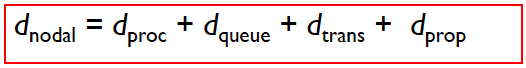
**Common Conversions**

**Time:** 1 second = 1,000 milliseconds

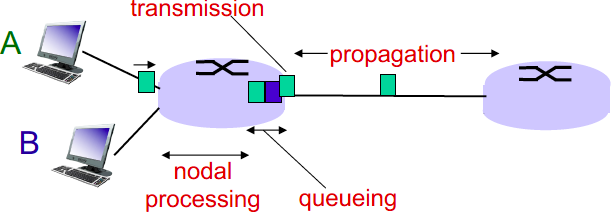
**Data Transfer:** 1 gigabit (Gb) = 1,000 megabits (Mb) 🡪 1 megabit (Mb) = 1,000 kilobits (Kb) 🡪 1 kilobit (Kb) = 1,000 bits (b)

**Storage:** 1 gigabyte(GB) = 1,024 megabytes (MB) 🡪 1 megabyte (MB) = 1,024 kilobytes (KB) 🡪 1 kilobyte = 1,024 bytes

**Week 1 – Introduction to Networks**



**Four Sources of Packet Delay**



**Combined delay = END-TO-END DELAY**

N \* [ proc + queue + trans + prop ]  
N = number of links

**1. Processing Delay (dPROC):** Checking bit errors, determine where to send the packet.

* **dPROC = < 1 ms. Usually done very quickly**

**2. Queuing Delay (dQUEUE):** Time waiting at the output link before transmission.

* **dQUEUE = Time spent in buffer**

**3. Transmission Delay (dTRANS):** Time required to push ALL BITS on the wire.

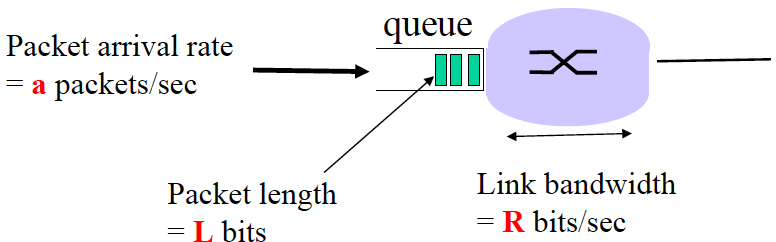
* **dTRANS = L / R where L = packet length / R = link bandwidth or rate**

**4. Propagation Delay (dPROP):** Time taken for ONE BIT to travel from the src 🡪 dest.

* **dPROP = d / s where d = physical length of link / s = propagation speed in medium**
* (~2 x 108 meters/s = speed of light / fiber)

**Queueing Delay**

**Traffic Intensity** = La / R (**La:** bits arriving at queue per second) (if **La > R** then **packets will drop**)

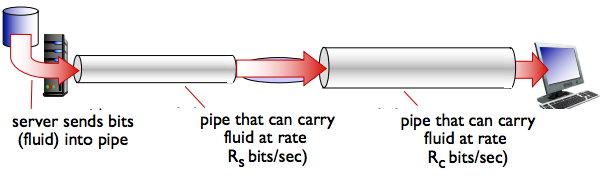
* **La/R ~= 0** is AVERAGE traffic intensity (Average is **L (N – 1) / (2R)** assuming queue is empty at t=0)
* **La/R = 0.8** should be FIXING YOUR NETWORK
* **La/R approaches -> 1** is BAD traffic intensity
* **La/R > 1** INFINITE delay, collapse of system

**Arrival Rate (a)** = R / L (**R/L:** packets arriving per second

**Throughput**

**Throughput**: The rate (bits / time unit) at which bits are transferred between sender / receiver.

* **Instantaneous:** Rate at given point in time (not useful, not accurate) | **Average:** Rate over long period of time (useful)



If RS < RC , what is the average throughput?

* RS is the average throughput

**The link on the end-end path that is the slowest will be the bottleneck. You can’t get faster than bottleneck.**

**Week 2 – Protocol Layering, Application Layer, Web**

**Caching**

**Access Link Utilisation**

* **Access Link Utilisation = bits per second requested / access link rate**
* When access link utilisation is high, queueing is high.
* With caching, if cache hit rate = 0.4 🡪 access link utilisation = 0.6

**Caching Solution**

* **Total delay =** **(Cache Hit Rate \* delay at cache) + (Access Link Utilisation \* delay from sever)**

**Caching Example**

15 requests per second

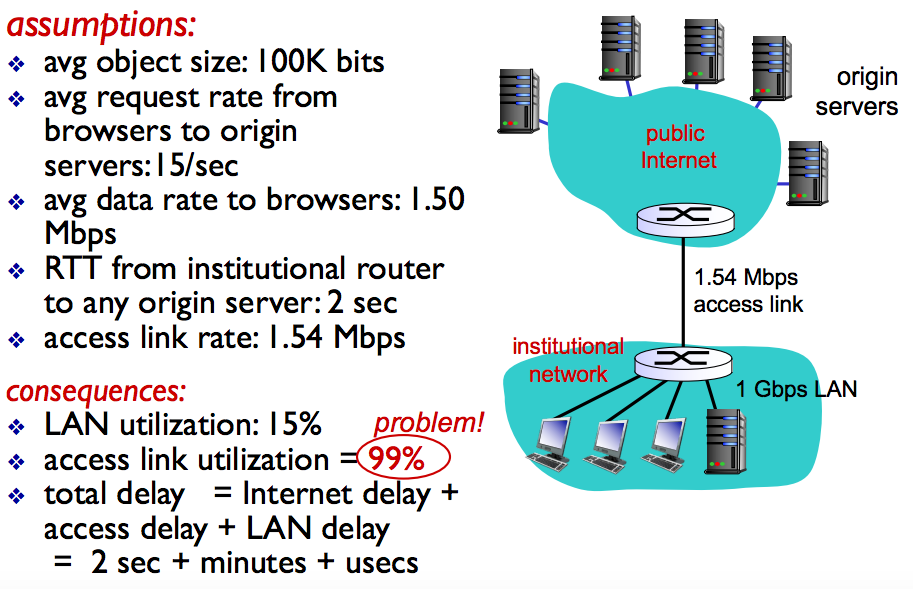
100k (100 \* 103) bits per request

**A = 15 x 100 \* 103 bits**

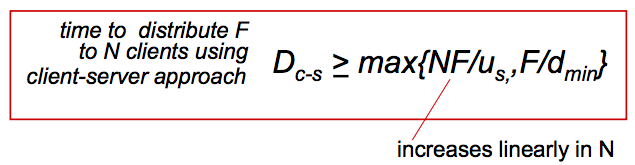
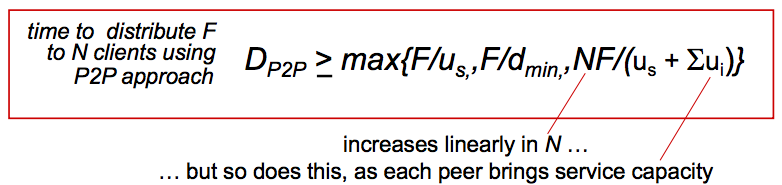
1.54 Mbps Link Speed  
**B = 1.54 x 106 bits**(1 megabit = 106 bits)

A / B = 0.974 **= 97% access link utilisation = ~2+ seconds**

With Caching Solution of 0.4 hit rate: Total delay is  
**= (60% access link utilisation \* 2 secs) + (40% \* ~millisecs)  
=** **~1.2 seconds**



**Week 4 – P2P Networks and Transport Layer**

**Client-Server Model P2P Model**

Performance of C-S vs. P2P: How much time does it take to distribute a file to N peers?

**N = # peers | F = file size | us = server upload capacity | ui = peer upload capacity | di= peer download capacity**