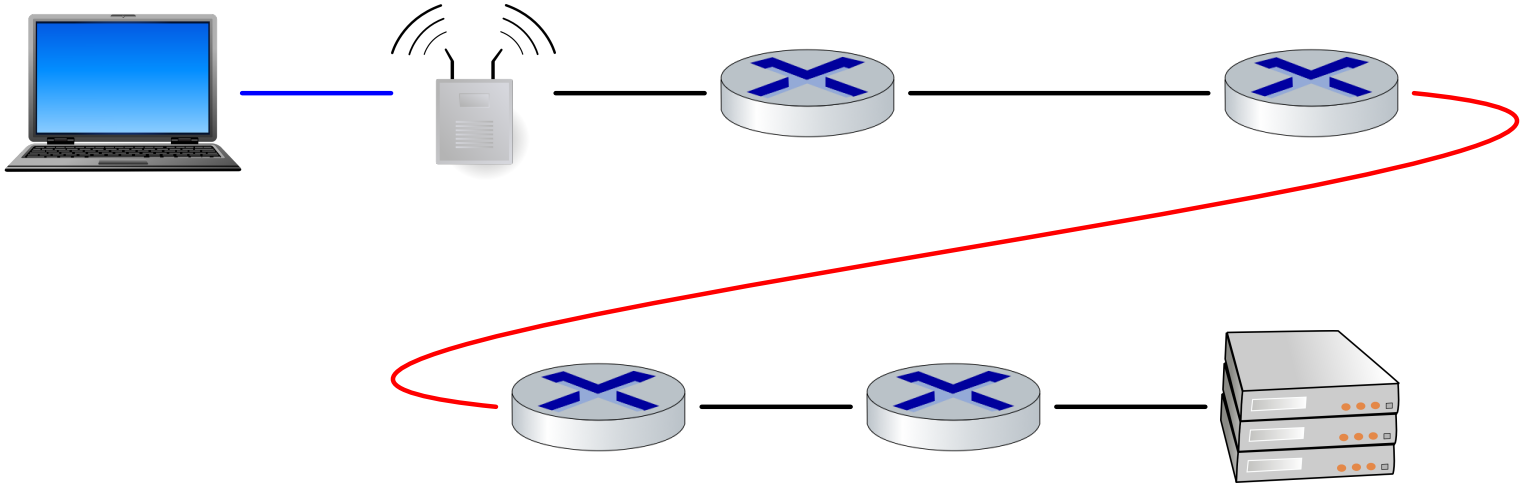
How Long Will It Take to Get a Response?



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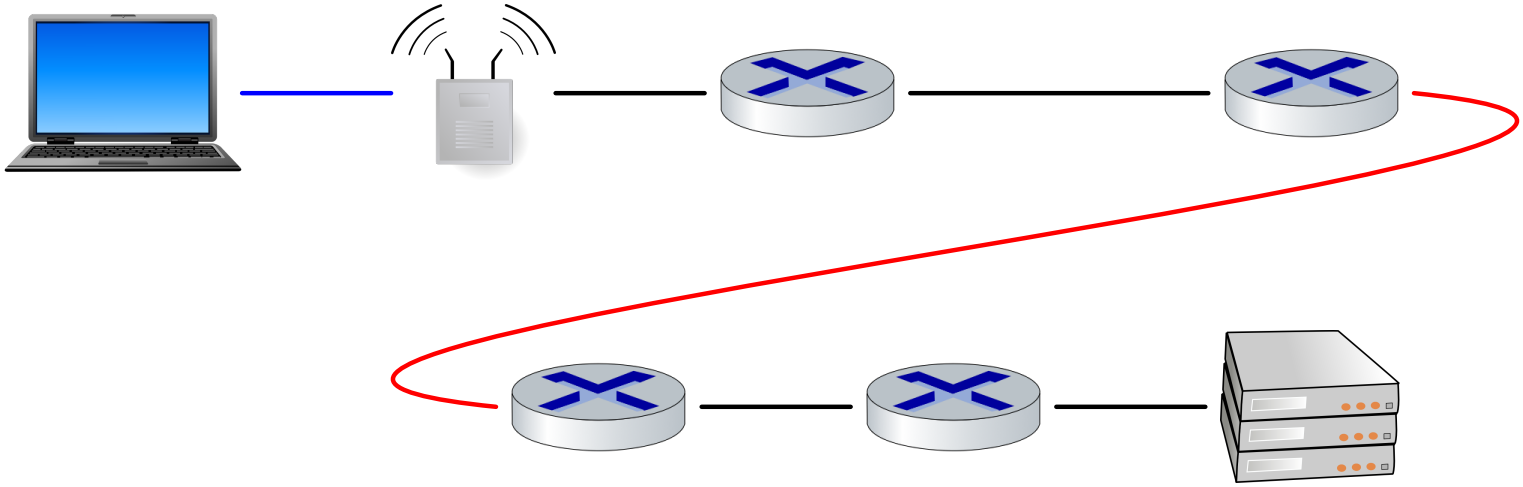

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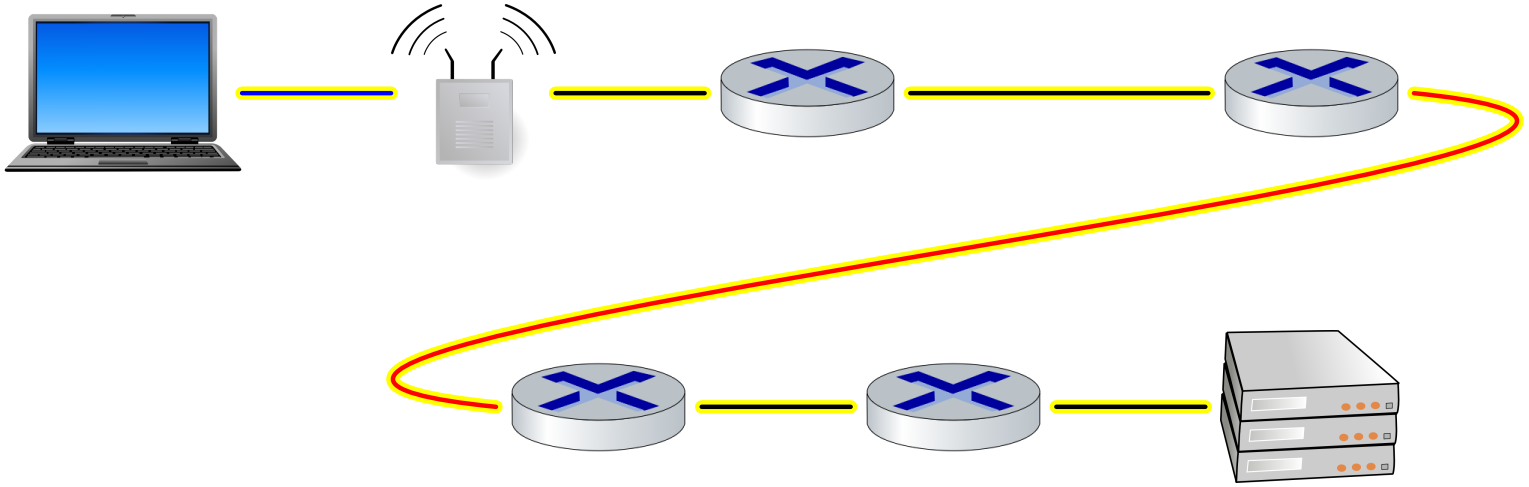
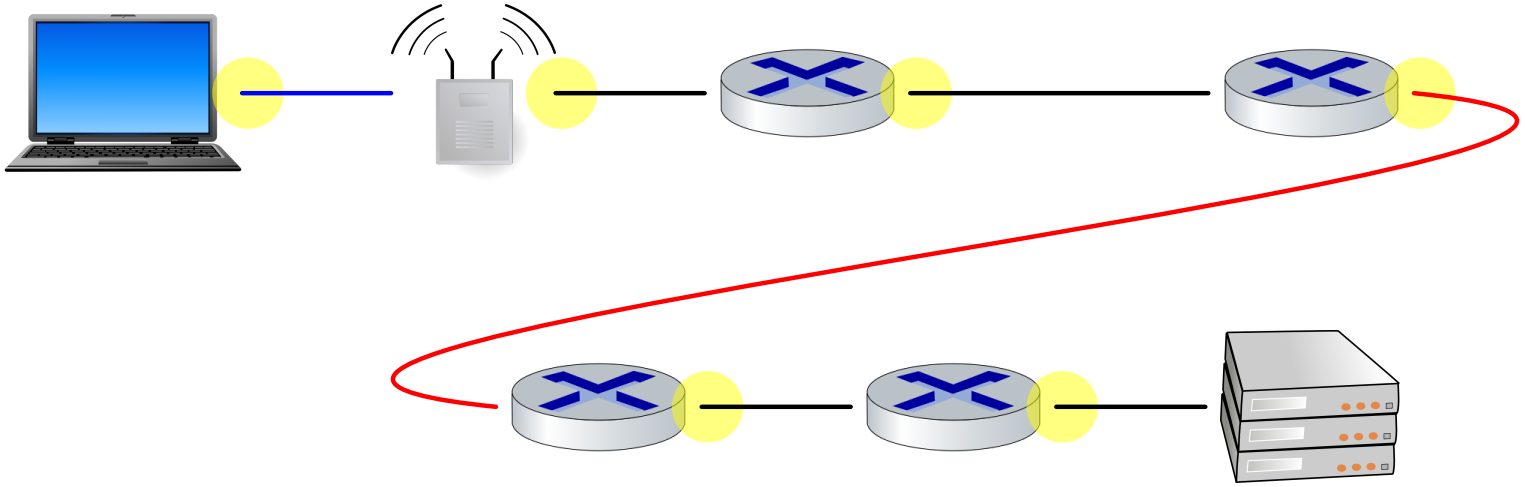


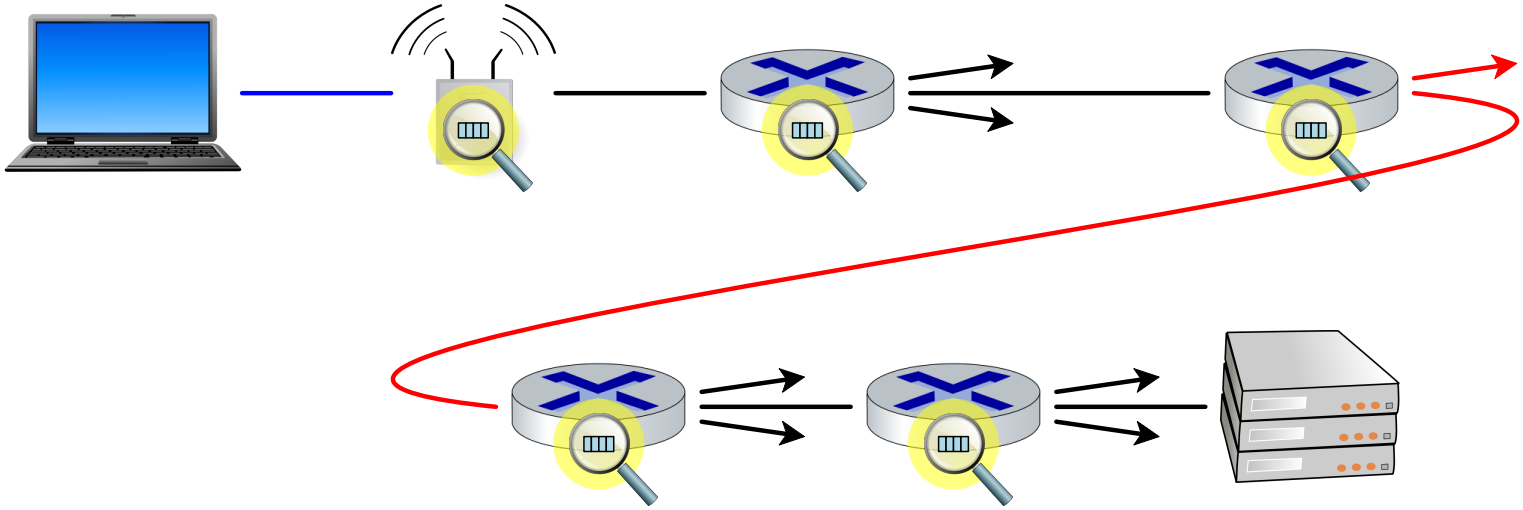
propagation delay

How Long Will It Take to Get a Response?



transmission delay

How Long Will It Take to Get a Response?



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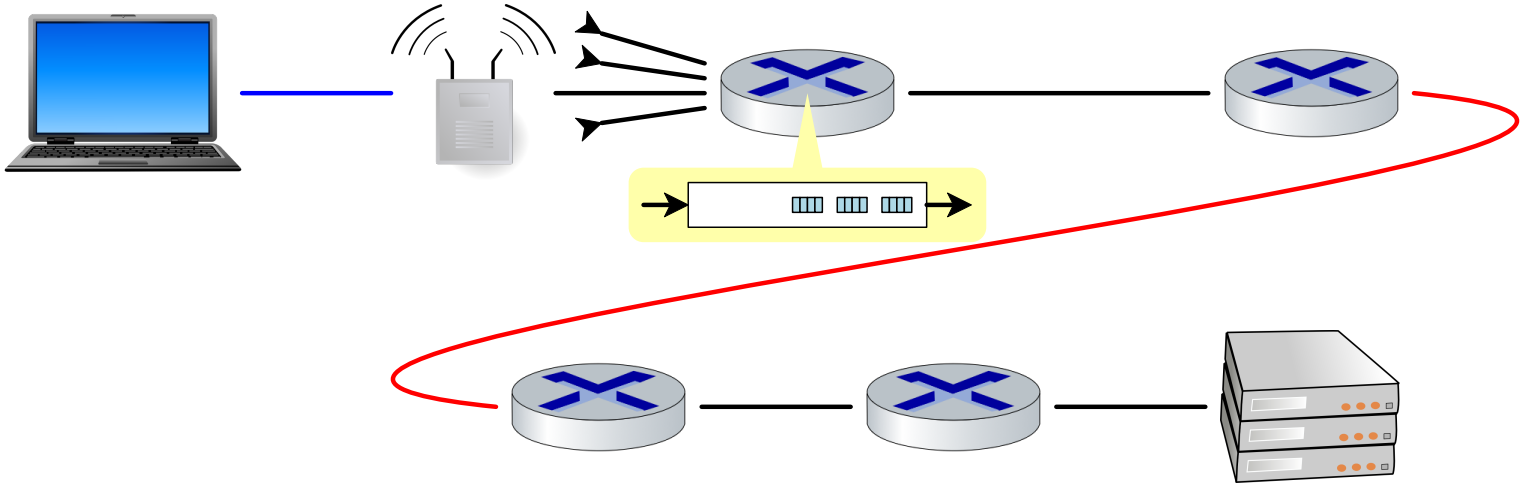
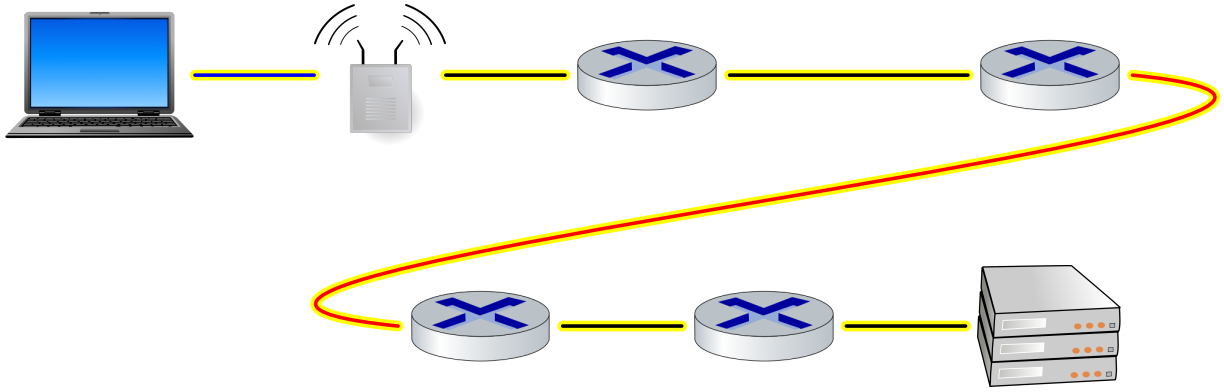


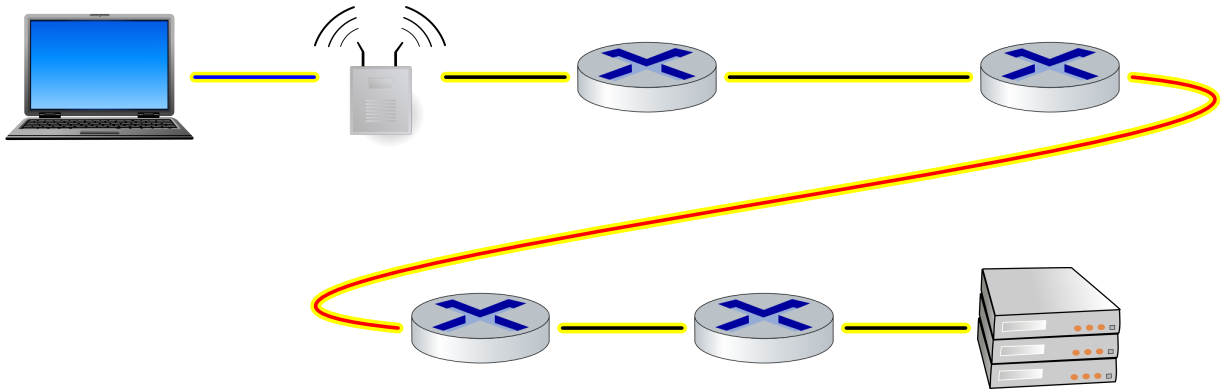
queueing delay

Propagation Delay



Time to travel along medium

Propagation Delay

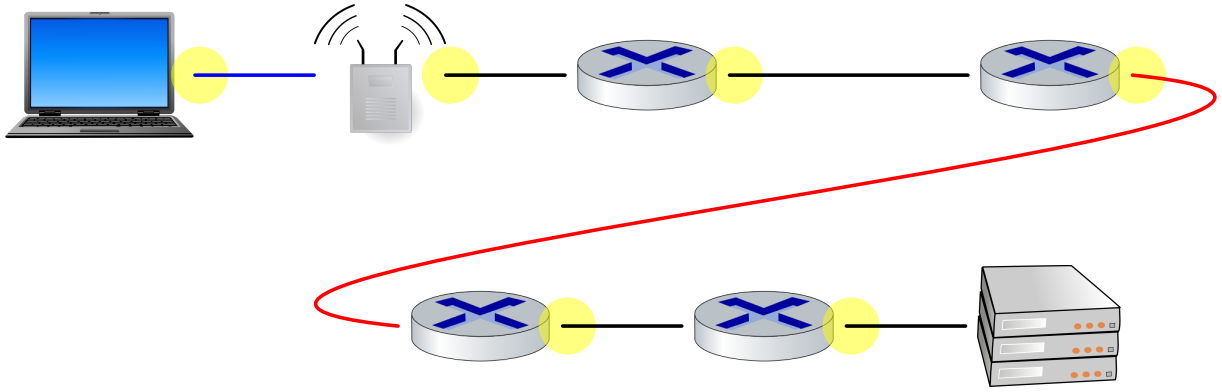


Time to travel along medium, depends on physics

- distance travelled
- speed of link — some fraction of the speed of light

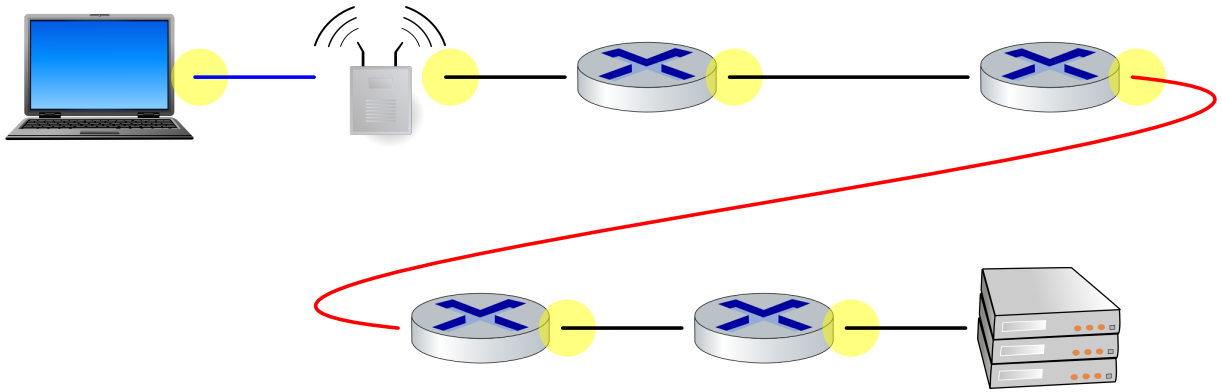
$$delay_{propagation} = \frac{scale \times distance}{speed\ of\ light}$$

Transmission Delay



Time to convert from bytes to medium

Transmission Delay

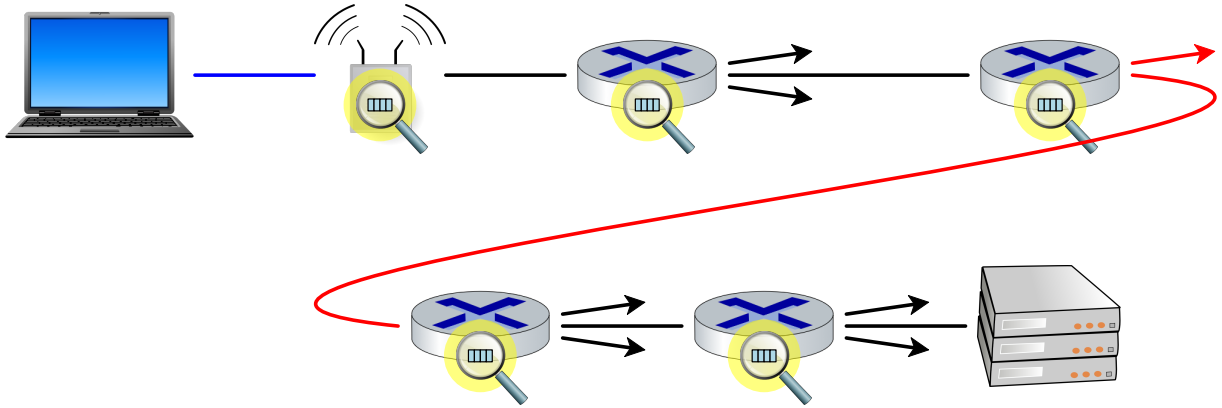


Time to convert from bytes to medium, depends on device and data

- device rate *R*
  - fiber, ethernet: 1-400 Gbps
  - WiFi: 54 Gbps
  - dial-up: 56.6 Kbps
- packet size

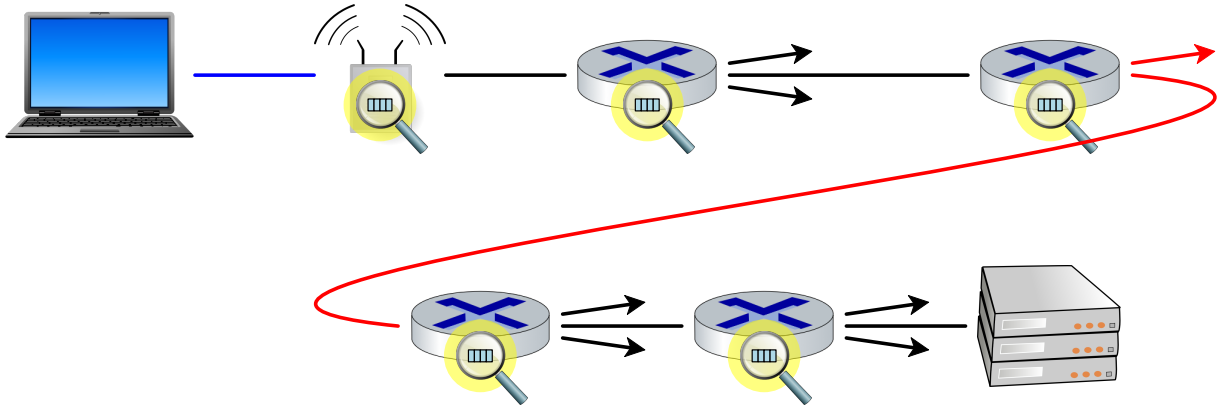
$$delay_{transmission} = \frac{size}{R}$$

Processing Delay



Time to inspect bytes and choose next step

Processing Delay

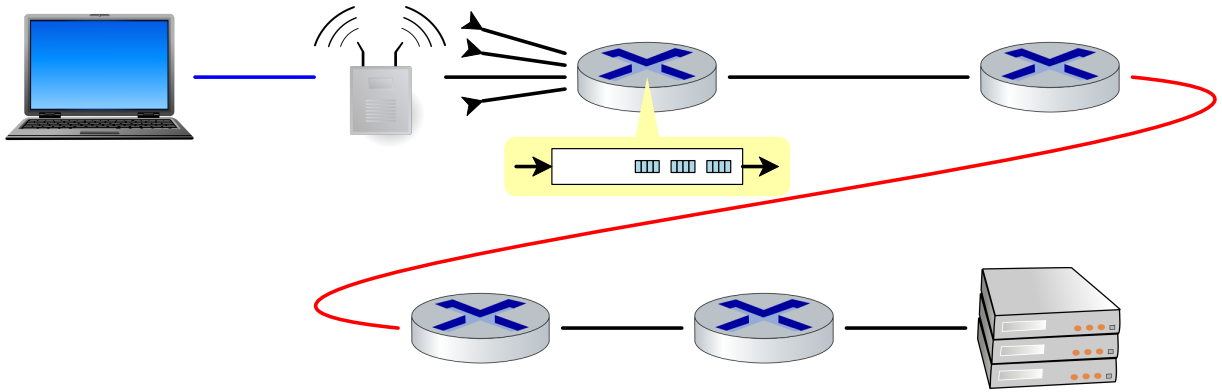


Time to inspect bytes and choose next step, depends on device speed

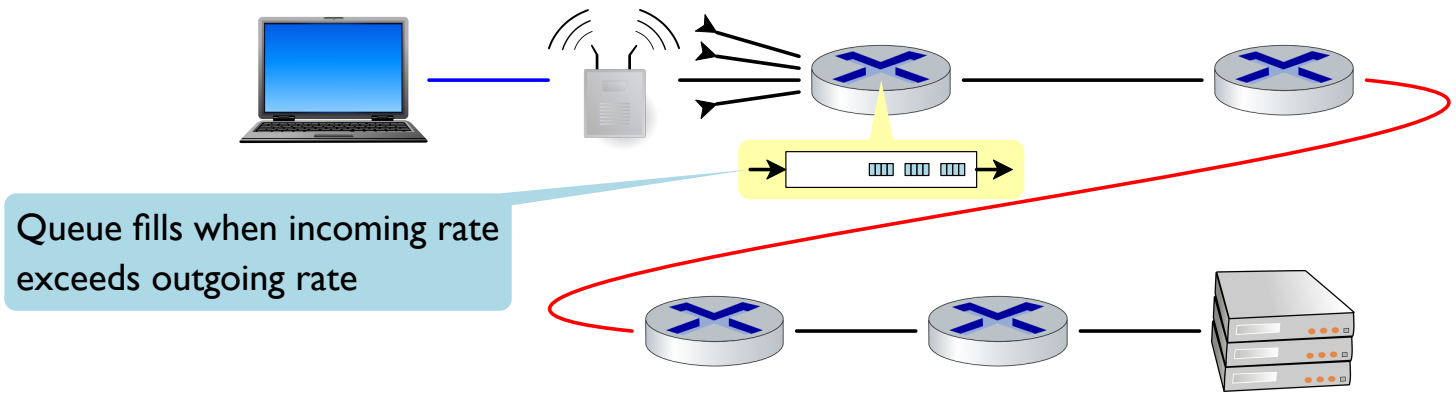
Typically a few nanoseconds, so we ignore it

$$delay_{processing} = 0$$

Queueing Delay

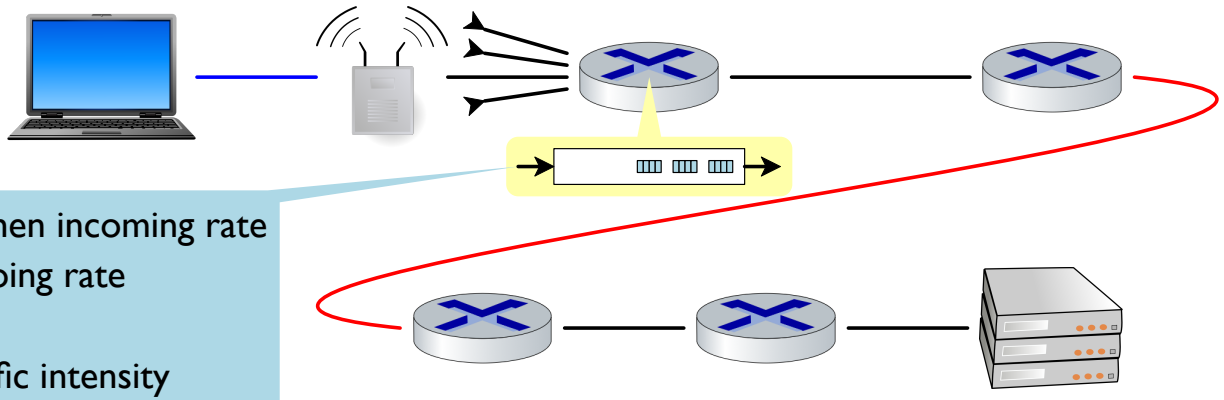


Queueing Delay



Queue fills when incoming rate exceeds outgoing rate

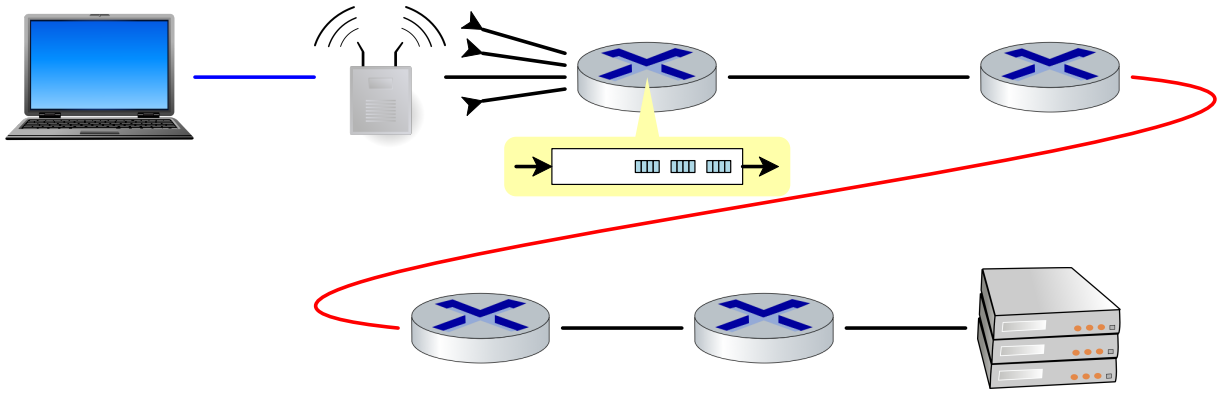
Queueing Delay



Queue fills when incoming rate exceeds outgoing rate

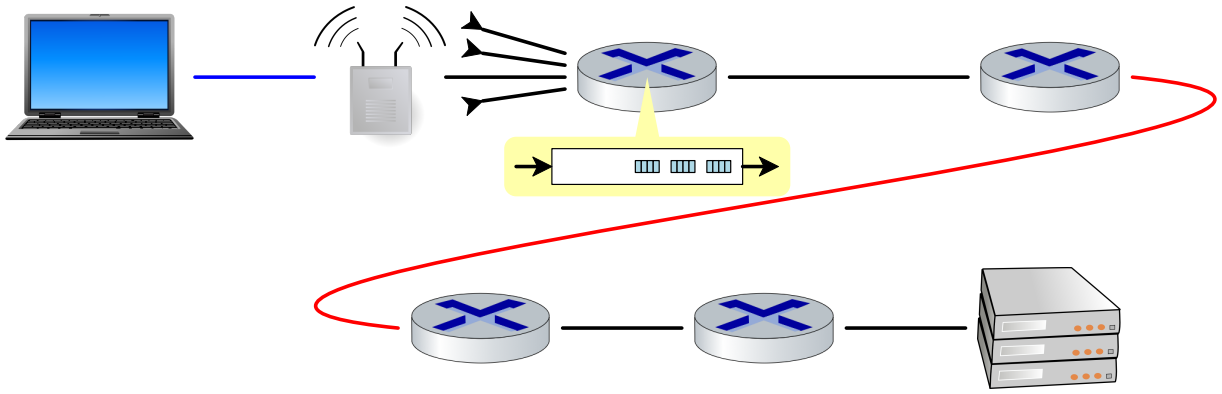
Sustained traffic intensity
⇒ packets get dropped

Queueing Delay



Time packets bytes are held in a queue

Queueing Delay



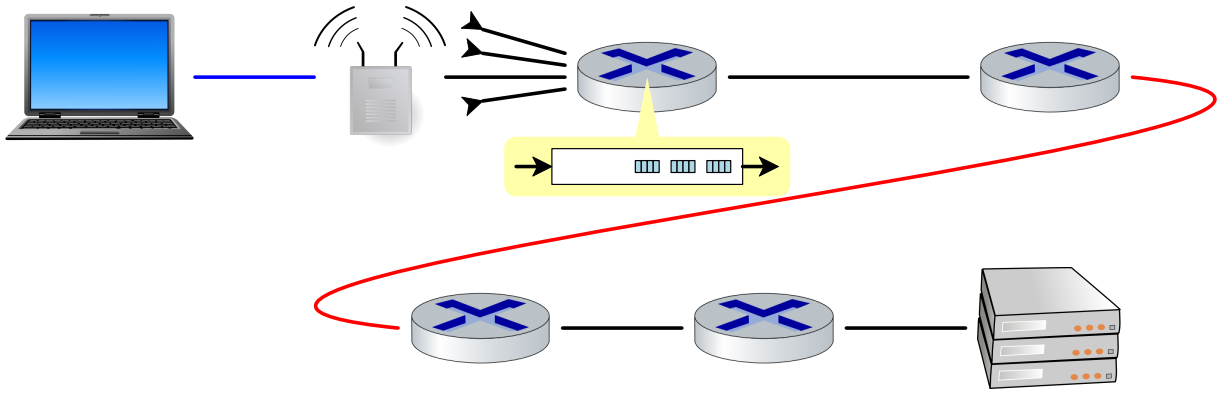
Time packets bytes are held in a queue, depends on traffic

$$\textit{incoming data rate} = \textit{average packet size} \times \textit{incoming packet rate}$$

$$\textit{traffic intensity} = \frac{\textit{incoming data rate}}{R}$$

$$\textit{traffic intensity} \leq 1 \Rightarrow \text{no delay}$$

Queueing Delay



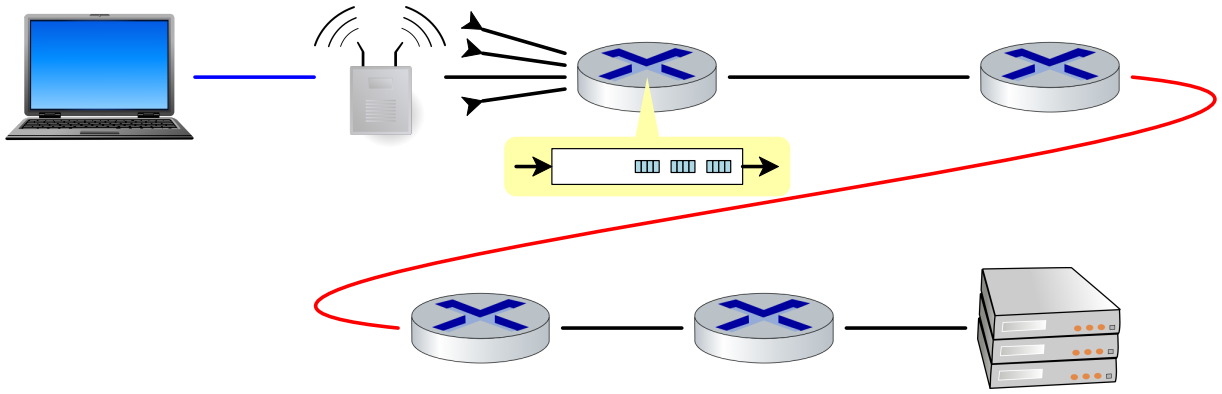
Time packets bytes are held in a queue, depends on traffic

$$incoming\ data\ rate = average\ packet\ size \times incoming\ packet\ rate$$

$$traffic\ intensity = \frac{incoming\ data\ rate}{R}$$

$$traffic\ intensity > 1 \Rightarrow \text{delay growing}$$

Queueing Delay



Time packets bytes are held in a queue, depends on traffic

$$delay_{queue} = ???$$

Total Delay

$$delay = delay_{\text{propagation}} + delay_{\text{transmission}} + delay_{\text{processing}} + delay_{\text{queueing}}$$

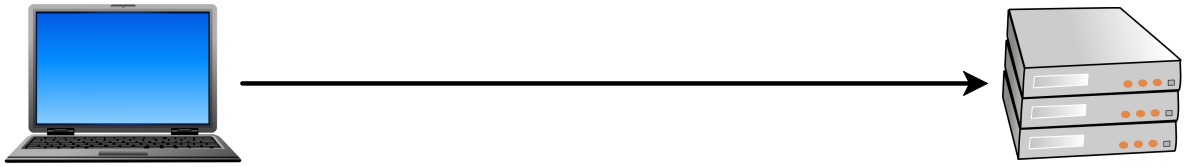
$$delay_{propagation} = \frac{scale \times distance}{speed\ of\ light}$$

$$delay_{transmission} = \frac{size}{R}$$

$$delay_{processing} = 0$$

$$delay_{queue} = ???$$

What Can We Measure?



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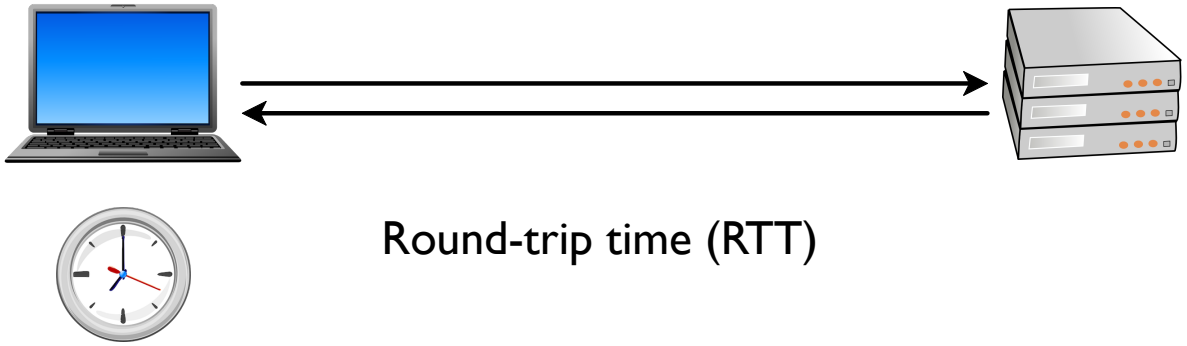
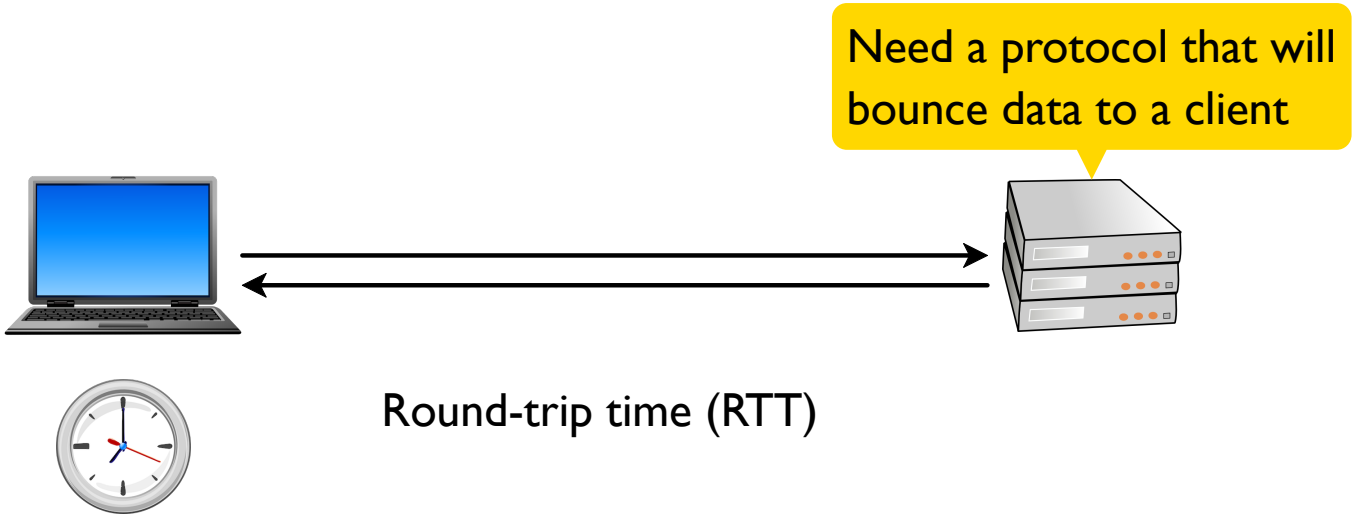


Round-trip time (RTT)

What Can We Measure?



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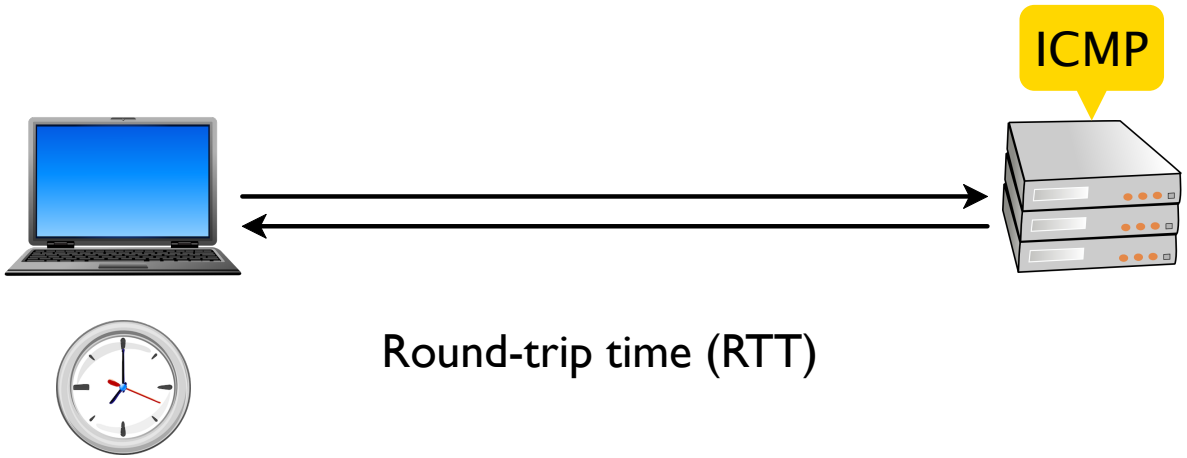

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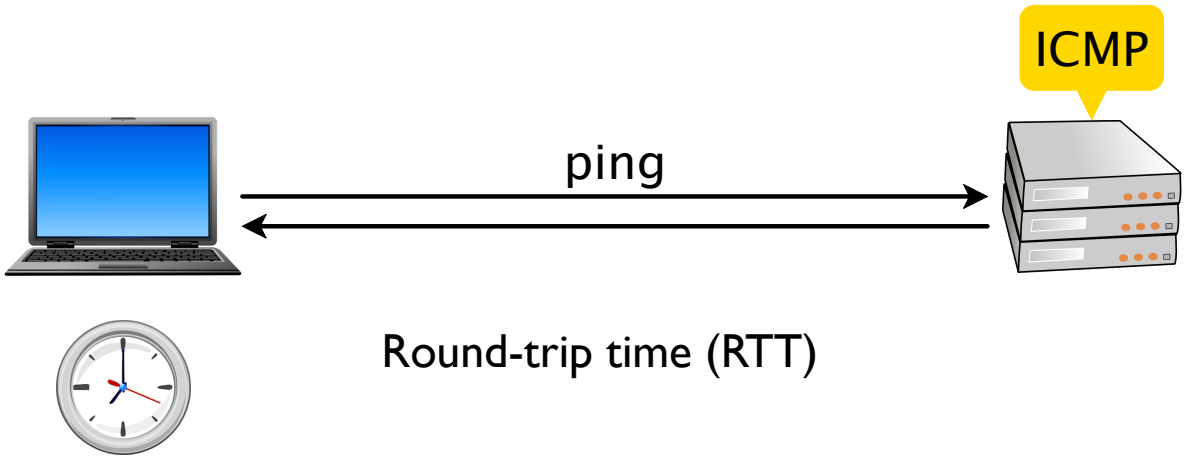
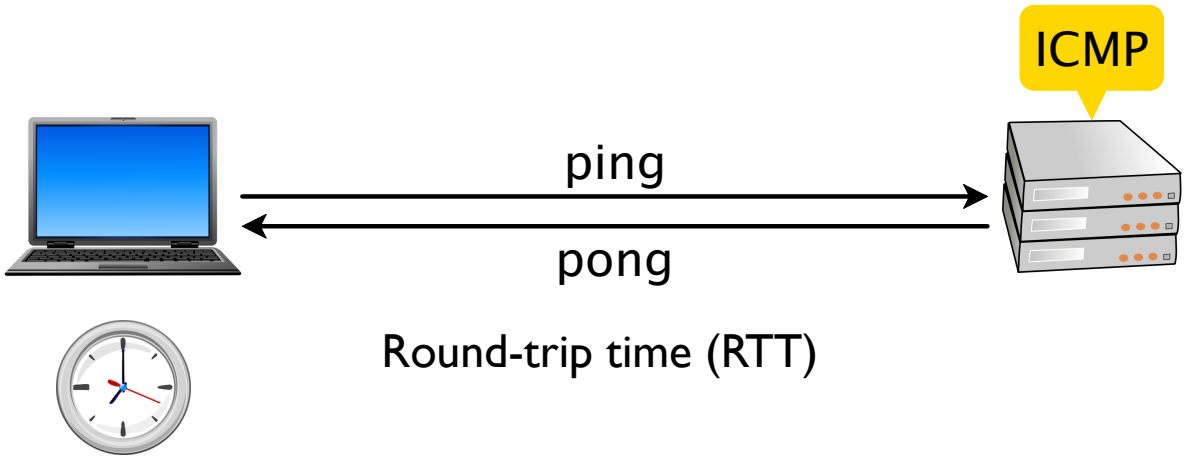


What Can We Measure?



Round-trip time (RTT)

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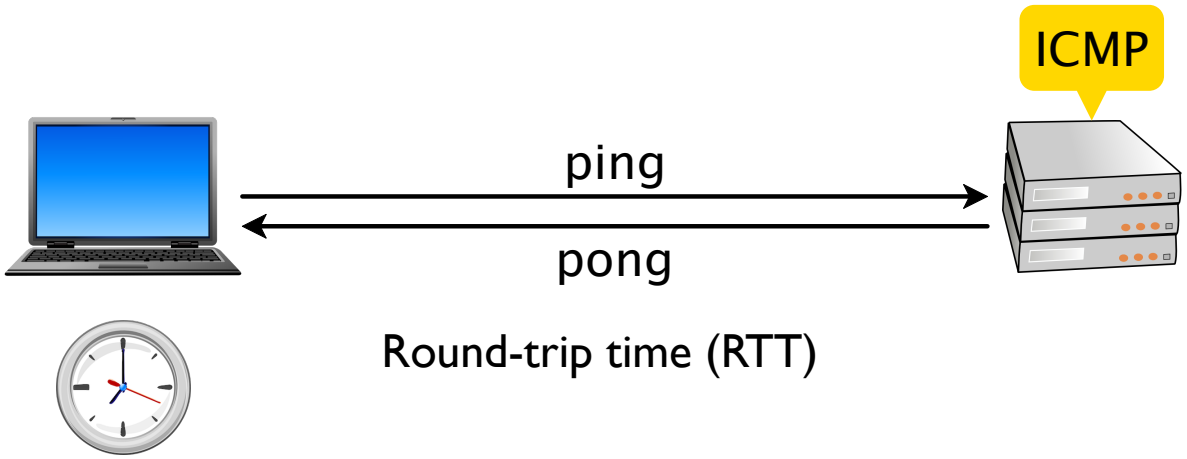
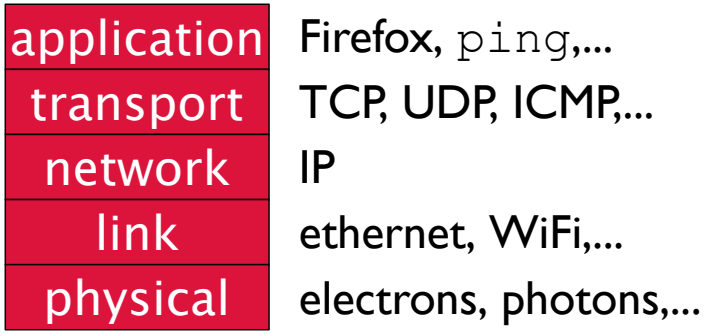


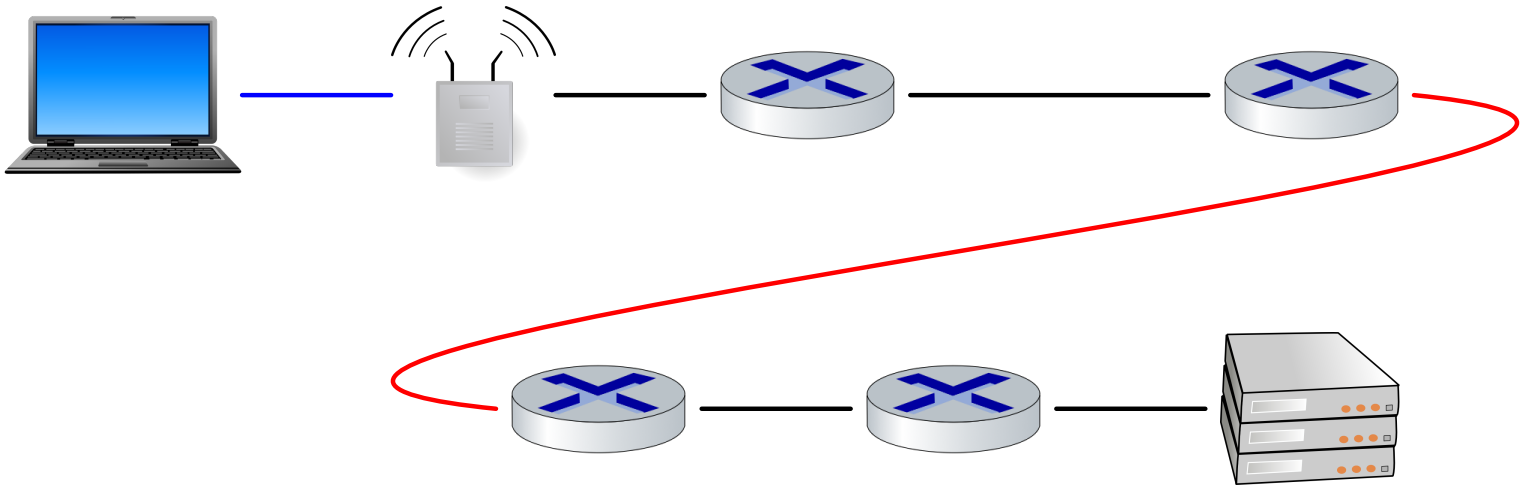
Round-trip time (RTT)

Run as the `ping` command

```
laptop$ ping www.cs.utah.edu
PING wp.wpenginepowered.com (141.193.213.10): 56 data bytes
64 bytes from 141.193.213.10: icmp_seq=0 ttl=51 time=35.962 ms
64 bytes from 141.193.213.10: icmp_seq=1 ttl=51 time=28.266 ms
64 bytes from 141.193.213.10: icmp_seq=2 ttl=51 time=34.257 ms
64 bytes from 141.193.213.10: icmp_seq=3 ttl=51 time=37.075 ms
64 bytes from 141.193.213.10: icmp_seq=4 ttl=51 time=135.983 ms
^C
--- wp.wpenginepowered.com ping statistics ---
5 packets transmitted, 5 packets received, 0.0% packet loss
round-trip min/avg/max/stddev = 28.266/54.309/135.983/40.950 ms
```


application
transport
network
link
physical
Firefox, ping,...
TCP, UDP, ICMP,...
IP
ethernet, WiFi,...
electrons, photons,...

Can We Get Any Information About a Route?



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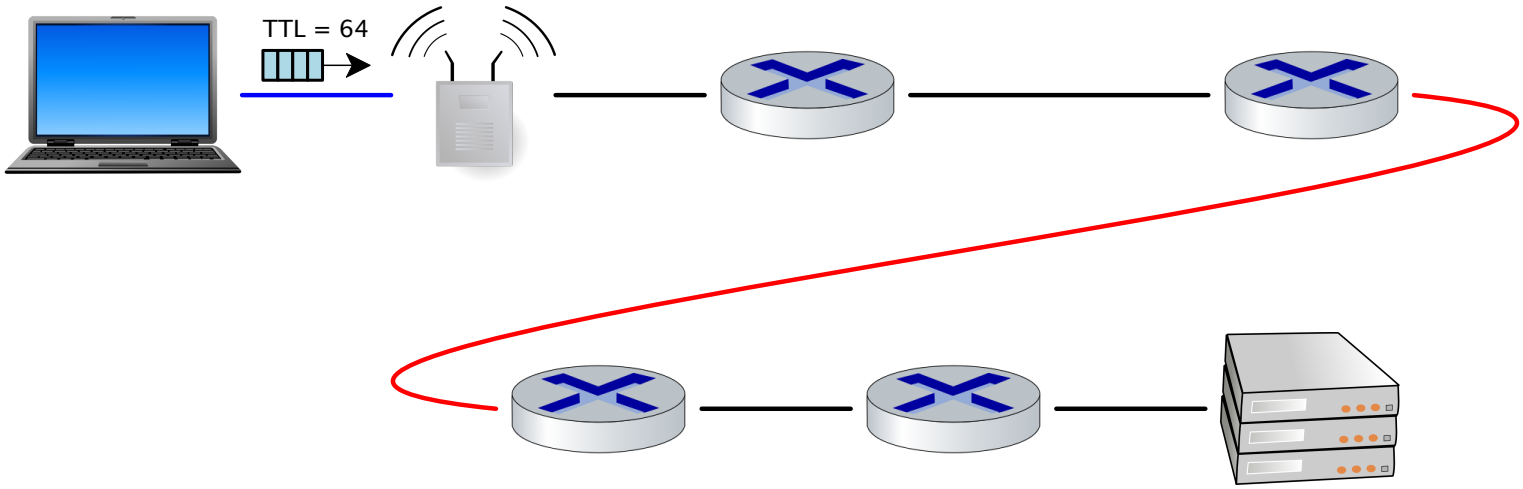

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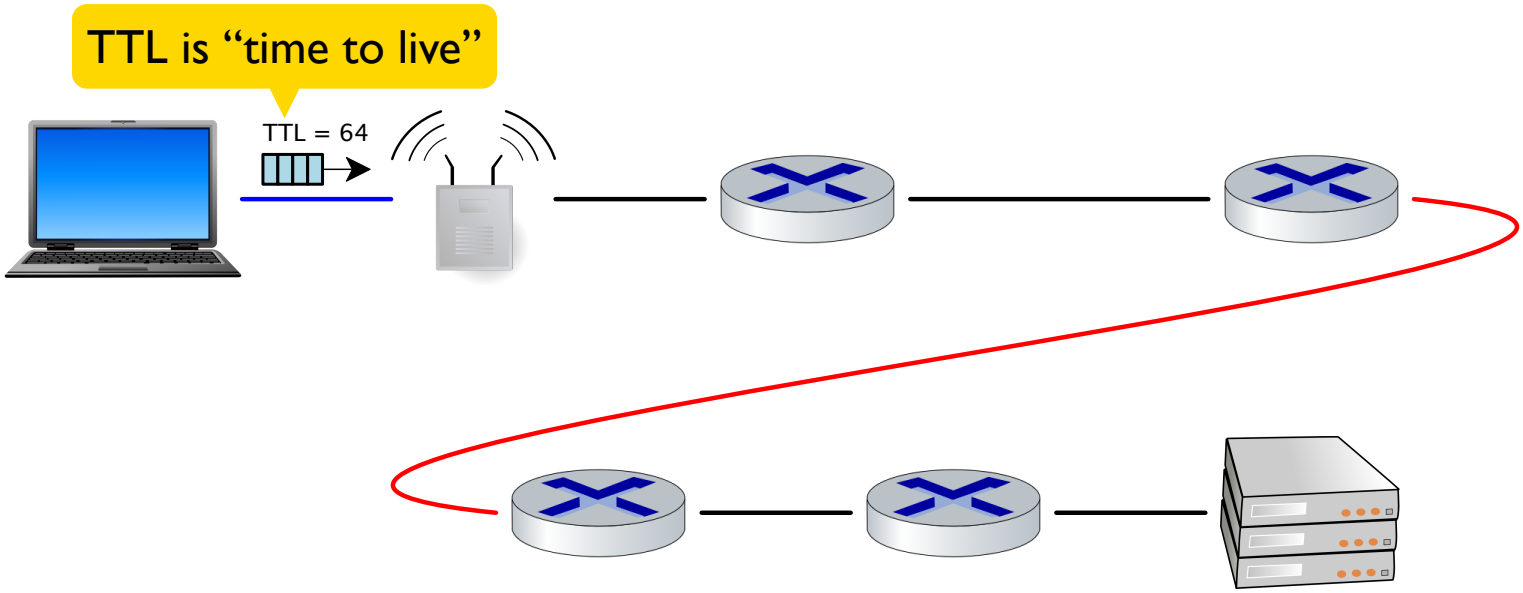

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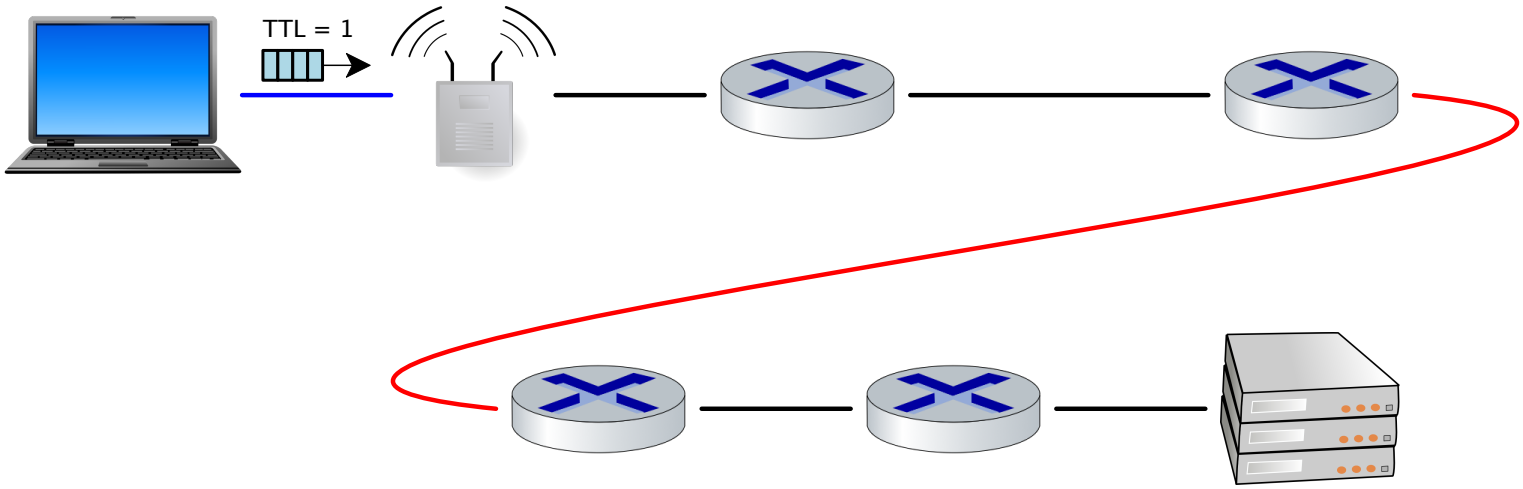

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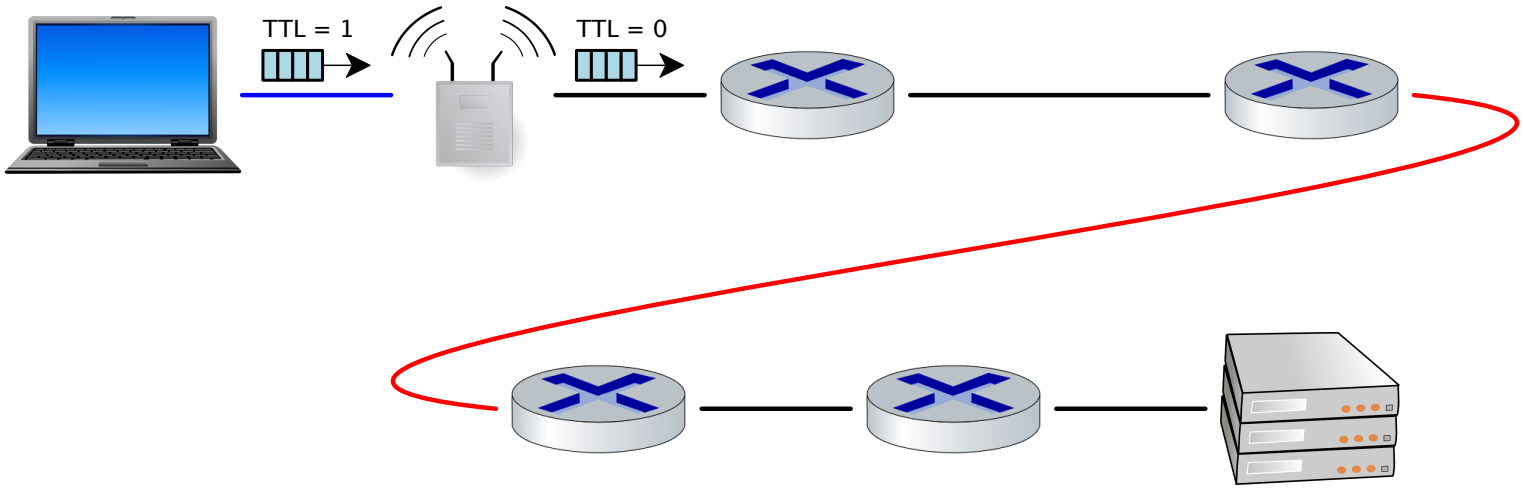

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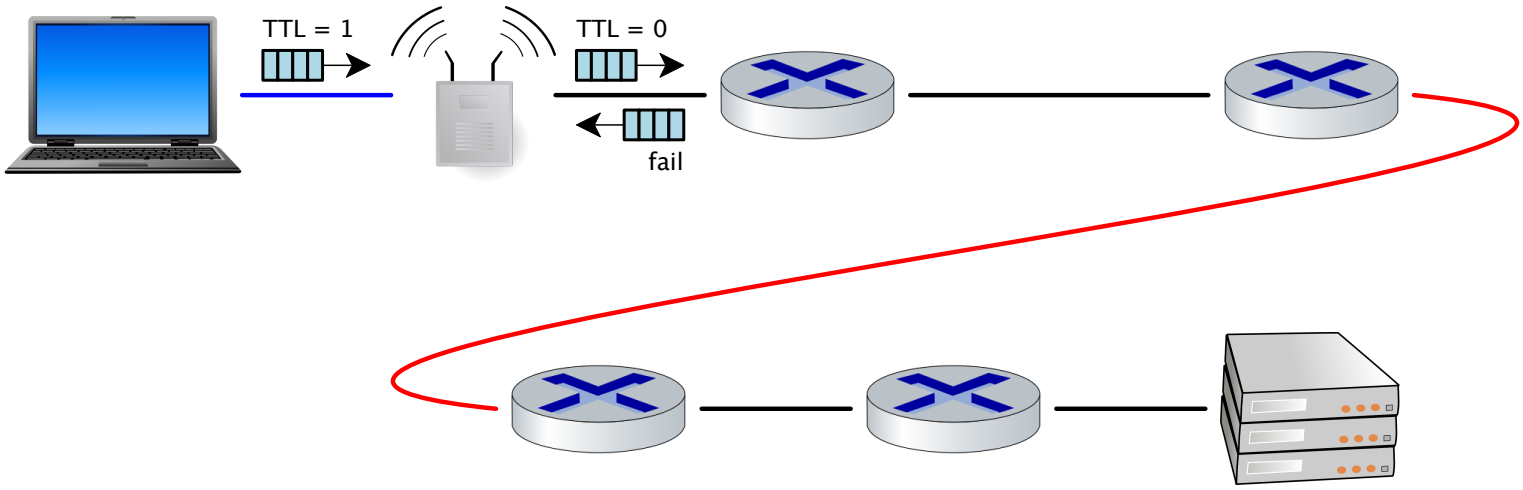

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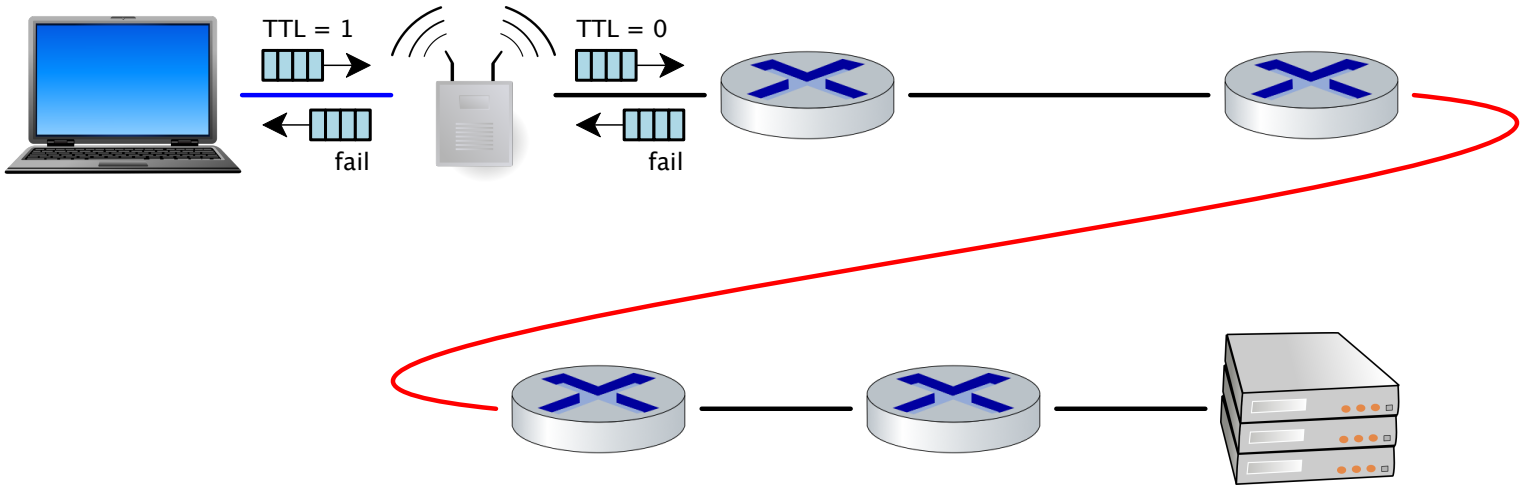

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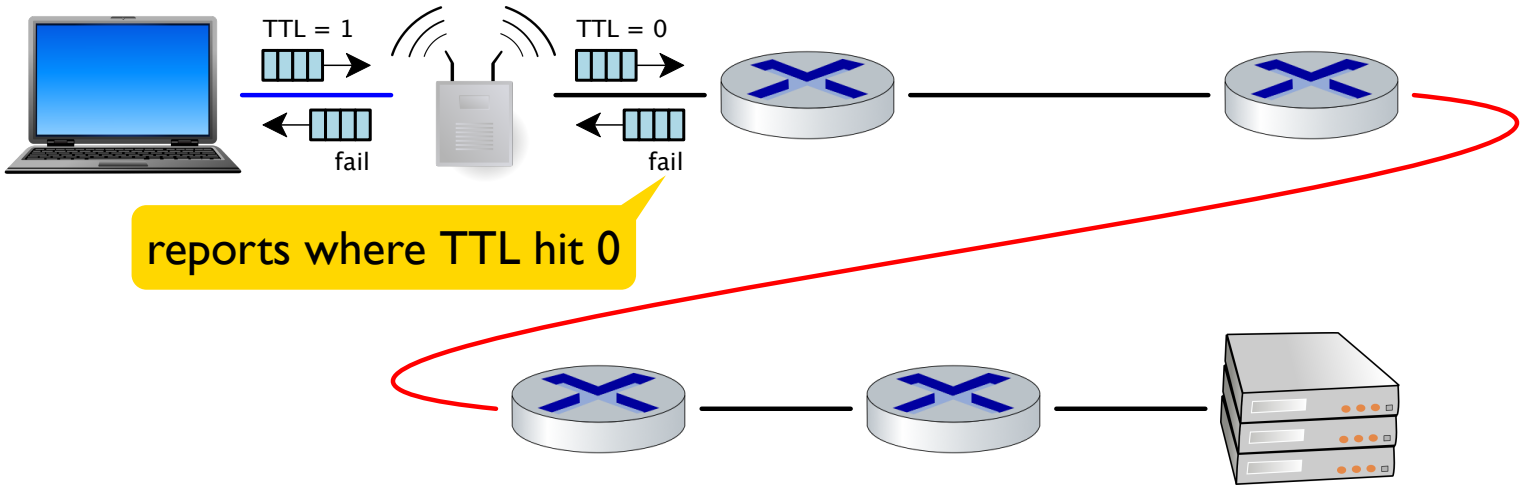

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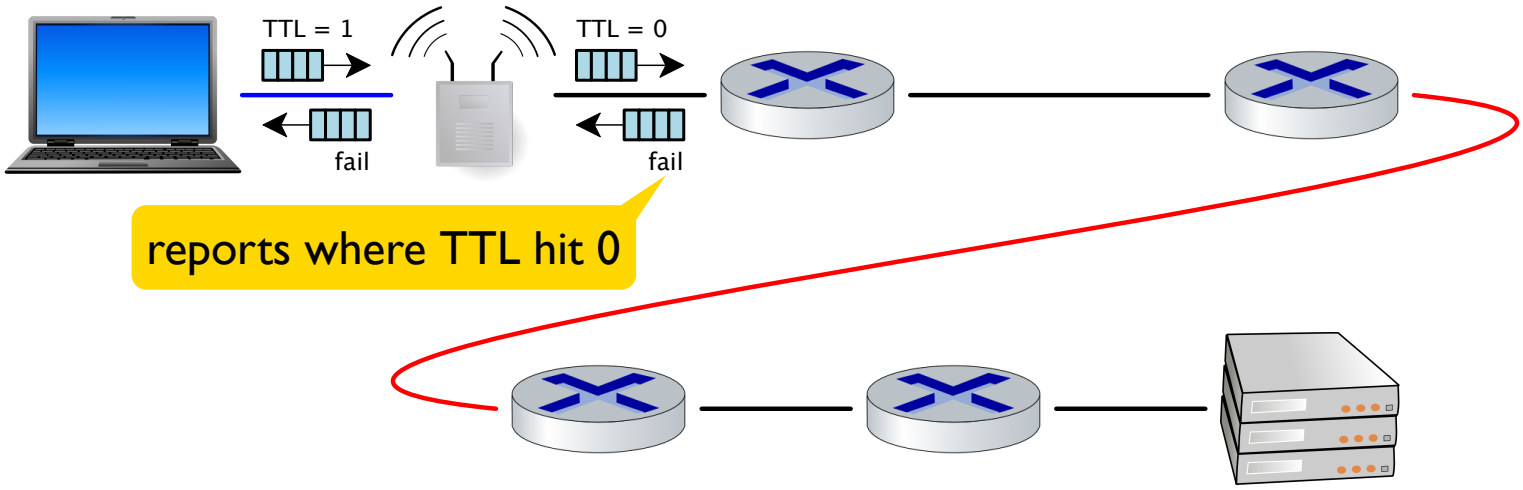

`traceroute` uses this trick systematically to explore the network

```
laptop$ traceroute www.cs.utah.edu
traceroute: Warning: www.cs.utah.edu has multiple addresses; using 141.193.213.10
traceroute to wp.wpenginepowered.com (141.193.213.10), 64 hops max, 52 byte packets
 1  10.0.0.1 (10.0.0.1)  11.987 ms  4.197 ms  4.602 ms
 2  100.93.170.195 (100.93.170.195)  15.651 ms
    100.93.170.194 (100.93.170.194)  18.858 ms
    100.93.170.195 (100.93.170.195)  16.754 ms
 3  po-333-417-rur501.saltlakecity.ut.utah.comcast.net (96.216.76.73)  16.825 ms
    po-333-418-rur502.saltlakecity.ut.utah.comcast.net (96.216.76.81)  15.903 ms
    po-333-417-rur501.saltlakecity.ut.utah.comcast.net (96.216.76.73)  18.208 ms
....
15  50.242.151.238 (50.242.151.238)  33.149 ms
    172.69.132.4 (172.69.132.4)  39.945 ms
    66.208.229.106 (66.208.229.106)  42.951 ms
16  141.193.213.10 (141.193.213.10)  33.762 ms
    172.71.156.2 (172.71.156.2)  60.377 ms
    141.193.213.10 (141.193.213.10)  32.911 ms
```

Latency vs. Throughput

- **Latency** ⇒ how long you have to wait for one small thing

  a time, such as milliseconds

  RRT can help us understand latency

- **Throughput** ⇒ how long you have to wait for everything

  a rate, such as bytes per second

  mailing a box of flash drives can have very high throughput, but also high latency