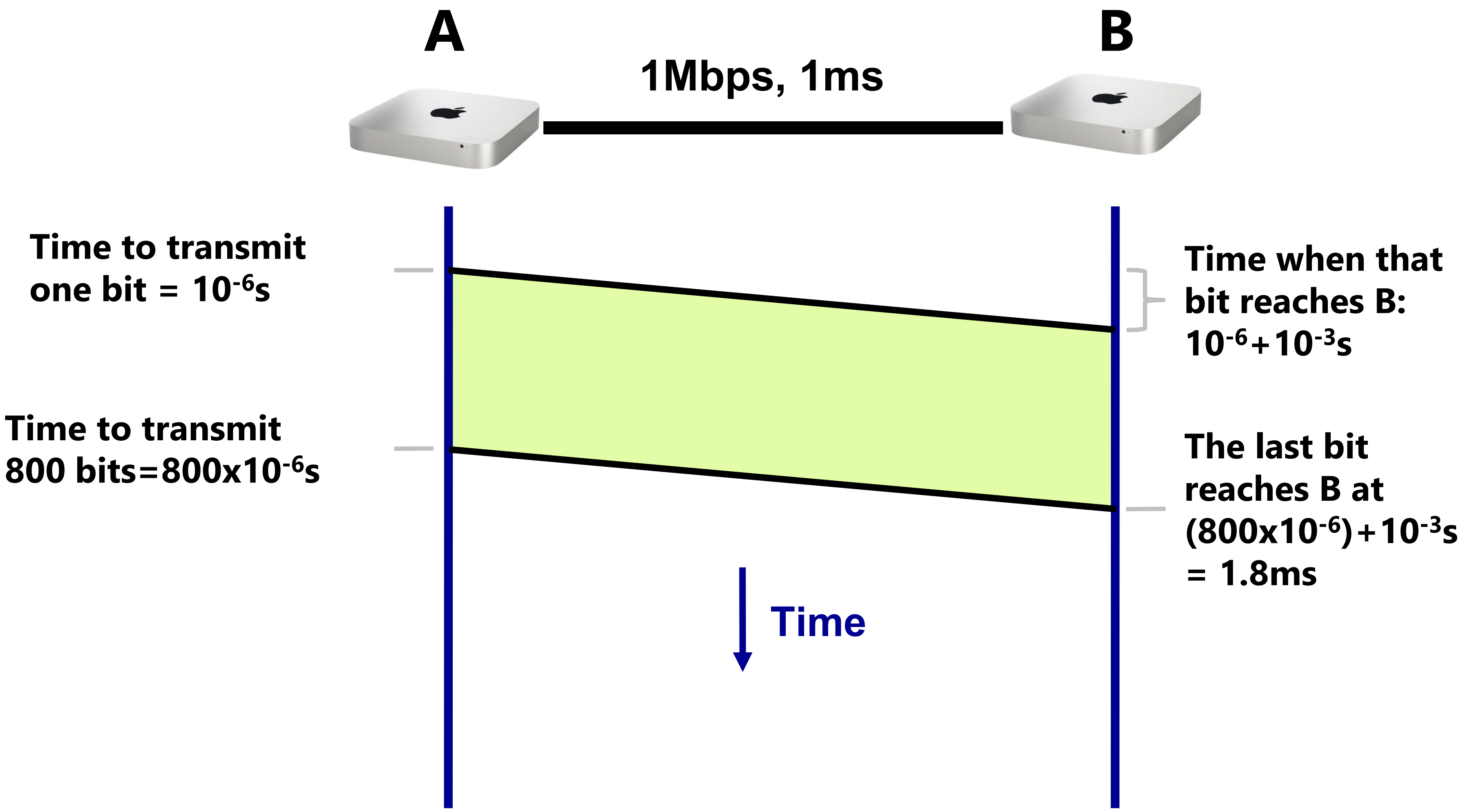
throughput

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

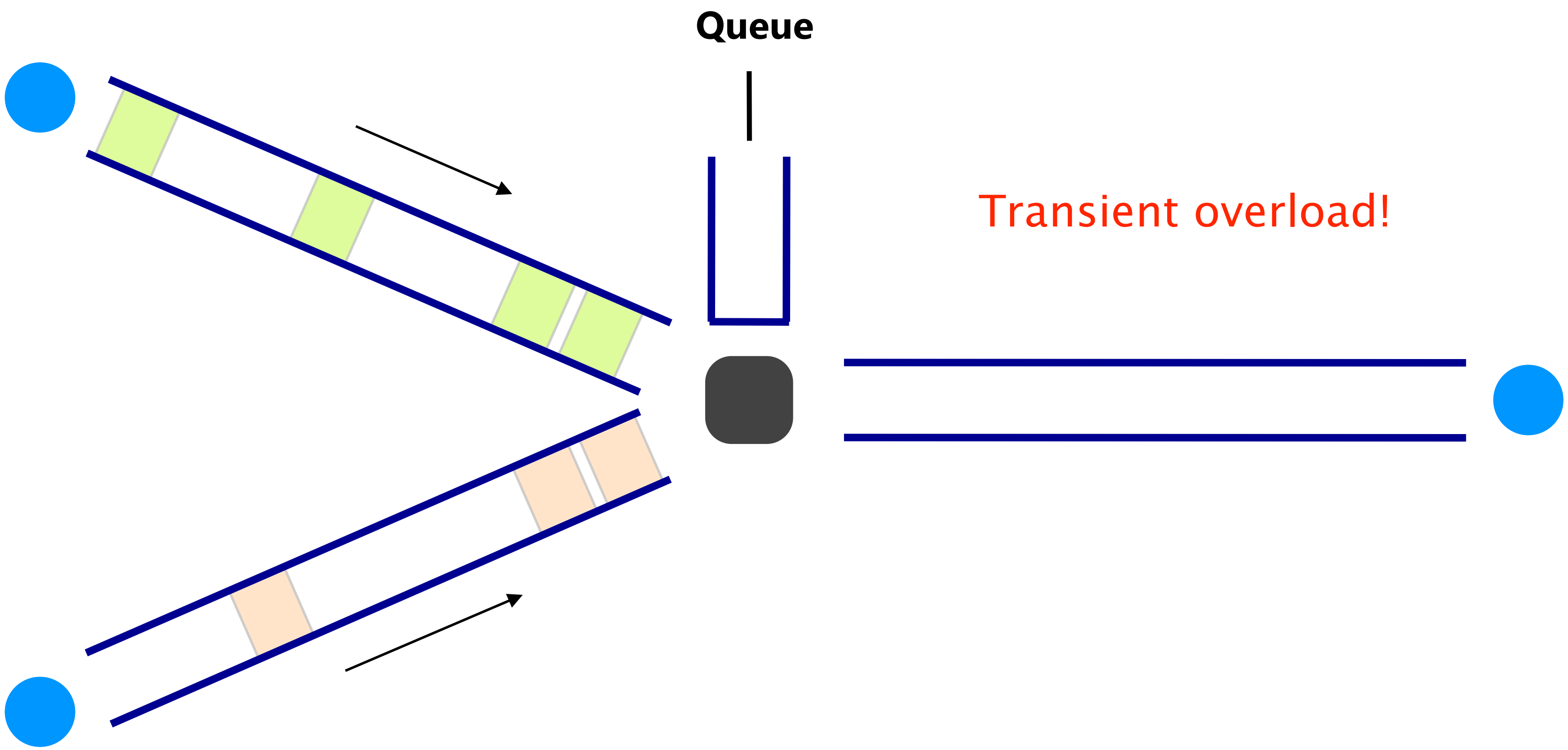
What fraction of packets sent to a destination are dropped?

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

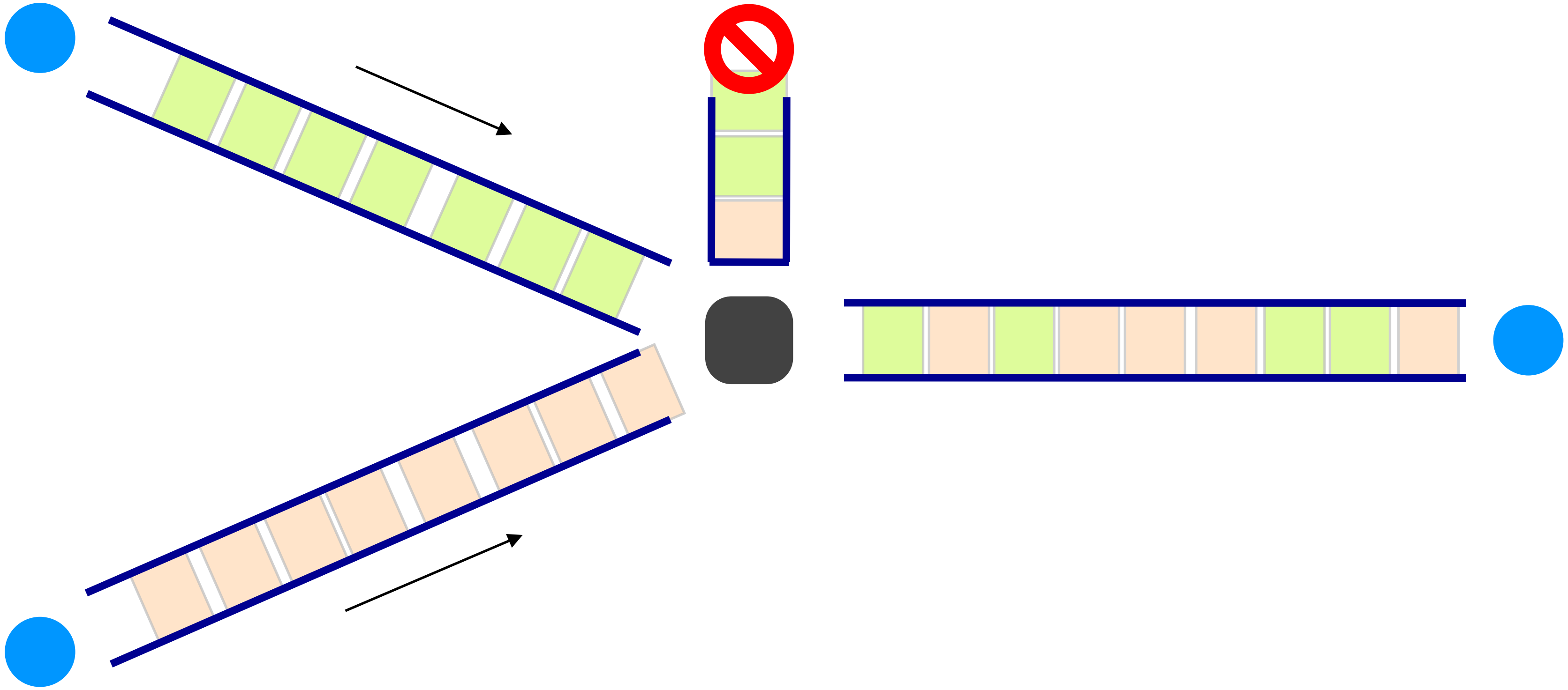
How long does it take to exchange 100 Bytes packet?



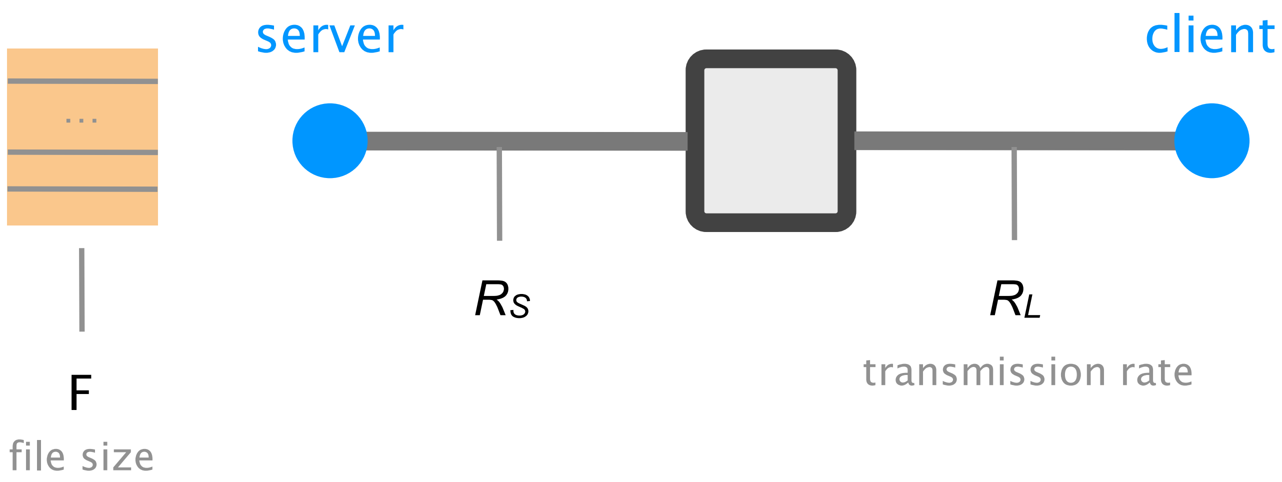
Queuing delay depends on the traffic pattern



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



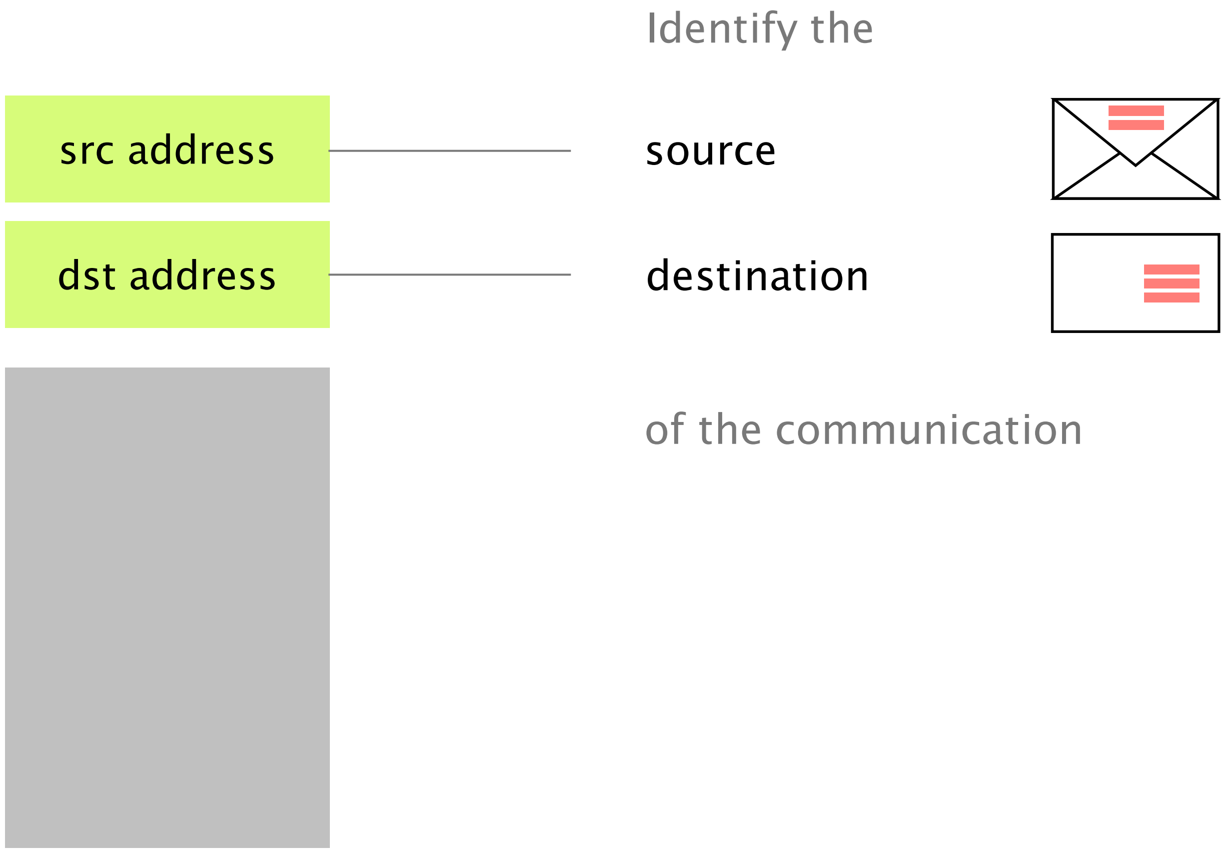
To compute throughput, one has to consider the bottleneck link



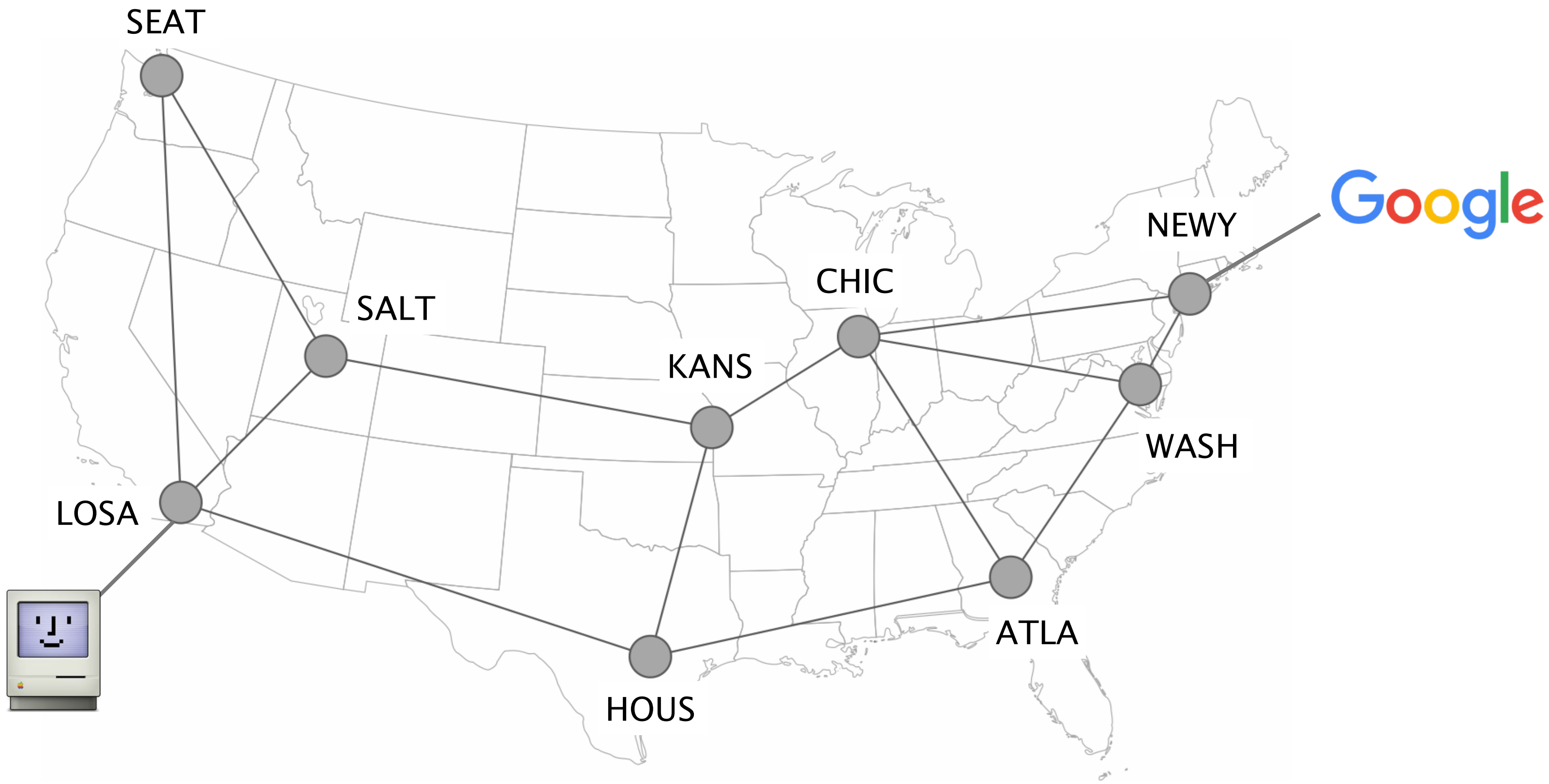
Average throughput $\min(R_S, R_L)$

= transmission rate of the bottleneck link

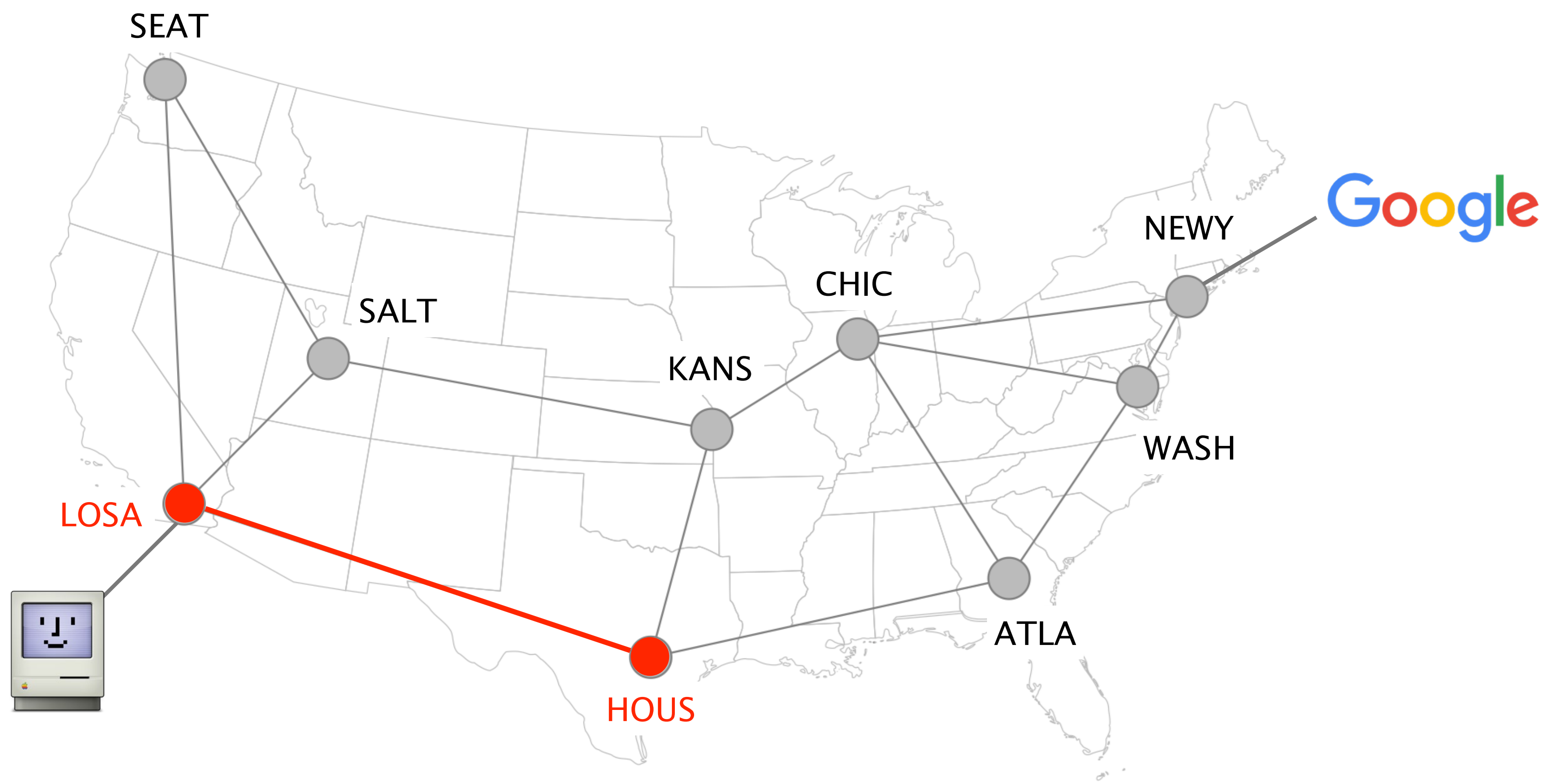
The **header** contains the **metadata** needed **to forward** the packet



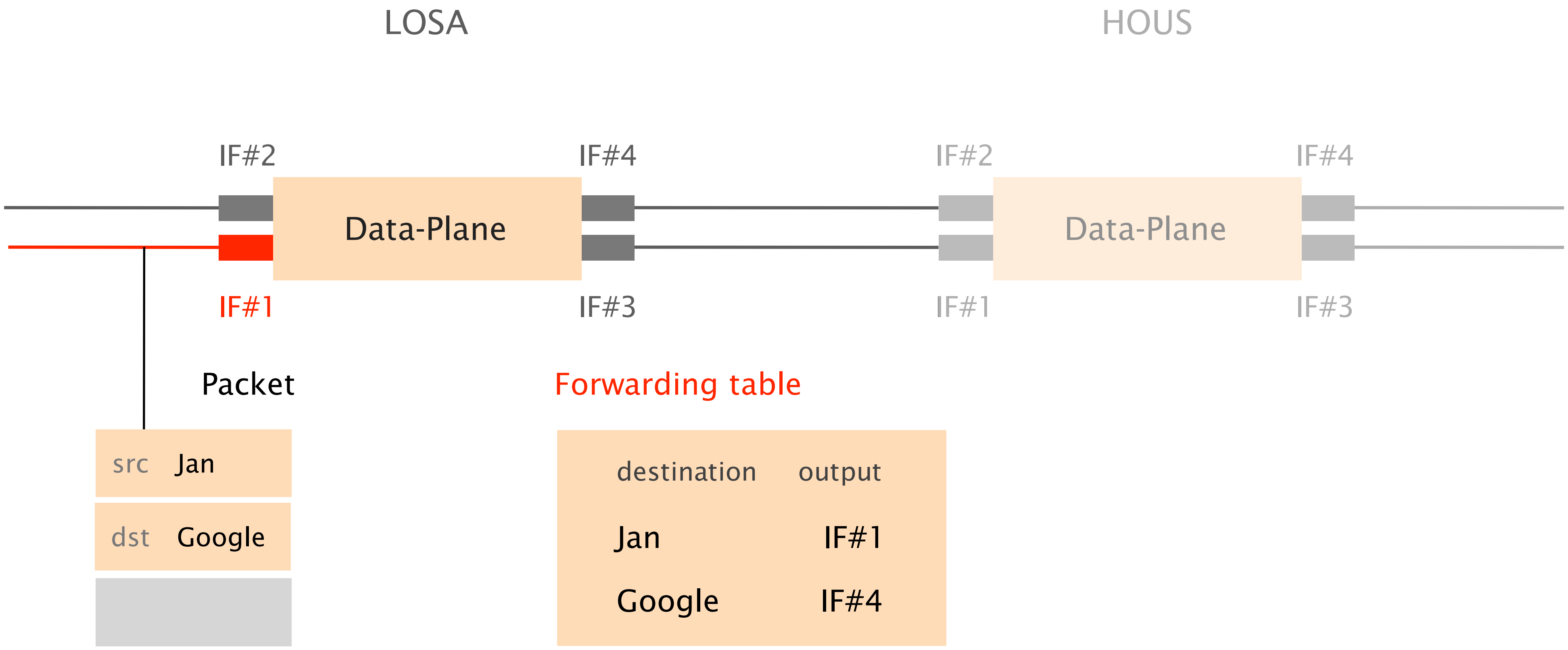
Routers forward IP packets hop-by-hop towards their destination



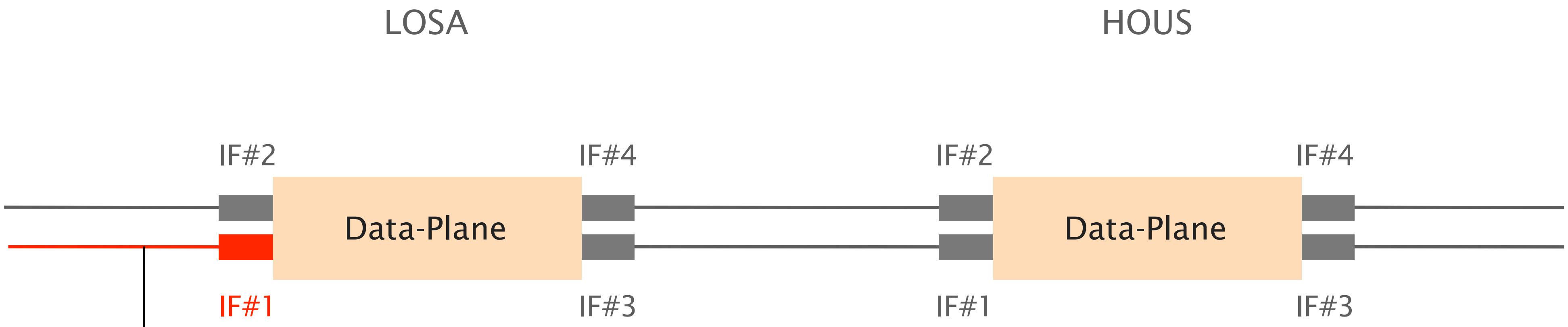
Let’s zoom in on what is going on between **two adjacent routers**



Upon packet reception, routers locally look up their forwarding table to know where to send it next



Here, the packet should be directed to IF#4



Packet

src Jan

dst Google

Forwarding table

destination	output
Jan	IF#1
Google	IF#4

Verifying that a routing state is valid is easy

simple algorithm

for one destination

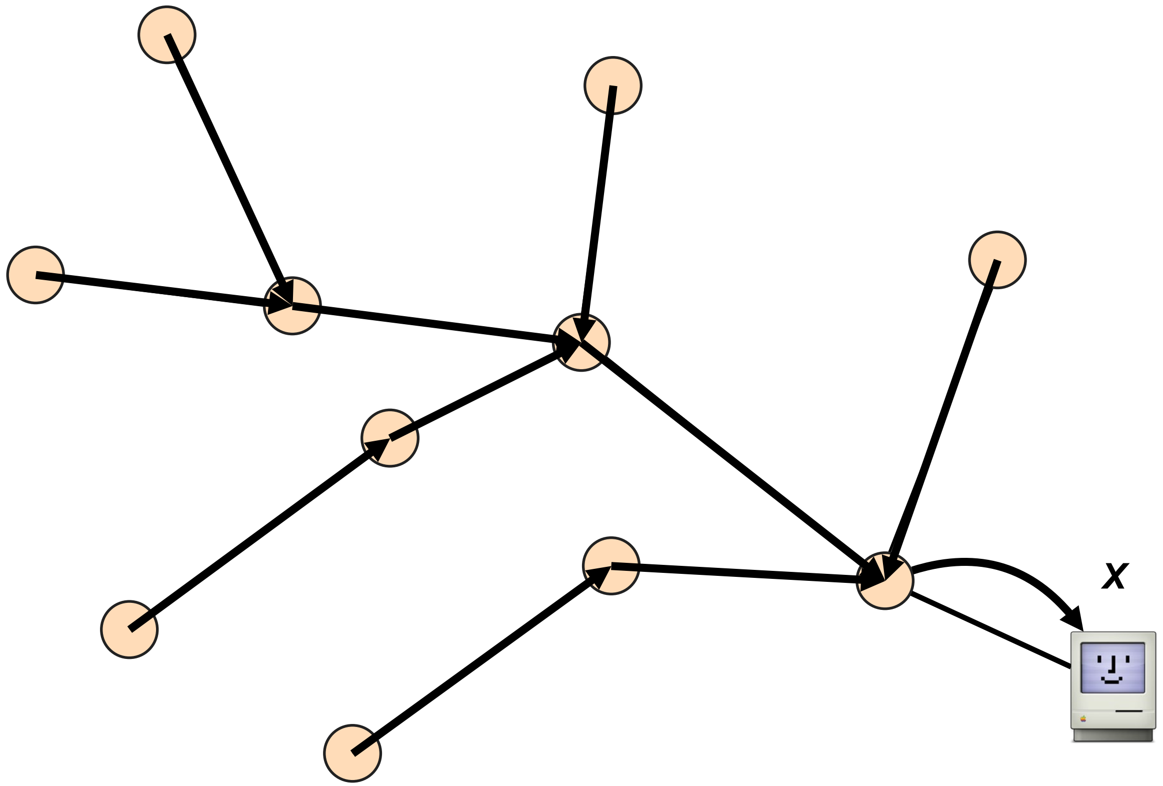
Mark all outgoing ports with an arrow

Eliminate all links with no arrow

State is valid *iff* the remaining graph
is a spanning-tree

The result is a spanning tree.

This is a valid routing state



Producing valid routing state is harder

but doable

prevent dead ends

easy

prevent loops

hard

Existing routing protocols differ in

how they avoid loops

prevent loops

hard

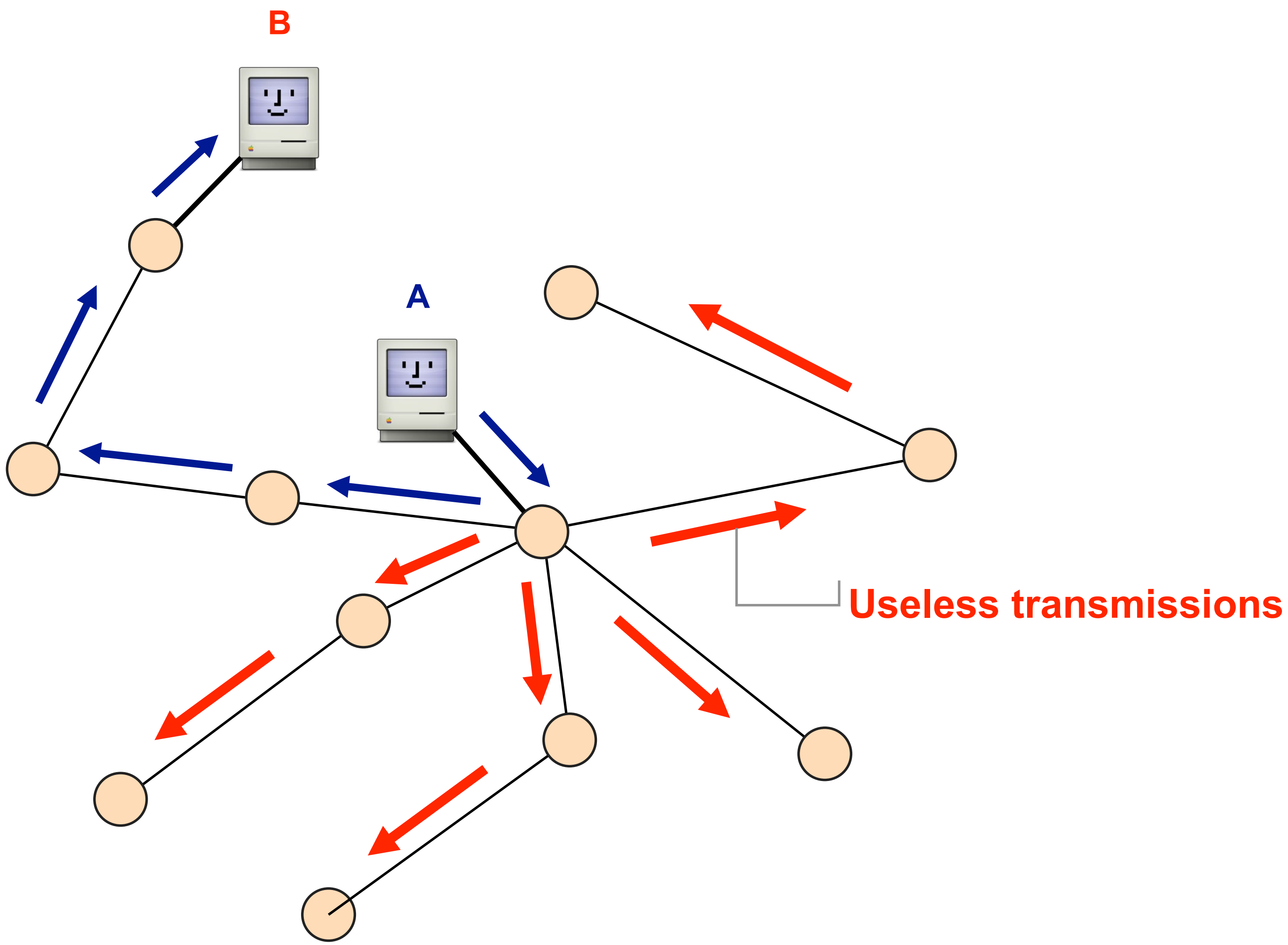
Essentially,

there are **three ways to compute** valid routing state

	Intuition	Example
#1	Use tree-like topologies	Spanning-tree
#2	Rely on a global network view	Link-State SDN
#3	Rely on distributed computation	Distance-Vector BGP

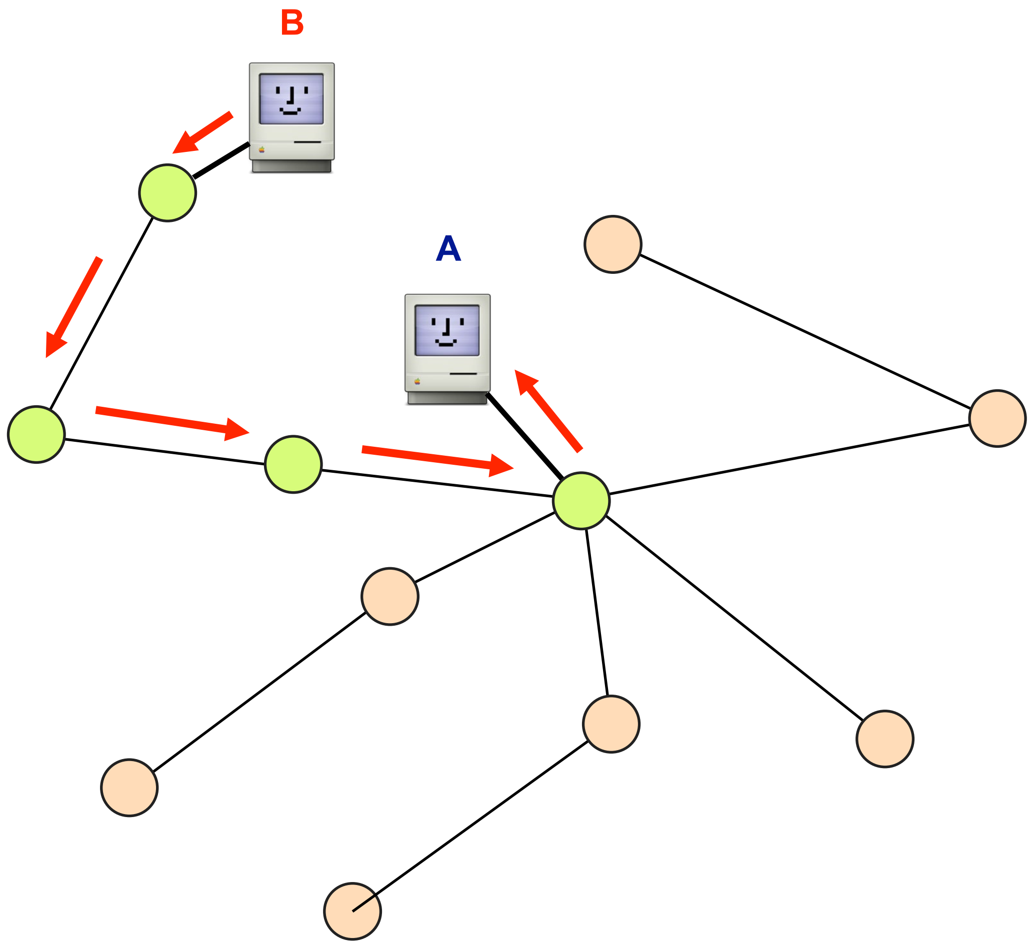
While flooding works,

it is quite wasteful



B answers back to A

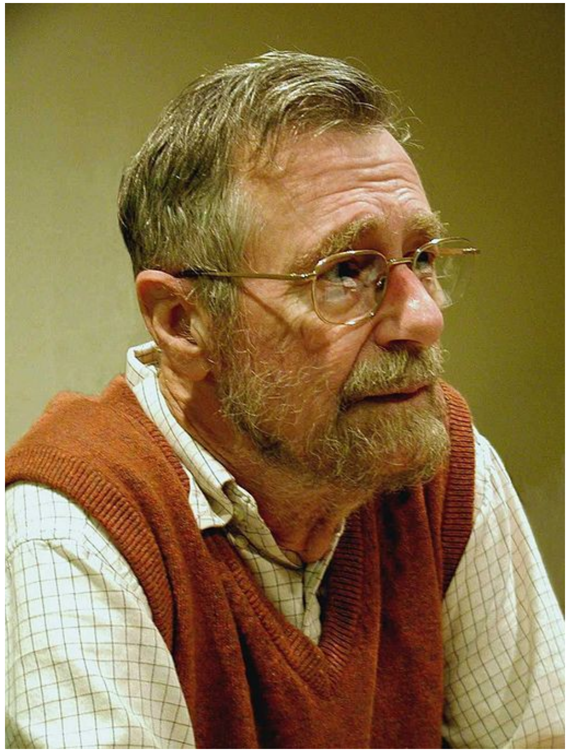
enabling the green nodes to also learn where B is



Edsger W. Dijkstra (1930-2002)

- Famous computer scientist
  - Programming languages
  - Distributed algorithms
  - Program verification

- Dijkstra's algorithm, 1959
  - Single-source shortest paths,
    given network with non-negative link costs



Once a node u knows the entire topology,
it can compute shortest-paths using **Dijkstra's algorithm**

Initialization

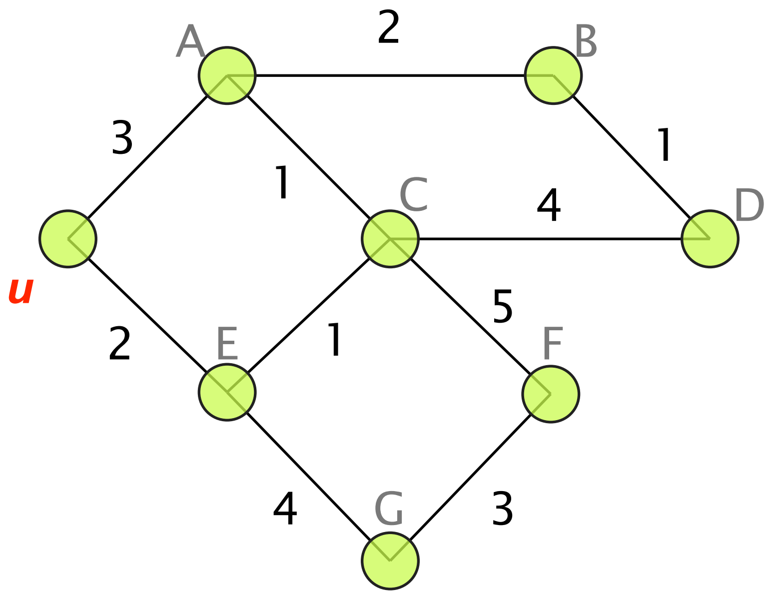
```
S = {u}
for all nodes v:
    if (v is adjacent to u):
        D(v) = c(u,v)
    else:
        D(v) = ∞
```

Loop

```
while not all nodes in S:
    add w with the smallest D(w) to S
    update D(v) for all adjacent v not in S:
        D(v) = min{D(v), D(w) + c(w,v)}
```

From the shortest-paths,

u can directly compute its forwarding table



Forwarding table

destination	*next-hop*
A	A
B	A
C	E
D	A
E	E
F	E
G	E

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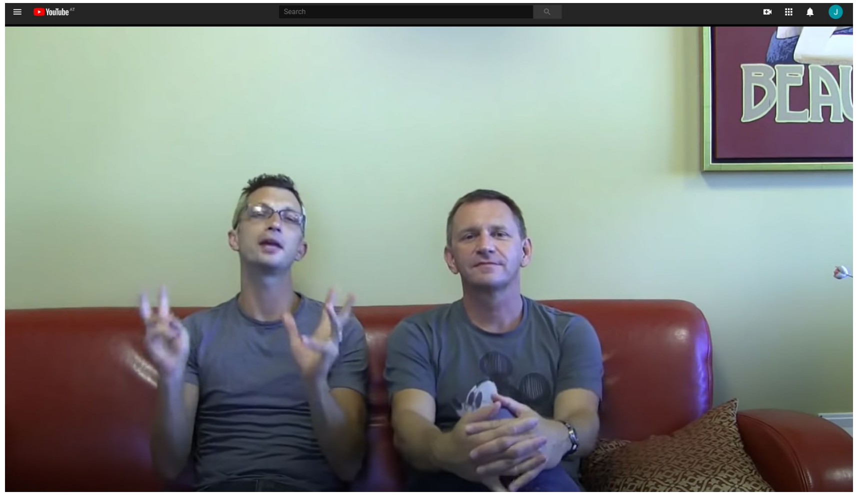
Further Lecture Notes

Hearing Topics from a Different Voice

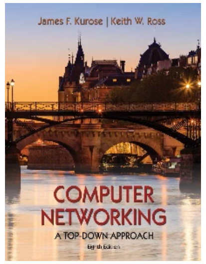
- Phil Levis and Nick McKeown @Stanford

  [CS144 Introduction to Computer Networking Fall 2016 on YouTube]()



- Jim Kurose – UMass
  http://gaia.cs.umass.edu/kurose_ross/videos/1/

Class textbook:
Computer Networking: A Top-Down Approach (8th ed.)
J.F. Kurose, K.W. Ross
Pearson, 2020
http://gaia.cs.umass.edu/kurose_ross



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Demo Time

Important network debugging tools

ping

Is a destination reachable?

traceroute (*tracert*)

How do I reach a destination?

...

ping - important options (Linux)

-c	count, number of queries
-i	wait, time in seconds between each packet
-s	packetsize, number of data bytes to send
-S	src_addr, source address to use if multiple IPs available

...

traceroute - output

```
> traceroute www.nyu.edu

traceroute to web.gslb.nyu.edu (128.122.119.202), 64 hops max, 52 byte packets

 1  82.130.102.1                                      (82.130.102.1)      0.849 ms    0.616 ms    0.820 ms
 2  rou-ref-rz-bb-ref-rz-etx                          (10.10.0.41)        0.741 ms    0.671 ms    0.643 ms
 3  rou-fw-rz-ee-tik                                  (10.1.11.129)       0.892 ms    0.836 ms    5.057 ms
 4  rou-fw-rz-gw-rz                                   (192.33.92.170)     1.040 ms    0.852 ms    0.892 ms
 5  swiez2                                            (192.33.92.11)      0.982 ms    1.032 ms    0.974 ms
 6  swizh1-100ge-0-1-0-0.switch.ch                    (130.59.38.110)     0.913 ms    0.884 ms    0.959 ms
 7  swice1-100ge-0-3-0-0.switch.ch                    (130.59.36.93)      5.796 ms    6.485 ms    4.591 ms
 8  switch.mx1.gen.ch.geant.net                       (62.40.124.21)      4.213 ms    4.173 ms    4.203 ms
 9  ae4.mx1.par.fr.geant.net                          (62.40.98.152)      11.508 ms   13.460 ms   11.560 ms
10  et-3-1-0.102.rtsw.newy32aoa.net.internet2.edu     (198.71.45.236)     85.752 ms   82.767 ms   82.455 ms
11  nyc-9208-i2-newy.nysernet.net                     (199.109.5.1)       82.457 ms   82.548 ms   82.434 ms
12  199.109.5.6                                       (199.109.5.6)       82.609 ms   82.624 ms   82.684 ms
13  dmzgwa-ptp-extgwa.net.nyu.edu                     (128.122.254.65)    83.006 ms   83.225 ms   83.279 ms
14  nyugwa-ptp-dmzgwa.net.nyu.edu                     (128.122.254.88)    82.815 ms   82.789 ms   82.701 ms
15  wsqdcgwa-vl902.net.nyu.edu                        (128.122.1.38)      83.156 ms   83.194 ms   82.933 ms
16  * * *
```

Hop

Domain name

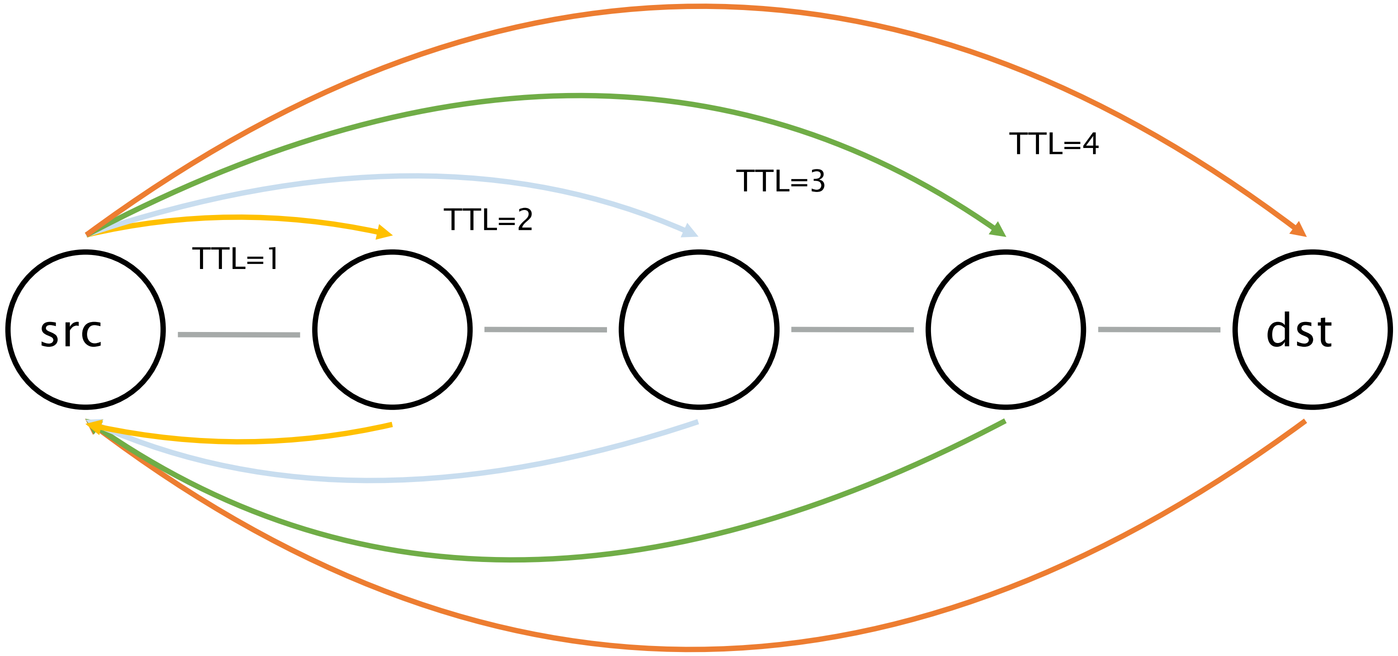
IP address

RTT measurements

No response/
timeout

Round Trip Time
Both directions!

traceroute - working principle



traceroute - problems

Behavior when multiple parallel paths exist

Will see that in the first group project

Devices that do not answer

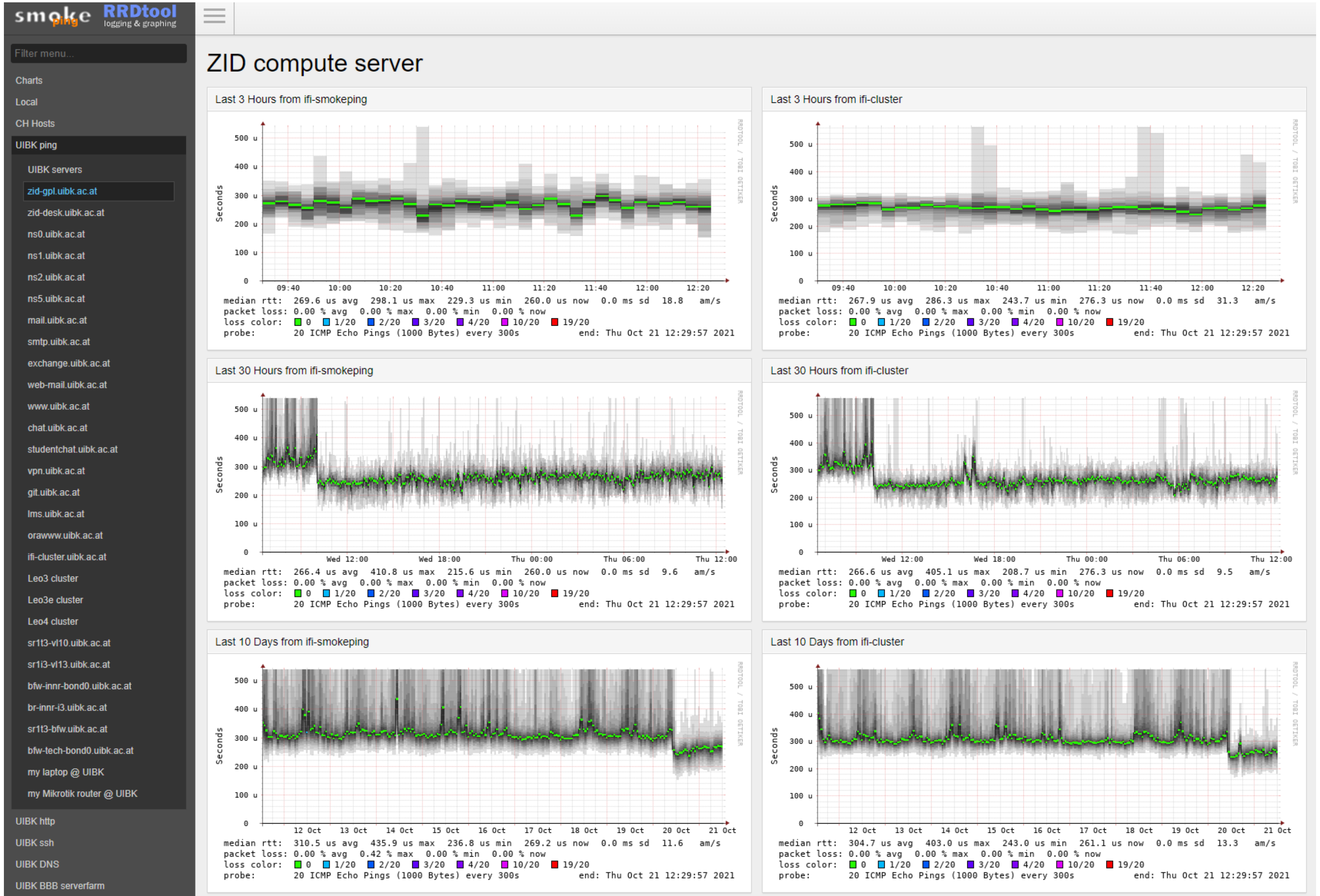
Different forward and backward paths

...

Let’s see how it looks like in practice

on a host, using Wireshark https://www.wireshark.org

Let’s see some dynamics – extended statistics and packet loss



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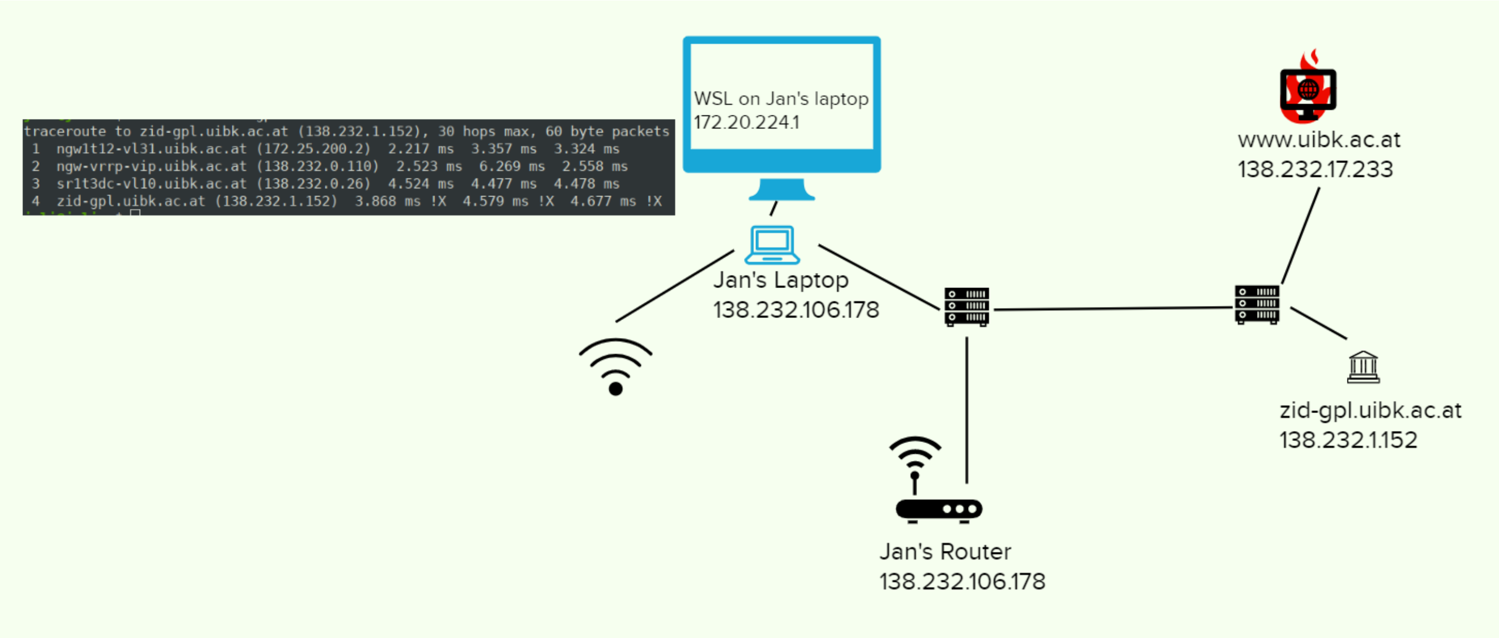
Challenge

Add your laptop to our RNIT Internet



- Execute `traceroute zid.gpl.uibk.ac.at` from home and/or school
- Add your route to the Mural

https://app.mural.co/t/rnit2872/m/rnit2872/1633449886153/7a1cffc55d22b50b56a7c77a762cc586b9582109?sender=u2b11e356f080ef4ab8703088