Tutorial 2

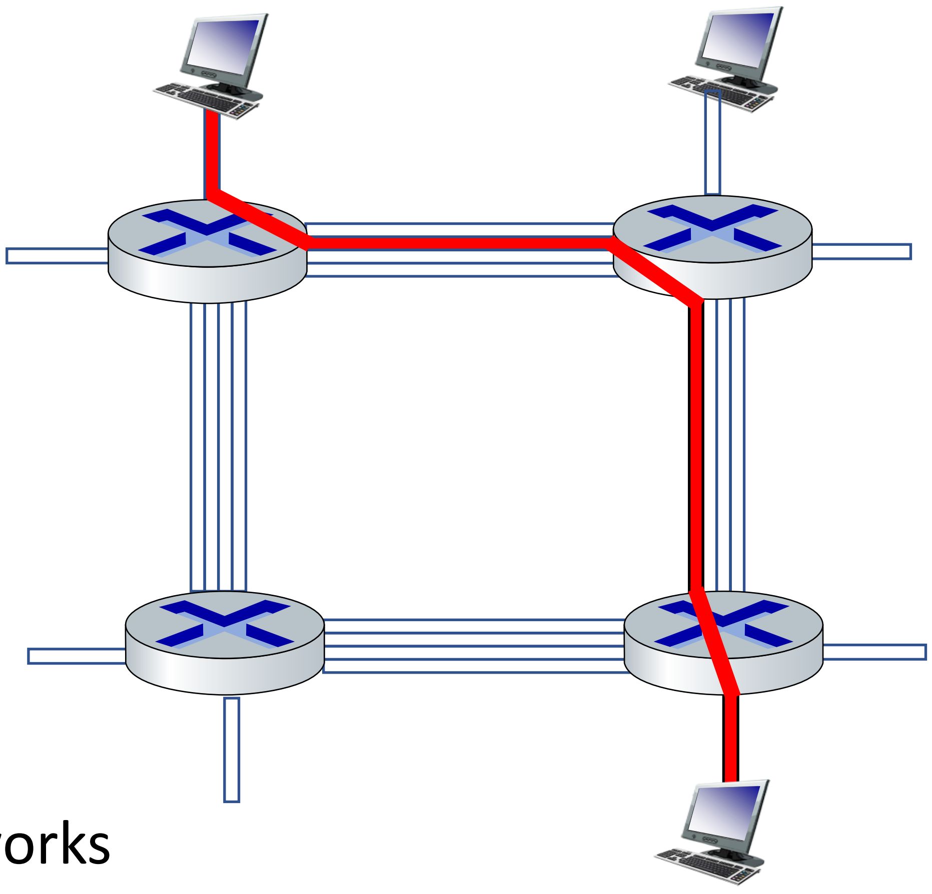
CS335A

Packet Switching vs Circuit Switching
Delays, Throughput, Loss

Circuit Switching

end-to-end resources allocated to, reserved for "call" between source and destination

- in diagram, each link has four circuits.
  - call gets 2nd circuit in top link and 1st circuit in right link.
- dedicated resources: no sharing
  - circuit-like (guaranteed) performance
- circuit segment idle if not used by call (no sharing)
- commonly used in traditional telephone networks

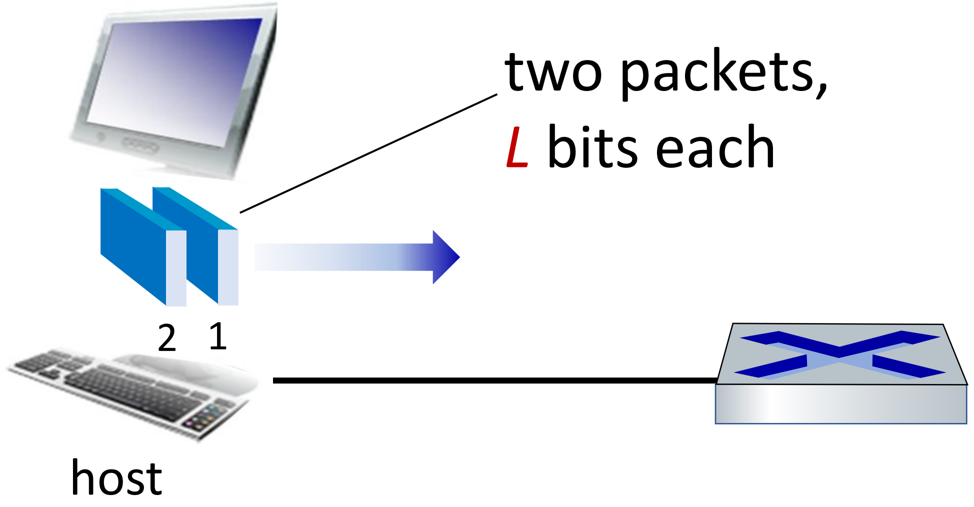


* Check out the online interactive exercises for more examples: http://gaia.cs.umass.edu/kurose_ross/interactive

Packet Switching

host sending function:

- takes application message
- breaks into smaller chunks, known as *packets*, of length *L* bits
- network forwards packets from one router to the next, across links on path from source to destination



Packet switching versus Circuit switching

Packet Switching

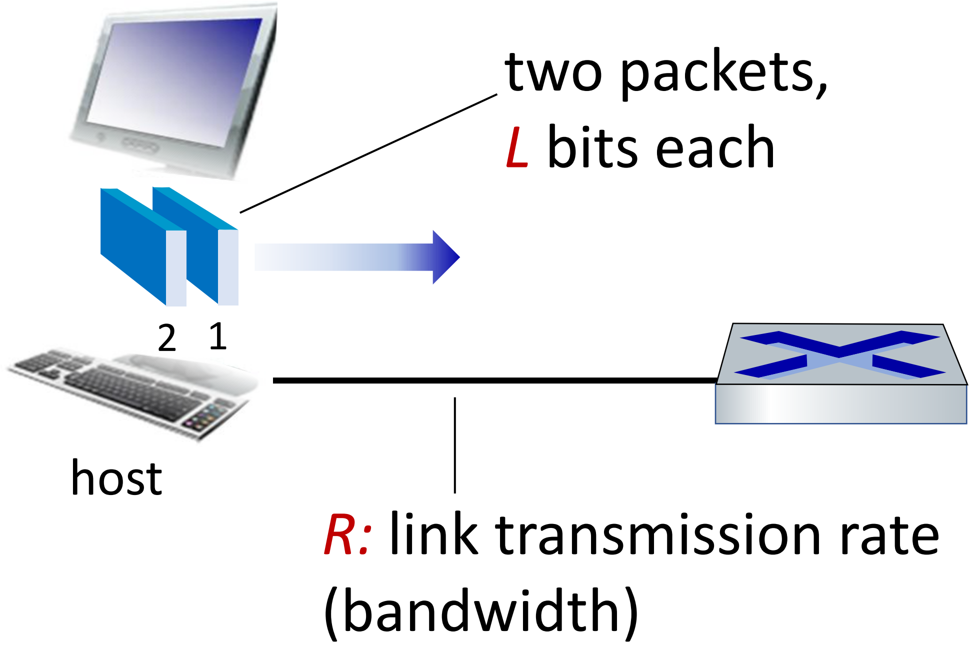
- resources are reserved on demand
- great for "bursty" data
  - sometimes has data to send, but at other times not
- resource sharing
- simpler, no call setup
- excessive congestion possible:
  - packet delay and loss due to buffer overflow
  - protocols needed for reliable data transfer, congestion control

Circuit Switching

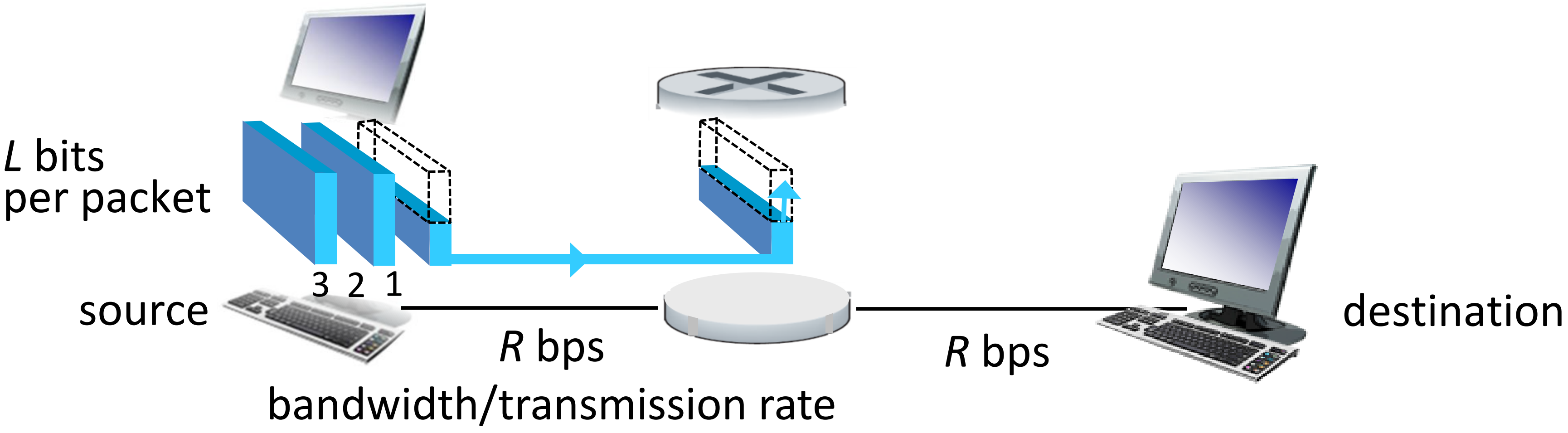
- resources are allocated end-to-end
  - reserved even during idle times
- no sharing
- call setup to allocate resources
- bandwidth guarantees

Host: sends *packets* of data

- *bandwidth:* the maximum rate at which data can be transmitted over a network connection *(R)*
  - how fast data can be placed into the physical link i.e. the cable
  - link *transmission rate*, link *capacity,* link *bandwidth*
  - measured in *bits per second (bps)*
    - *not bytes be careful in assignment*



Packet-switching: store-and-forward

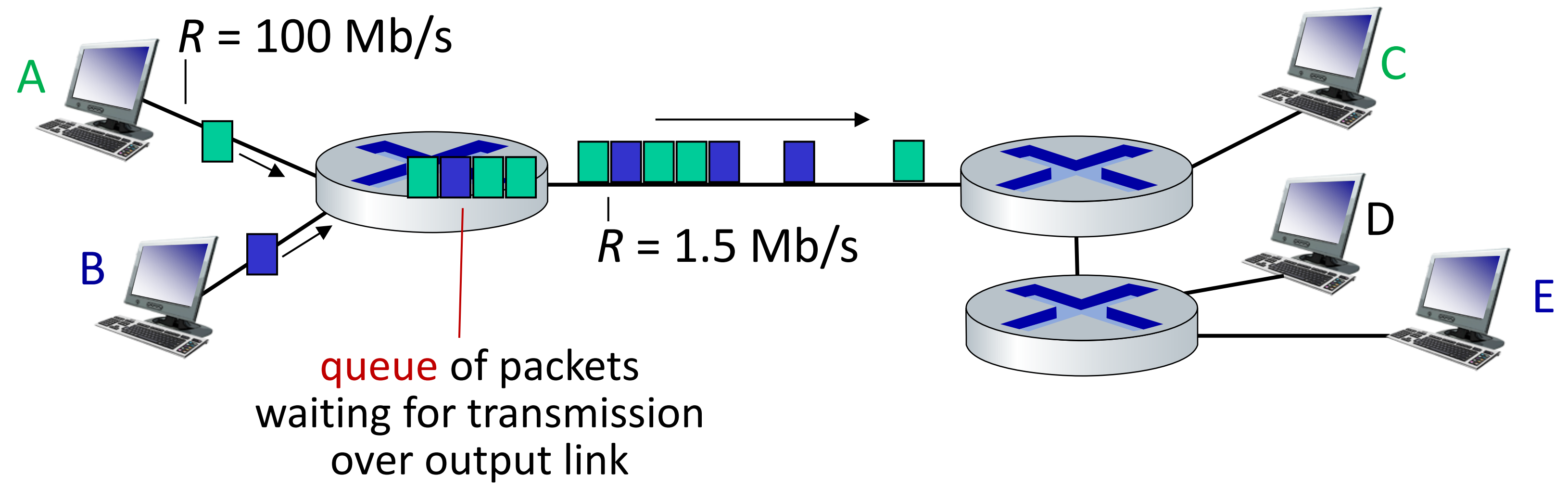


- packet transmission delay: takes L/R seconds to transmit (push out) L-bit packet into link at R bps

$$\text{packet transmission delay} = \text{time needed to transmit } L\text{-bit packet into link} = \frac{L \text{ (bits)}}{R \text{ (bits/sec)}}$$

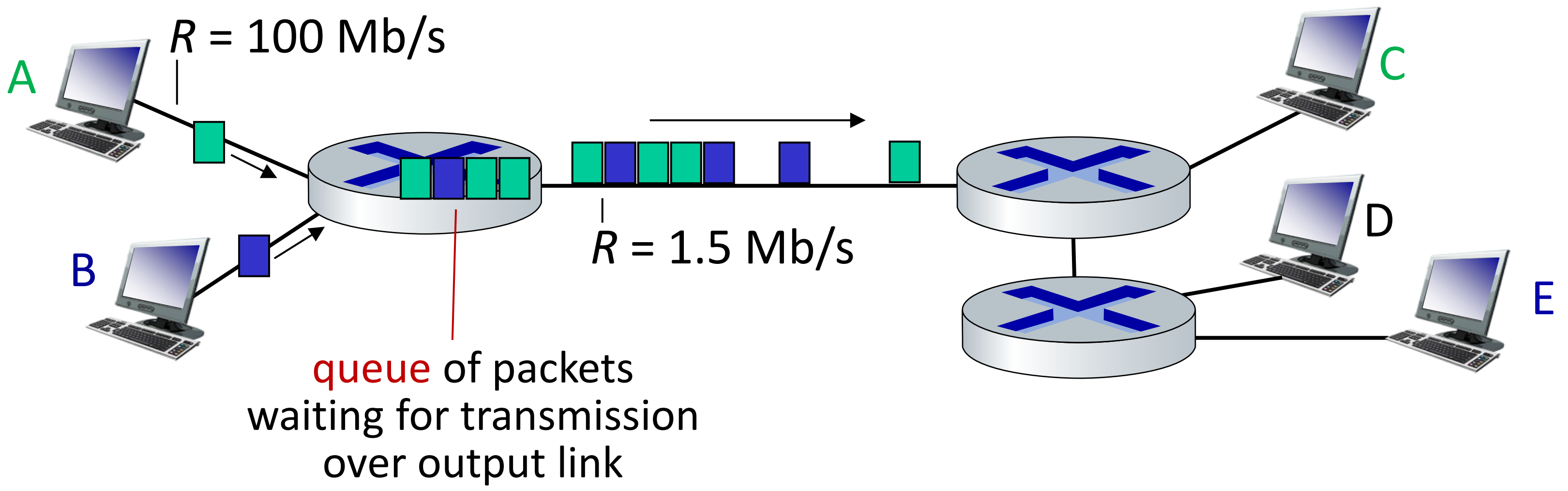
- *store and forward: entire* packet must arrive at router before it can be transmitted on next link

Packet-switching: queueing



Queueing occurs when work arrives faster than it can be serviced:

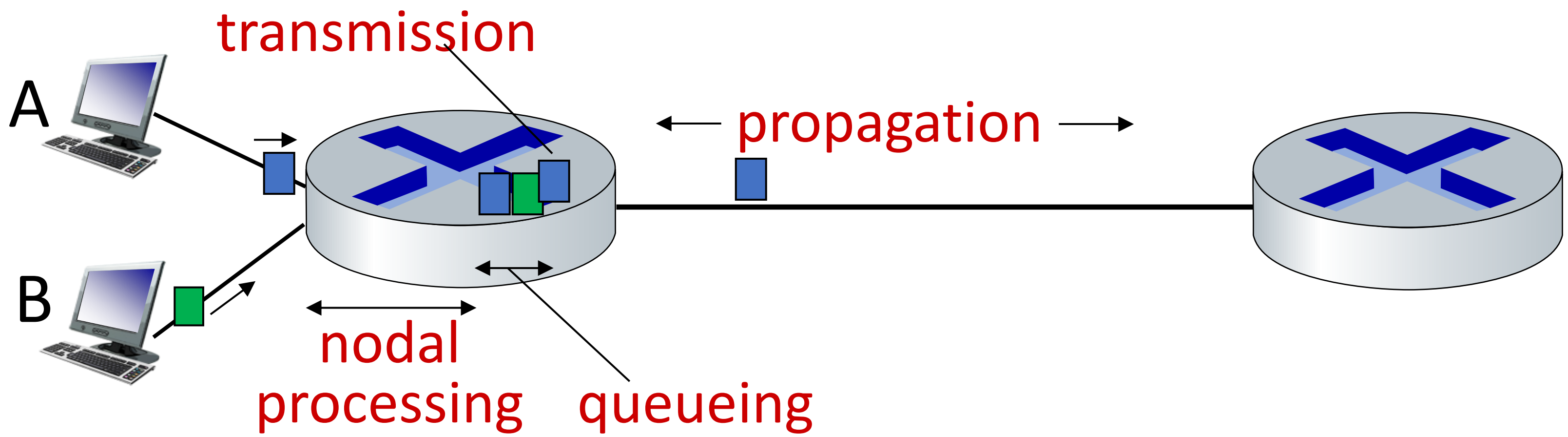
Packet-switching: queueing



Packet queuing and loss: if arrival rate (in bps) to link exceeds transmission rate (bps) of link for some period of time:

- packets will queue, waiting to be transmitted on output link
- packets can be dropped (lost) if memory (buffer) in router fills up

Packet delay: four sources



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

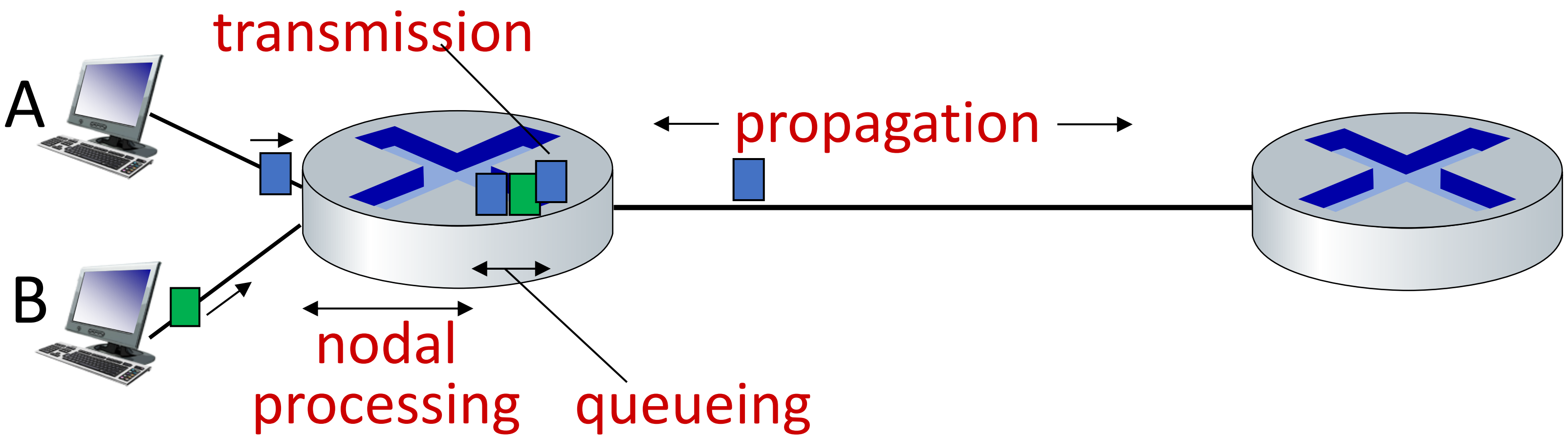
d_{proc}: nodal processing

- 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

Packet delay: four sources



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{trans}: transmission delay:

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

d_{prop}: propagation delay:

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

d_{trans} and d_{prop} *very* different

Transmission vs Propagation Delay

- **Transmission Delay**
  - time to push all bits of a packet **into the link** (from router)
  - depends on **packet size** and **link bandwidth**
  - $d_{trans} = L/R$

- **Propagation Delay**
  - time for the signal to **travel across the medium** (cable, air etc.)
  - depends on **distance** and **signal speed**
  - $d_{prop} = d/s$

Key Difference

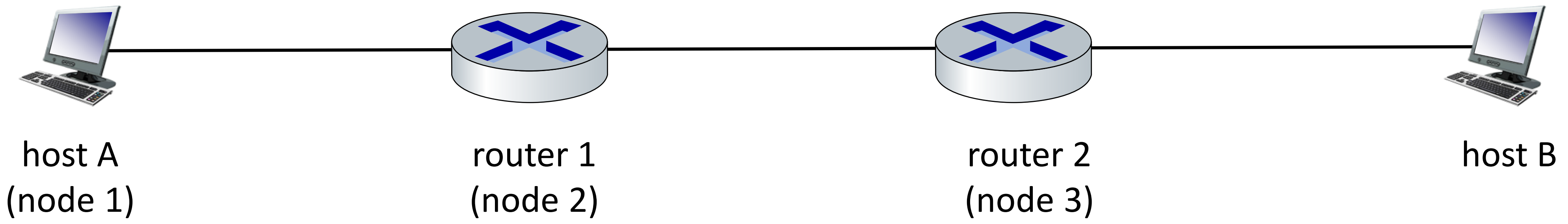
- transmission = **how fast data is put on the wire**
- propagation = **how fast data moves through the wire**

End to End Delay

The end-to-end delay is the *sum of all the nodal delays*

$$d_{end-to-end} = \sum_{i=1}^{N} d_{nodal,i} = \sum_{i=1}^{N} (d_{proc,i} + d_{queue,i} + d_{trans,i} + d_{prop,i})$$

Where *N = number of routers + the source host*



End to End Delay

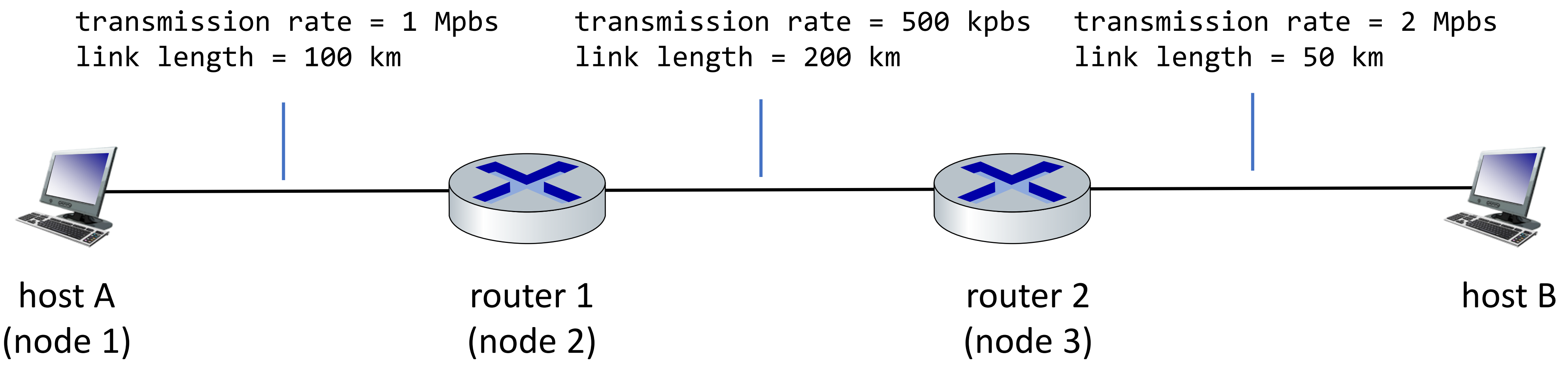
- **Packet size:** L = 1000 bits

- **Link 1:** R_1 = 1 Mbps, d_1 = 100 km
- **Link 2:** R_2 = 500 kbps, d_2 = 200 km
- **Link 3:** R_3 = 2 Mbps, d_3 = 50 km

- **Propagation speed:** s = $2 * 10^8$ m/s
- **Processing delay at each router:** 1 ms
- **Queuing delay at each router:** 2 ms

Problem:

Host **A** sends a packet of **1,000 bits** to host **B.**
Find the end-to-end delay.



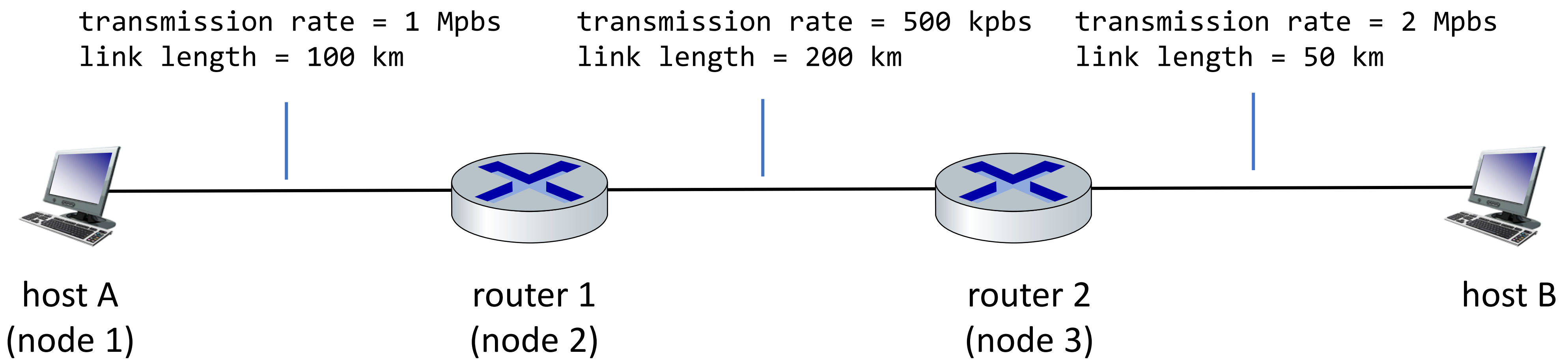
End to End Delay

- Propagation speed: s = 2 * 10^8 m/s
- Processing delay at each router = 1 ms
- Queuing delay at each router = 2 ms

For node 1:

$$d_{nodal,1} = d_{proc,1} + d_{queue,1} + d_{trans,1} + d_{prop,1} = 0 + 0 + \frac{L}{R_1} + \frac{d_1}{s}$$

$$= \frac{1000}{1 \cdot 10^6} + \frac{100 \cdot 1000}{2 \cdot 10^8} = 0.001 + 0.0005 = 0.0015\, s = 1{,}5\, ms$$



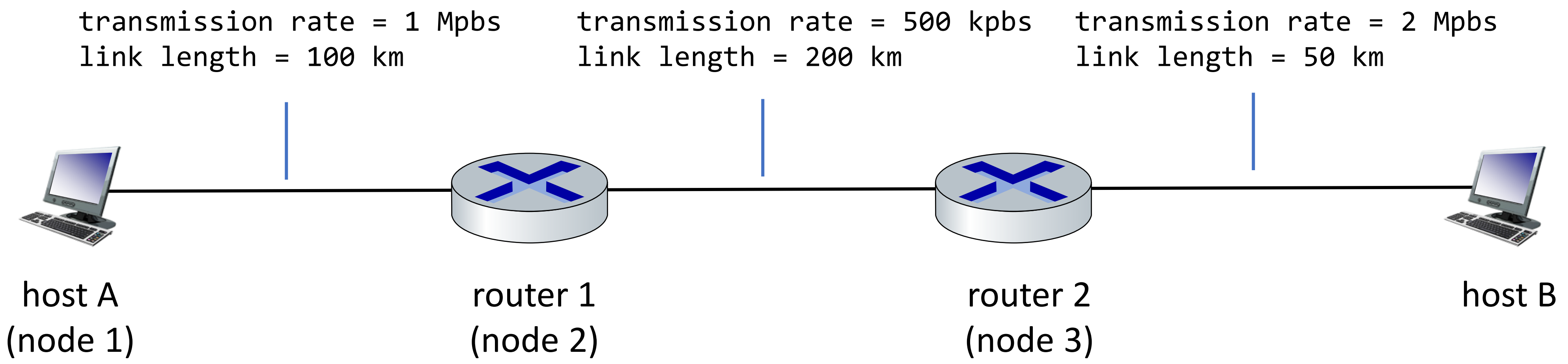
End to End Delay

- Propagation speed: s = 2 * 10^8 m/s
- Processing delay at each router = 1 ms
- Queuing delay at each router = 2 ms

For node 2:

$$d_{nodal,2} = d_{proc,2} + d_{queue,2} + d_{trans,2} + d_{prop,2} = 0.001 + 0.002 + \frac{L}{R_2} + \frac{d_2}{s}$$

$$= 0.003 + \frac{1000}{500 \cdot 1000} + \frac{200 \cdot 1000}{2 \cdot 10^8} = 0.003 + 0.002 + 0.001 = 0.006\, s = 6\, ms$$



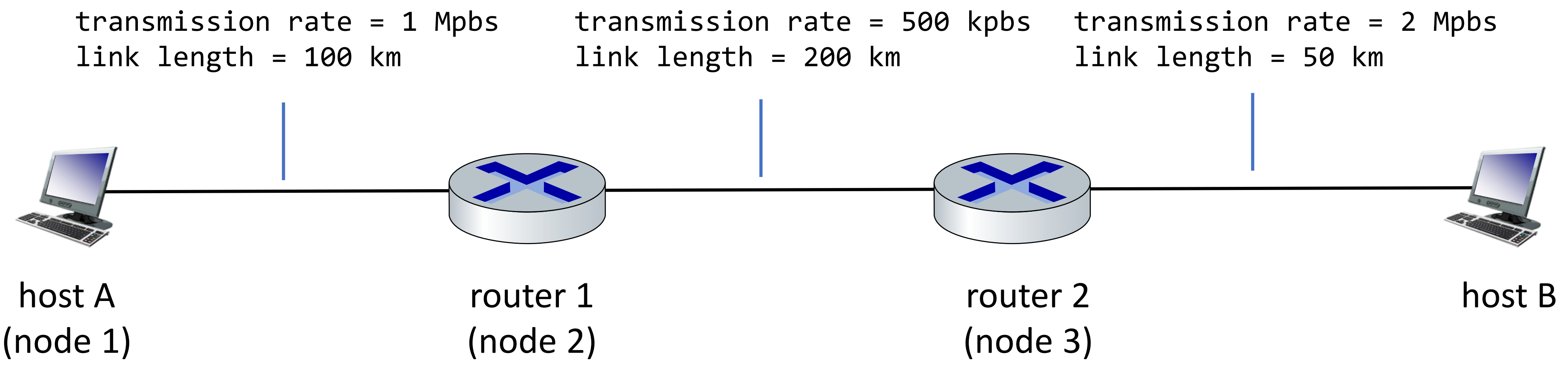
End to End Delay

- Propagation speed: s = 2 * 10^8 m/s
- Processing delay at each router = 1 ms
- Queuing delay at each router = 2 ms

For node 3:

$$d_{nodal,3} = d_{proc,3} + d_{queue,3} + d_{trans,3} + d_{prop,3} = 0.001 + 0.002 + \frac{L}{R_3} + \frac{d_3}{s}$$

$$= 0.003 + \frac{1000}{2 \cdot 10^6} + \frac{50 \cdot 1000}{2 \cdot 10^8} = 0.003 + 0.0005 + 0.00025 = 0.00375\, s = 3.75\, ms$$

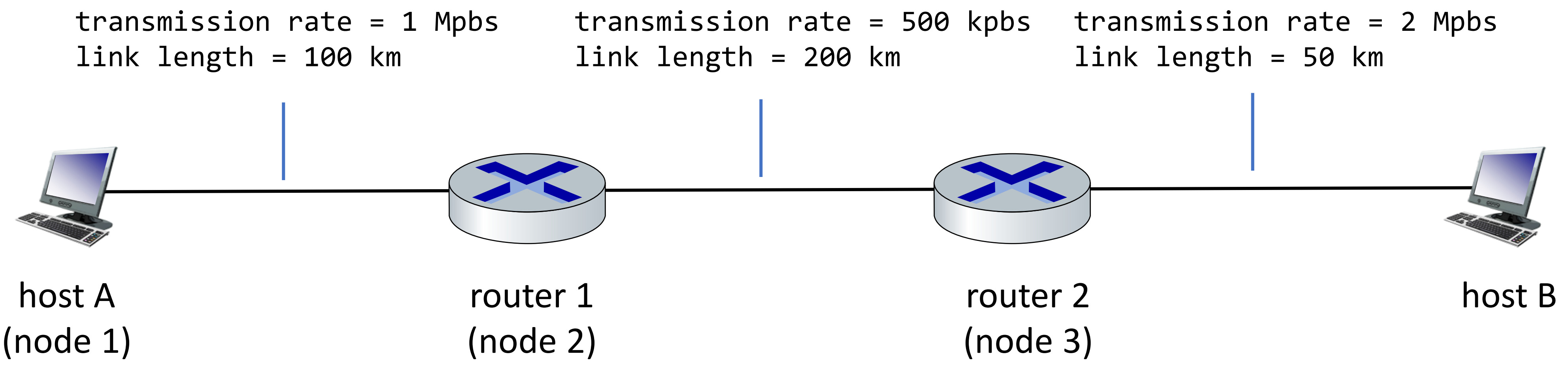


End to End Delay

- Propagation speed: s = 2 * 10^8 m/s
- Processing delay at each router = 1 ms
- Queuing delay at each router = 2 ms

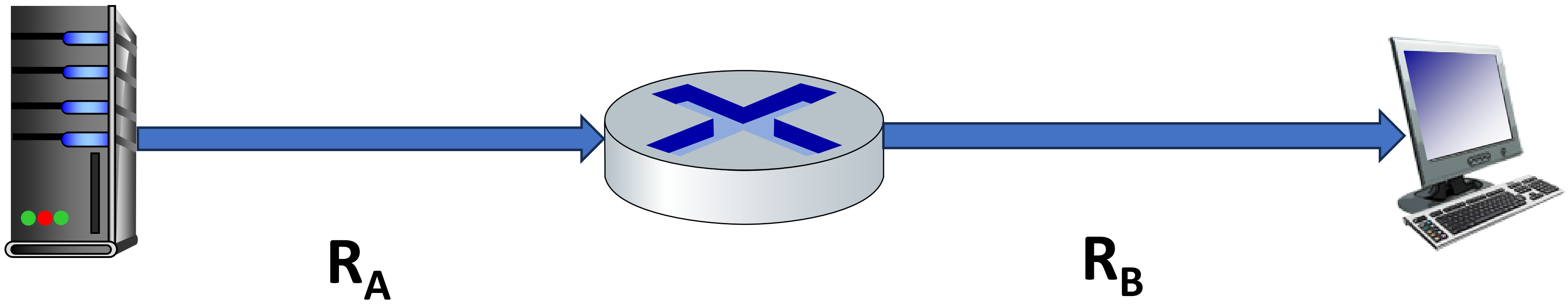
Finally, the end-to-end-delay is:

$$d_{end-to-end} = d_{nodal,1} + d_{nodal,2} + d_{nodal,3} = 1{,}5 + 6 + 3{,}75 = 11{,}25\ ms$$



Throughput

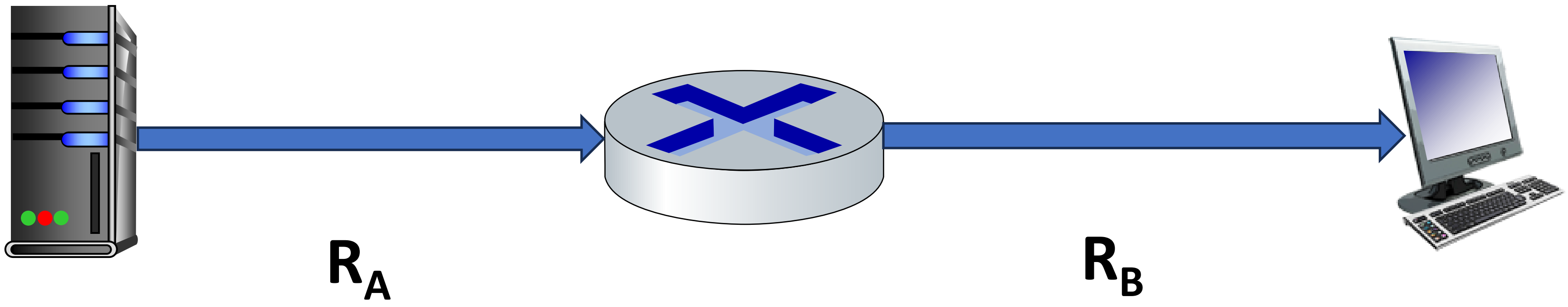
- *throughput:* rate (bits/time unit) at which bits are being sent from sender to receiver
  - example: transfer a large file from host A to B
  - throughput is the speed in bits/sec that B receives the file



Throughput

Consider that the data flow only from A to B

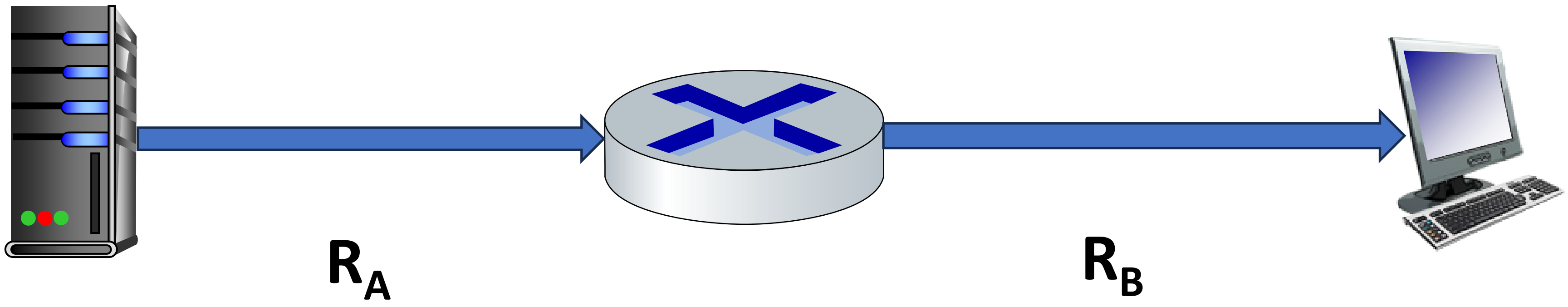
- The host A cannot transmit data with rate greater than R_A
- The router cannot transmit data with rate greater than R_B
- If **$R_A < R_B$**
  - then the bits that sends the host A via router, reach the host B with speed R_A
  - so the **end to end throughput is R_A**
- If **$R_A > R_B$**
  - then the router will not be able to forward data as fast as it receives it and
  - so the **end to end throughput is R_B**



Throughput

- Throughput is the is the transmission rate of the *bottleneck link*
- *Bottleneck link*: link on end-end path that is the slowest and thus constrains the end-end throughput

$$\text{Throughput} = \min\{R_A, R_B\}$$



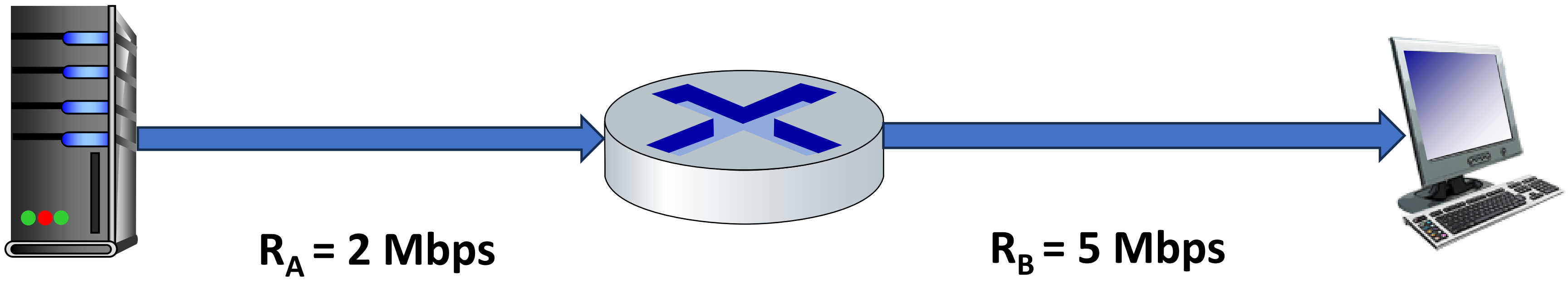
Throughput vs Bandwidth

Throughput

- Server may deliver file at **1 Mbps**, even if link capacity is higher
- Causes:
  - Handling other traffic
  - Old or slow hardware
- Throughput depends on **actual network usage and sharing**, not just link capacity

Bandwidth

- Bandwidth of link A = R_A = 2 Mbps
- Bandwidth of link B = R_B = 5 Mbps
- the actual **link capacity**: can transmit up to R bit/ps, the limit of the physical link



Throughput Example

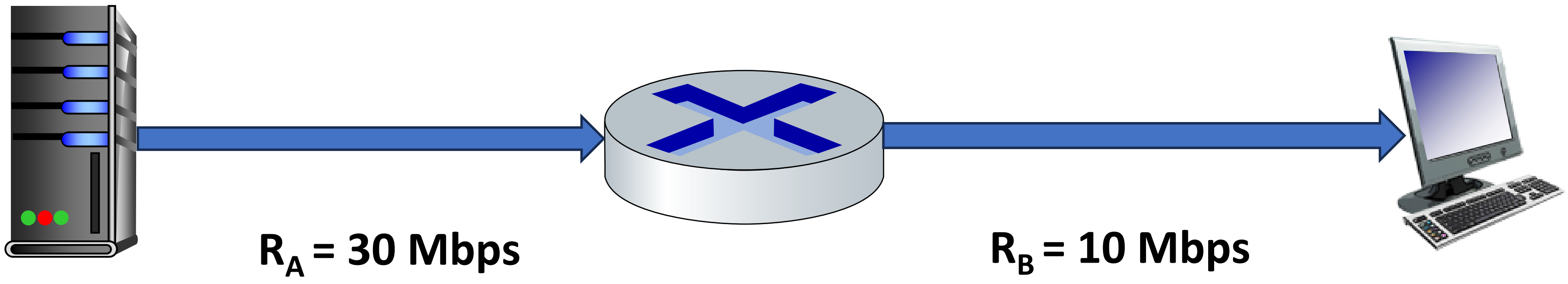
- file size = 4 Gbits
- R_A = 30 Mbps
- R_B = 10 Mbps
- time to transfer file from A to B?

- time = file size / throughput

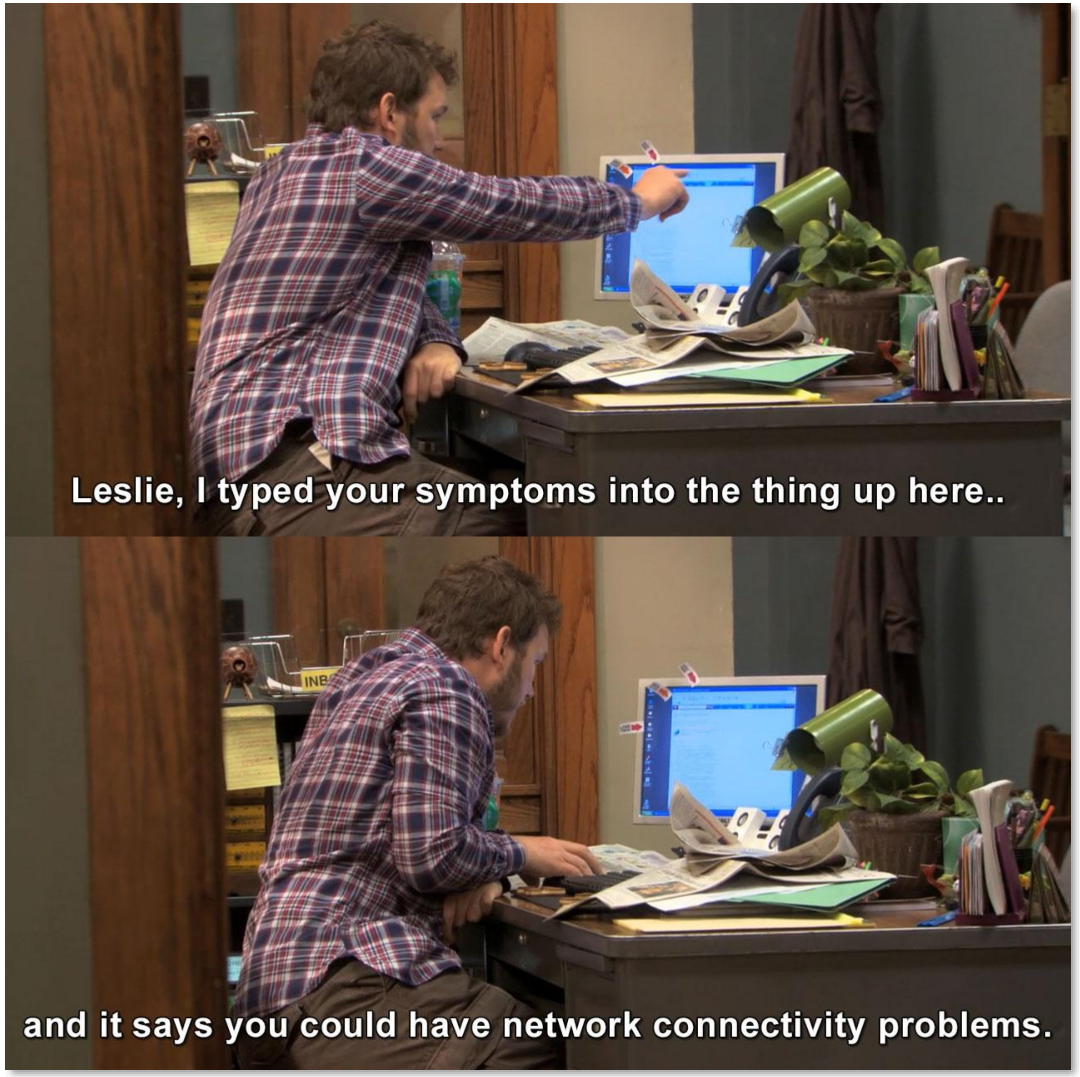
  = 4 Gbits / min{$R_{A,}$ R_B}

  = $4 * 10^9 / 10 * 10^6$

  = $4 * 10^2$ = 400 sec ~= 6,66 min



Questions???


Leslie, I typed your symptoms into the thing up here..
and it says you could have network connectivity problems.