# Computer Networks
# COL 334/672

Measuring Internet

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# Recap

- Structure of the Internet

- Various network services required for data transmission

- Layered Internet architecture

- **This class: How do we measure the performance of a network?**

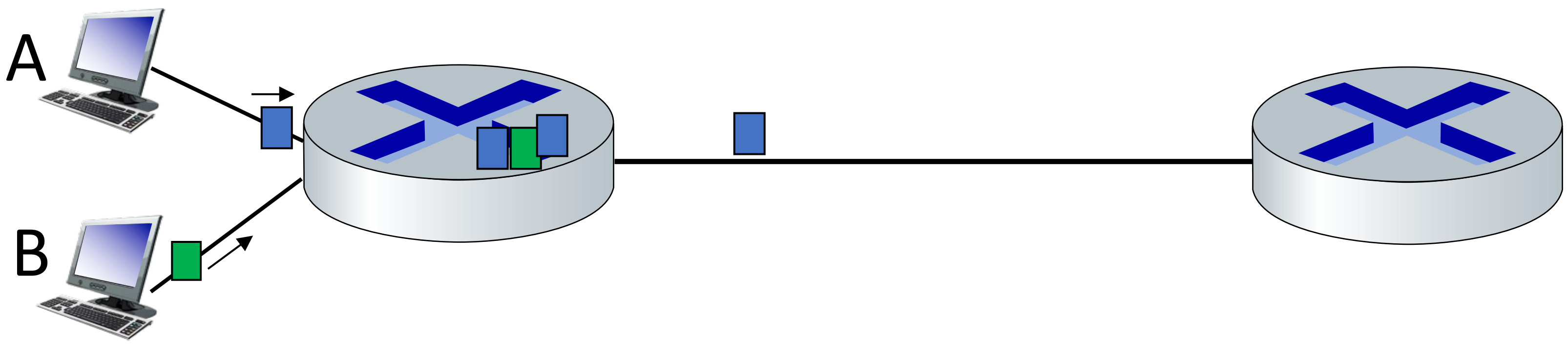
  Why? ***You can't improve what you can't measure***

# How would you characterize a network performance?

How fast you can send data over the network

- Latency or delay
- Loss
- Bandwidth

# Sources of packet delay




$d_{nodal}$ =

$d_{prop}$: propagation delay:

*time taken for the signal to reach its destination*

- $d$: length of physical link
- $s$: propagation speed ($\sim 2\text{x}10^8$ m/sec)
- $d_{prop} = d/s$

$d_{proc}$: nodal processing

- check bit errors
- determine output link
- typically < microsecs

$d_{queue}$: queueing delay

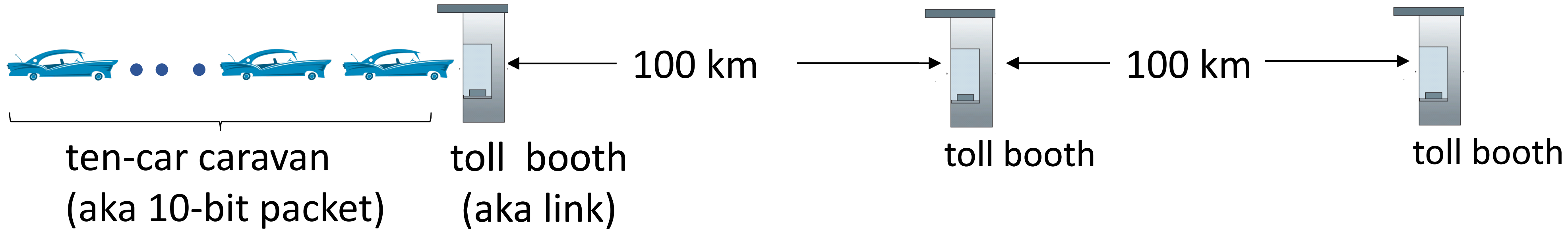
- time waiting at output link for transmission
- depends on congestion level of router

$d_{trans}$: transmission delay:

*time taken to transmit the packet from host to the link*

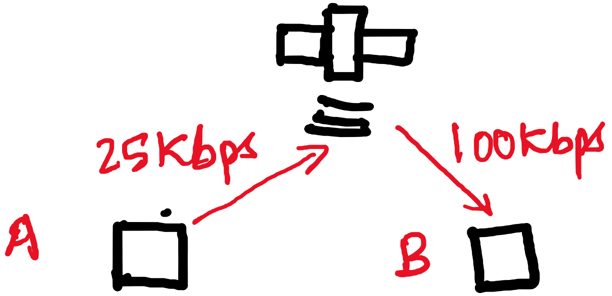
- $L$: packet length (bits)
- $R$: link *transmission rate (bps)*
- $d_{trans} = L/R$

# Caravan analogy




- car ~ bit; caravan ~ packet; toll service ~ link transmission
- toll booth takes 12 sec to service car (bit transmission time)
- "propagate" at 100 km/hr
- *Q:* How long until caravan is lined up before 2nd toll booth?
- time to "push" entire caravan through toll booth onto highway = 12*10 = 120 sec
- time for last car to propagate from 1st to 2nd toll both: 100km/(100km/hr) = 1 hr
- *A:* 62 minutes

# Problem




d = 30,000 km

packet size = 1000 bytes

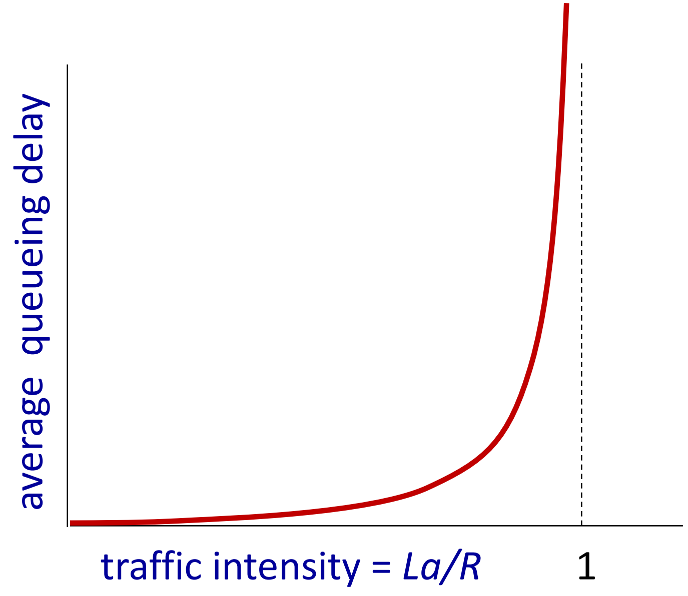
signal speed = $3 \times 10^8$ m/s

Q: How long does it take to send a packet from A to B?

# Packet queueing delay (revisited)

- *a:* average packet arrival rate
- *L:* packet length (bits)
- *R:* link bandwidth (bit transmission rate)

$$\frac{L \cdot a}{R} : \frac{\text{arrival rate of bits}}{\text{service rate of bits}}$$ *"traffic intensity"*




- *La/R* ~ 0: avg. queueing delay small
- *La/R* -> 1: avg. queueing delay large
- *La/R* > 1: more "work" arriving is more than can be serviced - average delay infinite!


*La/R* ~ 0


*La/R -> 1*

# Packet queueing delay (revisited)

- *a:* average pacl
- *L:* packet lengt
- *R:* link bandwic

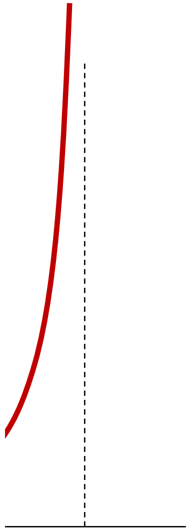
$\frac{L \cdot a}{R}$ : $\frac{\text{arrival}}{\text{service}}$

- *La/R* ~ 0: avg
- *La/R* -> 1: av
- *La/R* > 1: mo more than ca delay infinite

# Balaji Prabhakar: Can digital incentives help alleviate traffic?

Researchers are reducing traffic congestion and commute times using networks that gently nudge people toward better travel habits.

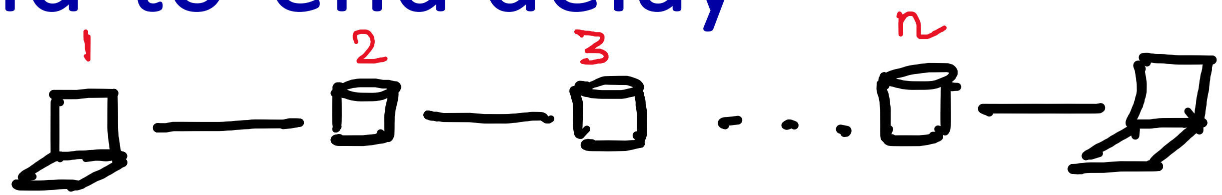
He calls it "nudging," and says that small shifts in commute times — just 20 minutes earlier or later — can make a considerable impact on the day's congestion in highly trafficked urban areas, like San Francisco.




~ 0

*La/R -> 1*

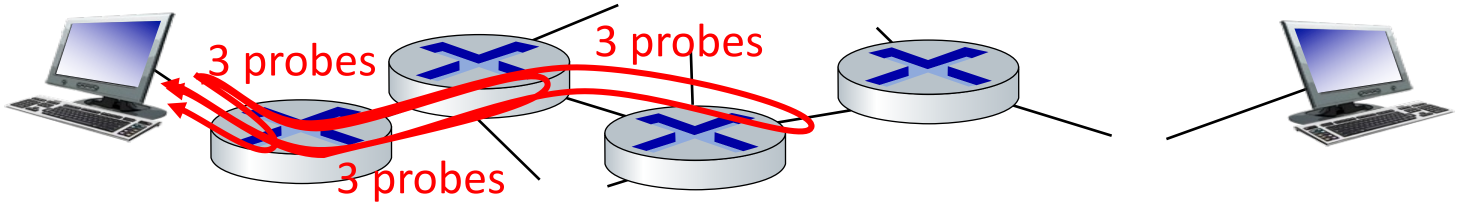
# End-to-end delay




- What is end-to-end delay?
- One-way delay vs round-trip time
- Delay-jitter

# How do you measure delay on network?

- **Network operator:** directly query each router in the network (e.g., using SNMP protocol)
- **End user:** various utilities
  - **ping**
  - **traceroute** program: provides delay measurement from source to router along end-end Internet path towards destination. For all *i:*
    - sends three packets that will reach router *i* on path towards destination (with time-to-live field value of *i*)
    - router *i* will return packets to sender
    - sender measures time interval between transmission and reply



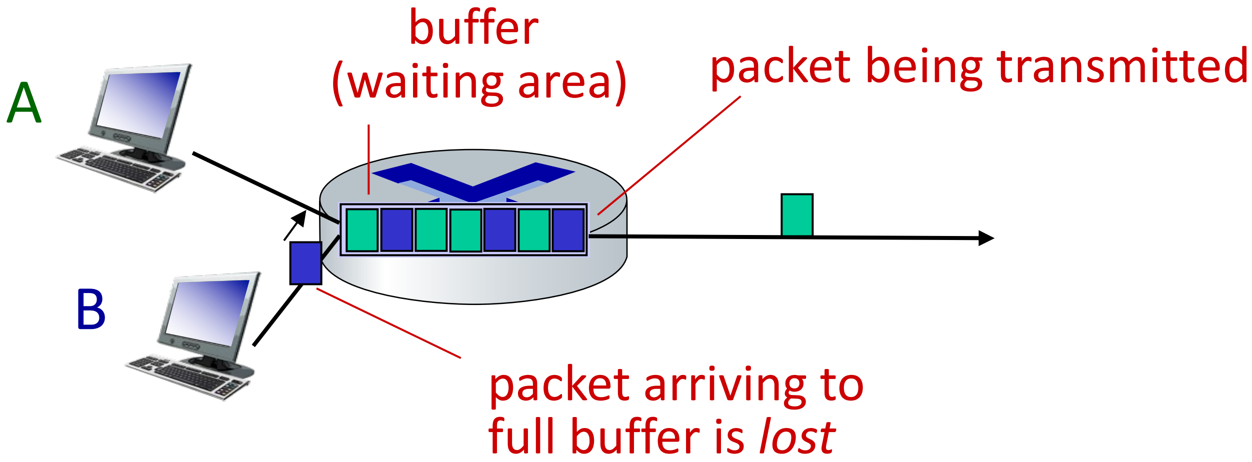
# Real Internet delays and routes

## traceroute: airtel network to olympics.com

```
traceroute to olympics.com (23.58.93.83), 64 hops max, 52 byte packets
 1  dsldevice.lan (192.168.1.1)  3.793 ms  6.097 ms  2.330 ms
 2  abts-north-dynamic-255.187.69.182.airtelbroadband.in (182.69.187.255)  7.155 ms  4.828 ms  5.167 ms
 3  125.18.240.149 (125.18.240.149)  94.428 ms
    125.18.240.153 (125.18.240.153)  6.395 ms
    125.18.240.149 (125.18.240.149)  6.126 ms
 4  182.79.208.12 (182.79.208.12)  6.186 ms
    116.119.109.0 (116.119.109.0)  5.822 ms  6.520 ms
 5  a23-58-93-83.deploy.static.akamaitechnologies.com (23.58.93.83)  5.946 ms  7.018 ms  4.783 ms
```

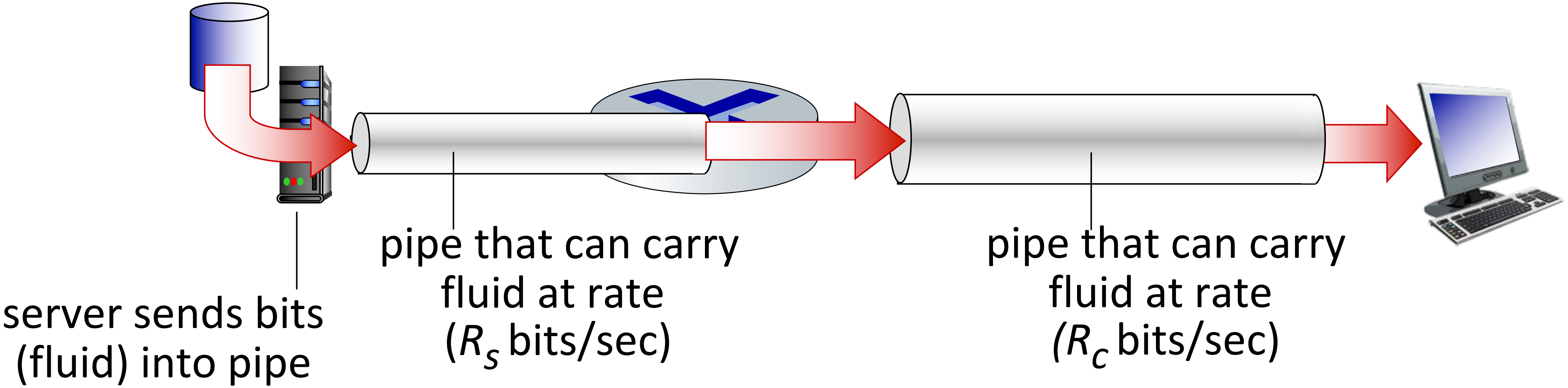
# Packet loss

- queue (aka buffer) preceding link in buffer has finite capacity
- packet arriving to full queue dropped (aka lost)
- lost packet may be retransmitted by previous node, by source end system, or not at all
- Typically measured as the percentage of total packets sent



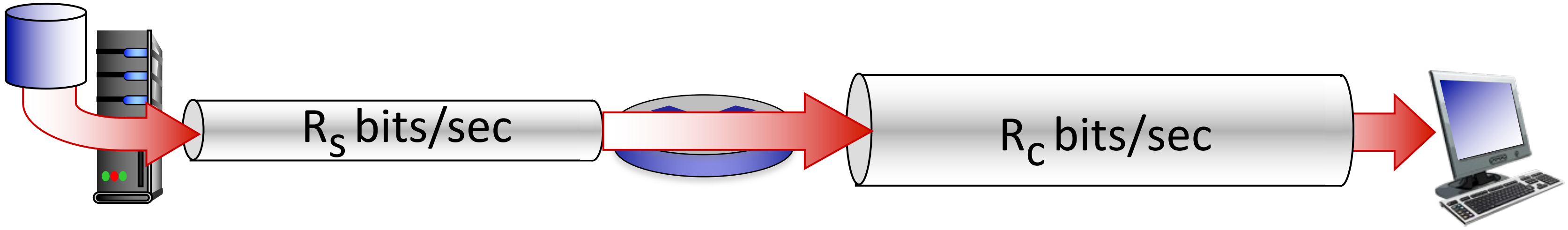
# Throughput

- *throughput:* rate (bits/time unit) at which bits are being sent from sender to receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time



# Throughput

$R_s < R_c$ What is average end-end throughput?

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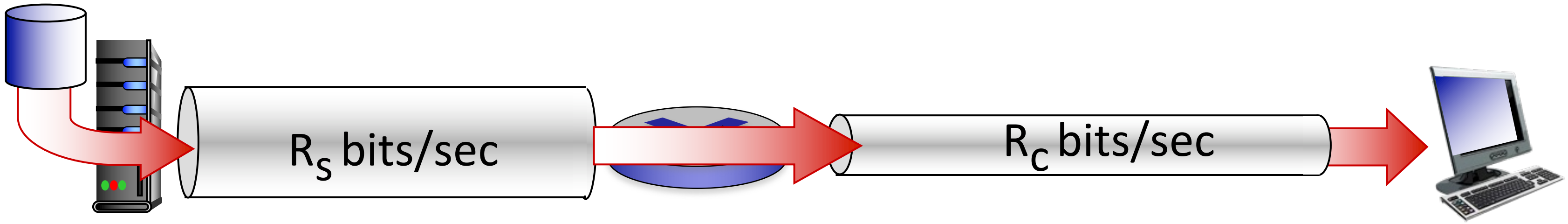
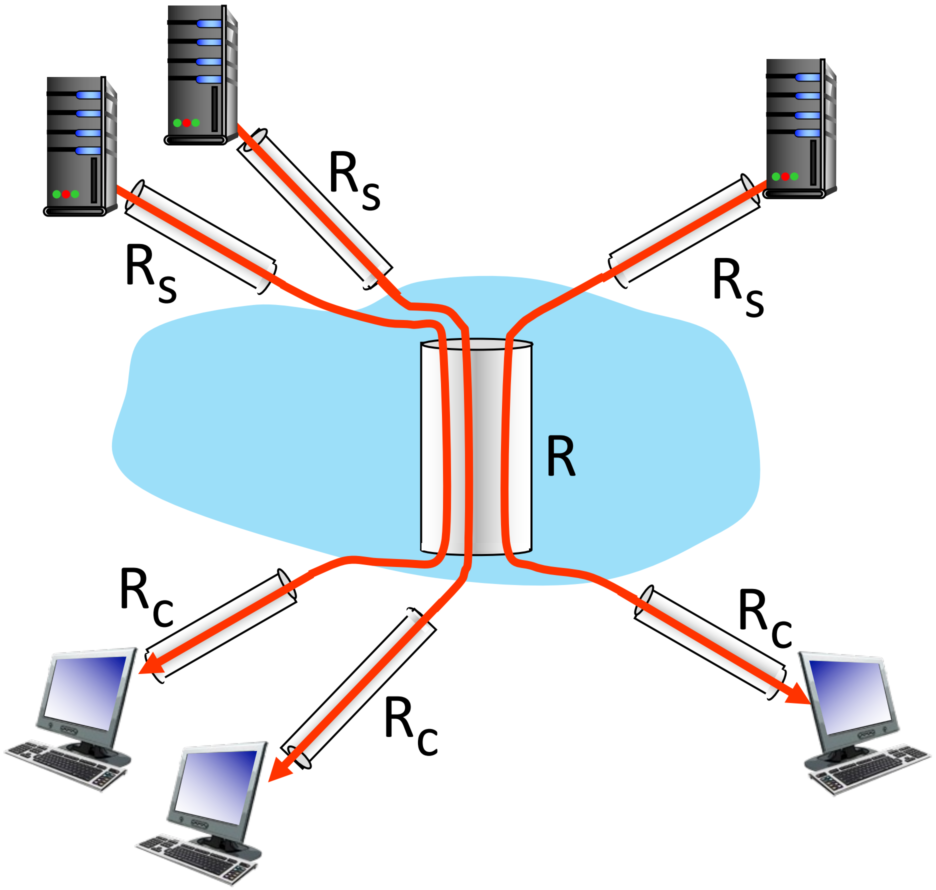



*bottleneck link*

link on end-end path that constrains end-end throughput

# Throughput: network scenario




10 connections (fairly) share backbone bottleneck link *R* bits/sec

- per-connection end-end throughput: $min(R_c,R_s,R/10)$
- in practice: $R_c$ or $R_s$ is often bottleneck

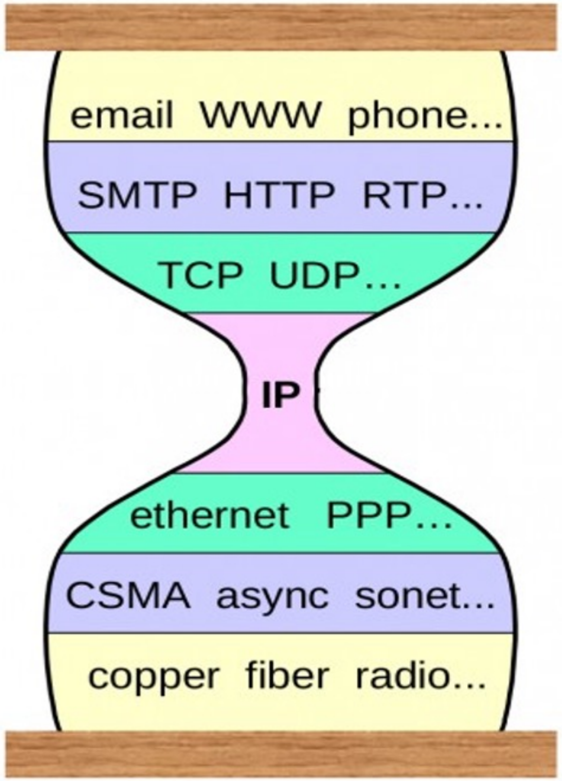
# Summary

- Network performance metrics
  - Delay
  - Loss
  - Throughput

- How are these used by different stakeholders?
  - Designers: efficacy of protocols
  - Operators: capacity planning and network management
  - Regulators: policymaking

# Next Classes

| Topic | Sub-topics |
|---|---|
| Link layer | MAC protocol, switching, error detection/correction |
| Network layer | Forwarding and routing, data plane, control plane |
| Transport layer | Multiplexing, UDP, TCP, flow and congestion control |
| Application layer | Distributed application paradigm, DNS, HTTP, Email, CDN, video streaming and conferencing |




Internet hourglass structure