Introduction to Networking and Systems Measurements

Lecture 2: Basic Network Measurements

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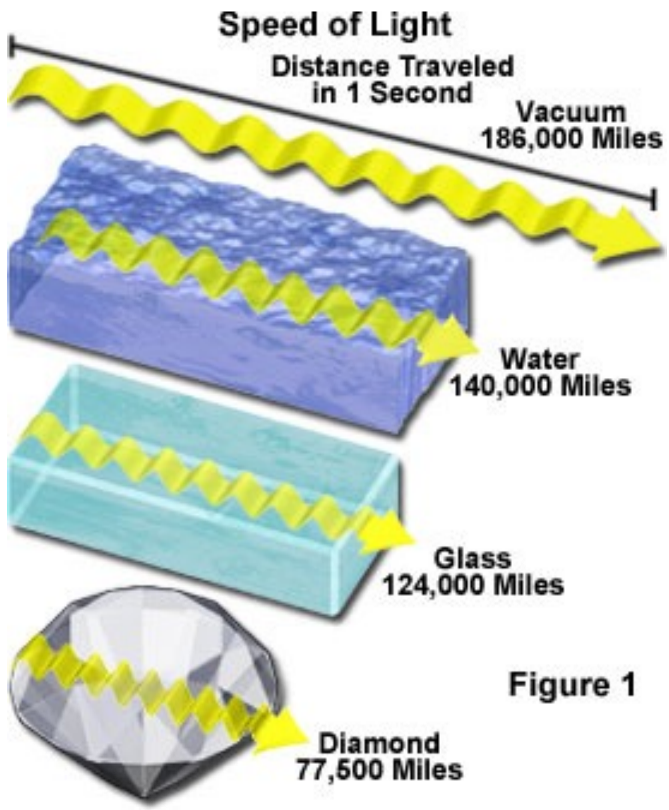
Time flies

- 1ns = 20cm in fibre
- 10Gb/s is about 10 bits per nanosecond
- so at 10Gb/s a 512byte packet is ~ 8meters long



Ping

- Ping is basically a “are you still there” test
- “connectivity” test
- “how long does it take to get there” test
- “loss approximation” test

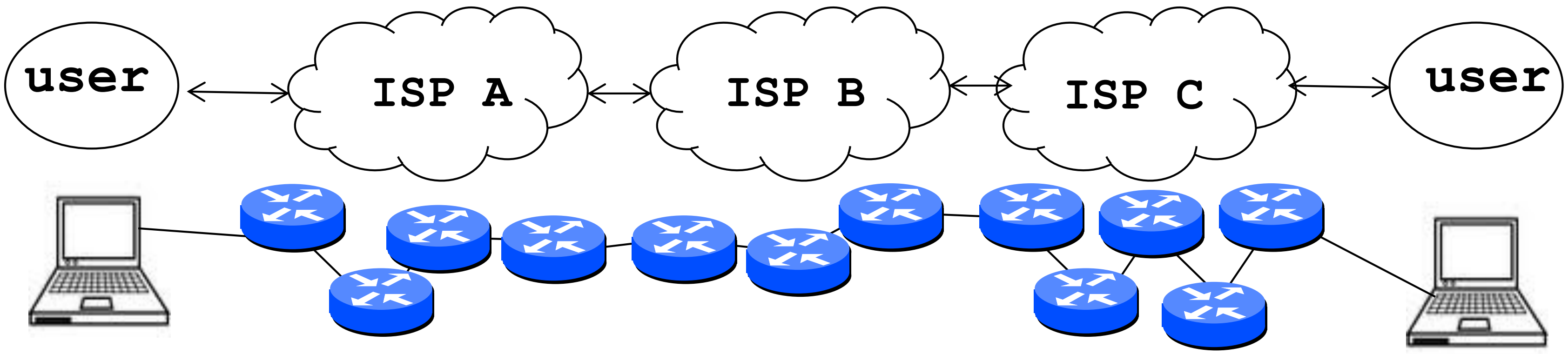
```
$ ping www.stanford.edu
PING www.stanford.edu (54.192.2.121): 56 data bytes
64 bytes from 54.192.2.121: icmp_seq=0 ttl=242 time=3.730 ms
64 bytes from 54.192.2.121: icmp_seq=1 ttl=242 time=3.845 ms
…
^C
--- www.stanford.edu ping statistics ---
8 packets transmitted, 8 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 3.730/3.808/3.849/0.047 ms
```

PING traps

- Uses ICMP (control messages of the Internet)
- Might not follow the same path as *normal packets*
- Might be filtered
- A ping test is not the actual round trip time for an application – merely the host-host IP control layer
- One way delay is not simply half round trip time
- Learn by doing (run tcpdump at the same time)

Recall the Internet *federation*

- The Internet ties together different networks
  - >18,000 ISP networks



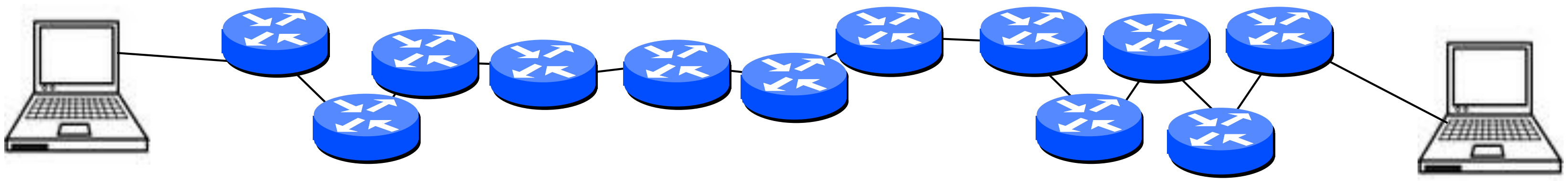
We can see (hints) of the nodes and links using traceroute…

Traceroute: Internet debug thy self

- Recall the Internet ***Zombie plan*** – *Time-To-Live (TTL)*
- *Each router decrements TTL; when TTL =0 send error*

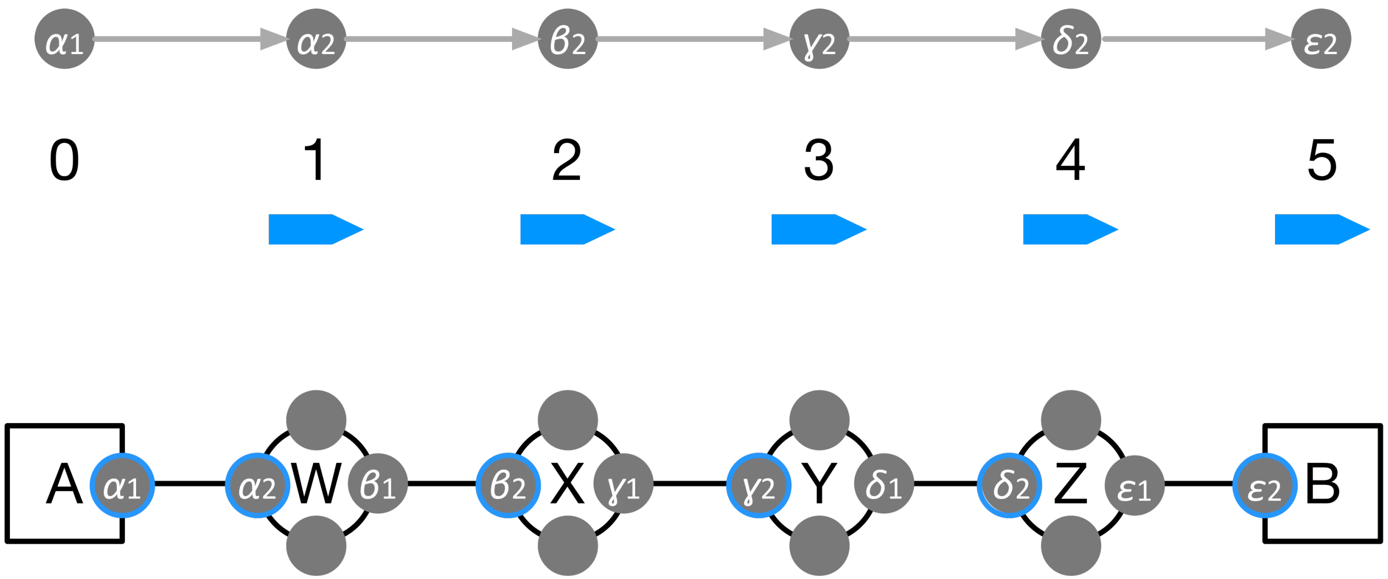
`Traceroute` artificially sets low TTL and receives the error

Each step of the path is iteratively discovered



…

Traceroute as we wish…



But ***ONLY*** one *direction*

"Real" Internet traceroute

traceroute: rio.cl.cam.ac.uk to munnari.oz.au

(tracepath on windows is similar)

Three delay measurements from rio.cl.cam.ac.uk to gatwick.net.cl.cam.ac.uk

```
traceroute munnari.oz.au
traceroute to munnari.oz.au (202.29.151.3), 30 hops max, 60 byte packets
 1  gatwick.net.cl.cam.ac.uk (128.232.32.2)  0.416 ms  0.384 ms  0.427 ms
 2  cl-sby.route-nwest.net.cam.ac.uk (193.60.89.9)  0.393 ms  0.440 ms  0.494 ms
 3  route-nwest.route-mill.net.cam.ac.uk (192.84.5.137)  0.407 ms  0.448 ms  0.501 ms
 4  route-mill.route-enet.net.cam.ac.uk (192.84.5.94)  1.006 ms  1.091 ms  1.163 ms
 5  xe-11-3-0.camb-rbr1.eastern.ja.net (146.97.130.1)  0.300 ms  0.313 ms  0.350 ms
 6  ae24.lowdss-sbr1.ja.net (146.97.37.185)  2.679 ms  2.664 ms  2.712 ms
 7  ae28.londhx-sbr1.ja.net (146.97.33.17)  5.955 ms  5.953 ms  5.901 ms
 8  janet.mx1.lon.uk.geant.net (62.40.124.197)  6.059 ms  6.066 ms  6.052 ms
 9  ae0.mx1.par.fr.geant.net (62.40.98.77)  11.742 ms  11.779 ms  11.724 ms
10  ae1.mx1.mad.es.geant.net (62.40.98.64)  27.751 ms  27.734 ms  27.704 ms
11  mb-so-02-v4.bb.tein3.net (202.179.249.117)  138.296 ms  138.314 ms  138.282 ms
12  sg-so-04-v4.bb.tein3.net (202.179.249.53)  196.303 ms  196.293 ms  196.264 ms
13  th-pr-v4.bb.tein3.net (202.179.249.66)  225.153 ms  225.178 ms  225.196 ms
14  pyt-thairen-to-02-bdr-pyt.uni.net.th (202.29.12.10)  225.163 ms  223.343 ms  223.363 ms
15  202.28.227.126 (202.28.227.126)  241.038 ms  240.941 ms  240.834 ms
16  202.28.221.46 (202.28.221.46)  287.252 ms  287.306 ms  287.282 ms
17  * * *
18  * * *
19  * * *
20  coe-gw.psu.ac.th (202.29.149.70)  241.681 ms  241.715 ms  241.680 ms
21  munnari.OZ.AU (202.29.151.3)  241.610 ms  241.636 ms  241.537 ms
```

trans-continent link

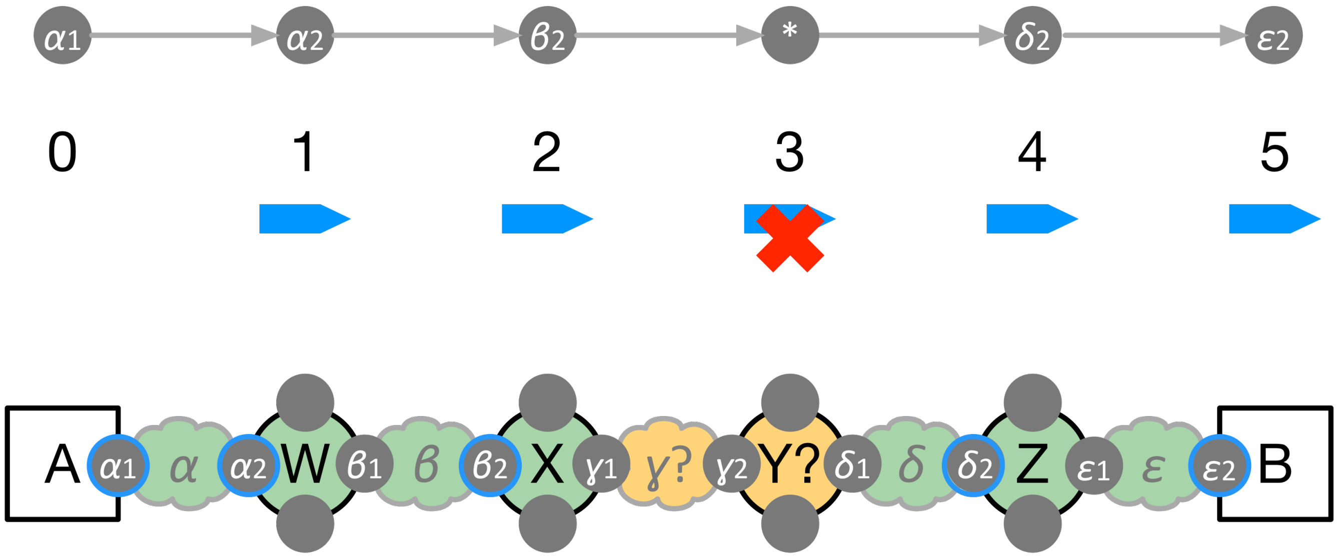
* means no response (probe lost, router not replying)

Traceroute traps – a bit like ping

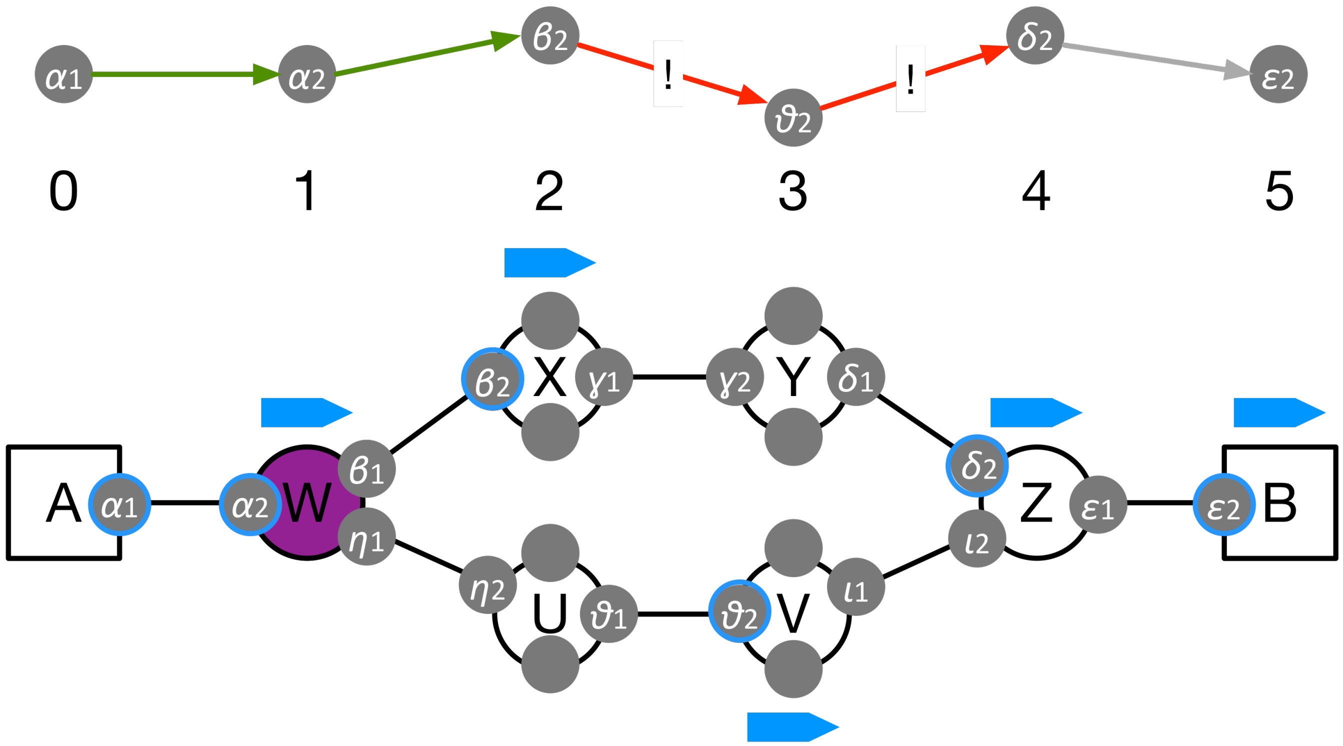
- Uses UDP or ICMP (but traffic is often TCP)
- Might not follow the same path
- Might be filtered
- Only infers one direction of the path
- Replies can be very weird
- One way delay is **not** simply half round trip time (networks may have many paths)

- Learn by doing (try with and without the –I option)

Traceroute doesn't always know



Traceroute lies



Beyond traceroute

- *Paris traceroute*

  Uses many probes to identify multiple paths

  www.paris-traceroute.net

- *Reverse traceroute*

  Uses a remote server to probe reverse path

Link capacity…..

- Recall capacity is a property of where and what we measure
- Nominal network capacity is physical

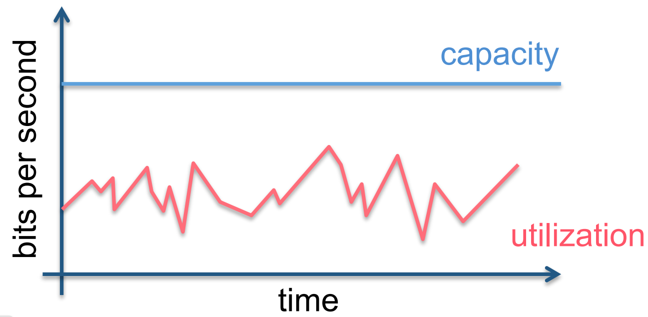
eg 100BaseTX Ethernet: 100 Mbps
WiFi 802.11g: 54 Mbps

- IP-layer capacity < nominal capacity
  - Coding schemes
  - Framing bits, overhead
  - Medium access control

Link capacity & utilization

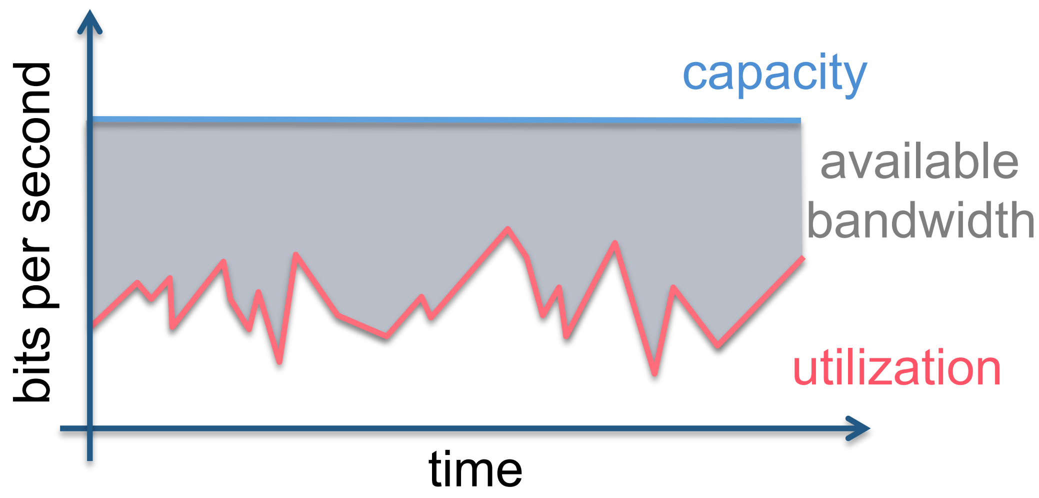
- Link capacity (C(Δt)) ≈ IP-layer capacity
  - Maximum IP-layer rate of maximum-sized packets
  - IP-layer capacity depends on size of packet relative to layer-2 overhead
- Link utilization (u(Δt))
  - u(Δt) = Average bits transmitted on the link during Δt
  - Percent utilization =

% link capacity that is utilized



Available Capacity

- Available bandwidth (A(Δt))
  - Maximum unused bandwidth
  - $A(\Delta t) = C(\Delta t) - u(\Delta t)$



End-to-end capacity and End-to-end effective bandwidth

Router1 -----C1----- Router2 -----C2----- Router

C1: 100 Mbps	C2: 30 Mbps
u1: 80 Mbps	u2: 3 Mbps
A1: 20 Mbps	A2: 27 Mbps

End-to-end capacity: min{C1, C2}=30 Mbps

End-to-end available bandwidth: min{A1, A2}=20 Mbps

Probing method

Flooding

Issue enough probes to "fill" path

- Pro
  - Measure what users can get
- Con
  - Large overhead impacts network and users

Advanced methods

A number of methods in literature:

Packet pair, size-delay, self-induced congestion

- Pro
  - Less overhead than flooding
- Con
  - Rely on assumptions that don't always hold in practice

Effective Bandwidth Measurement

- How much capacity in my network?
  - Is it working at spec.? Am I getting my money's worth?
  - Systems can adapt to change of Effective Bandwidth

Considerations

- TCP versus UDP
  - UDP not biased by congestion/flow control
  - Flooding with UDP may create too much congestion and bias results
  - Multiple TCP connections reduces bias
- Multi-threaded TCP
  - How many threads?
  - Which size transfers?
- UDP
  - How to pick sending rate?

iperf versions and other tools for measuring available bandwidth

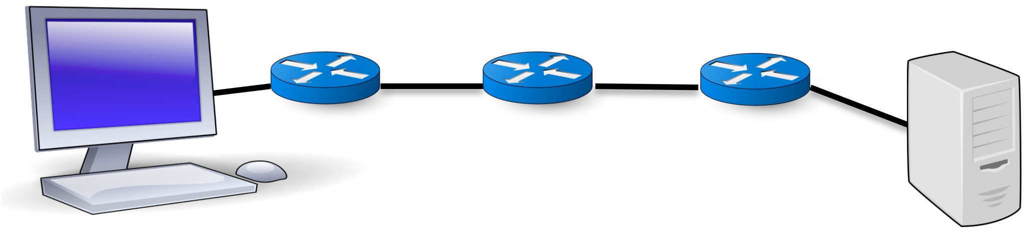
- iperf/iperf3
  - Control of client and server
  - Configurable tests
- iperf2 for UDP
- iperf3 is a rewrite with different/improved TCP

Others: eg.

- NetPerf is yet another TCP and UDP tool
  - NetPerf implicitly codes ideas of confidence, sample size, etc.

iperf Vantage points

- Runs application at both client and server



source:
iperf client
`iperf -c server`

destination:
iperf server
`iperf -s`

An Example *iperf* Output

```
$ iperf3 -u -t 10 -b 100Mbit --get-server-output -c 192.168.1.174
Connecting to host 192.168.1.174, port 5201
[  4] local 192.168.1.231 port 51069 connected to 192.168.1.174 port 5201
[ ID] Interval           Transfer     Bandwidth       Total Datagrams
[  4]   0.00-1.00   sec  10.8 MBytes  90.2 Mbits/sec  1379
                :
[  4]   9.00-10.00  sec  12.0 MBytes   100 Mbits/sec  1532
- - - - - - - - - - - - - - - - - - - - - - - - -
[ ID] Interval           Transfer     Bandwidth       Jitter    Lost/Total Datagrams
[  4]   0.00-10.00  sec   118 MBytes  99.0 Mbits/sec  0.839 ms  2034/15114 (13%)
[  4] Sent 15114 datagrams

Server output:
Accepted connection from 192.168.1.231, port 58542
[  5] local 192.168.1.174 port 5201 connected to 192.168.1.231 port 51069
[  5]   0.00-1.00   sec  7.05 MBytes  59.2 Mbits/sec  1.190 ms  226/1129 (20%)
                :
[  5]   9.00-10.00  sec  11.4 MBytes  95.9 Mbits/sec  2.670 ms  74/1537 (4.8%)
```

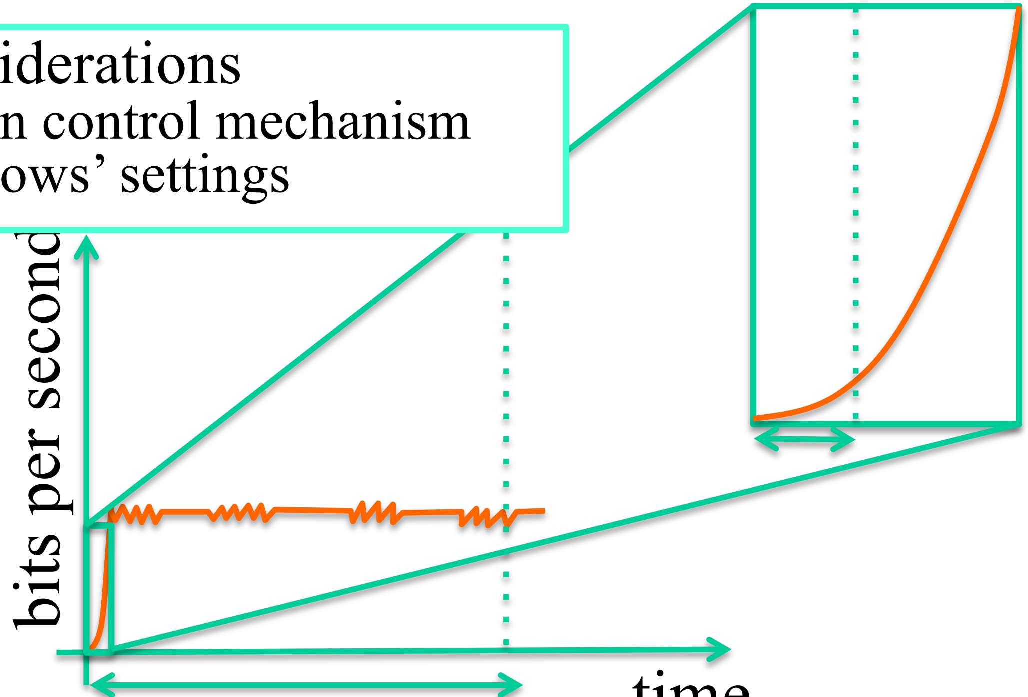
Effective bandwidth traps or

how to do *Effective* effective-bandwidth measurement

- Bulk transfer capacity depends on many factors
- Transfer size
- TCP variant and configuration
- Cross traffic
- Congestion on reverse (ACK) path

Consideration: Transfer size

Other considerations
- Congestion control mechanism
- TCP windows' settings



Too small mainly measures slow start

Too large creates unnecessary overhead

Thanks to Renata Teixera for inspiring this slide

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Conclusion and Compromise

- Identify what you want to measure (why?)
- Consider the hidden model of measurement
  - (independence, statistical validity, known and unknown)
- 75% functional is better than 0% perfect
  - Even better if you know/acknowledge/show the error