EE450, Fall 2015, Zahid

lecture #5

Tuesday, Sept 8

Network Performance Measures

- Delay (latency) (sec)
- Throughput (bps)
- Packet Losses (Error rate) EE555

- Deterministic
- Random (EE555) EE590)

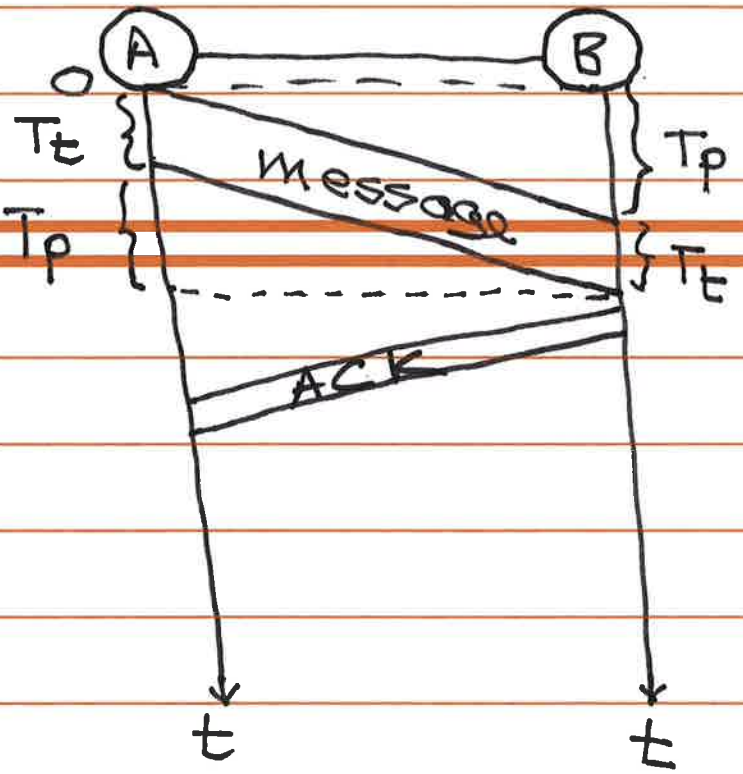
a) Transmission Delay T_t

$$T_t = \frac{\text{Message length (bits)}}{\text{Data (Bit) Rate (bps)}}$$

b) Propagation Delay T_p

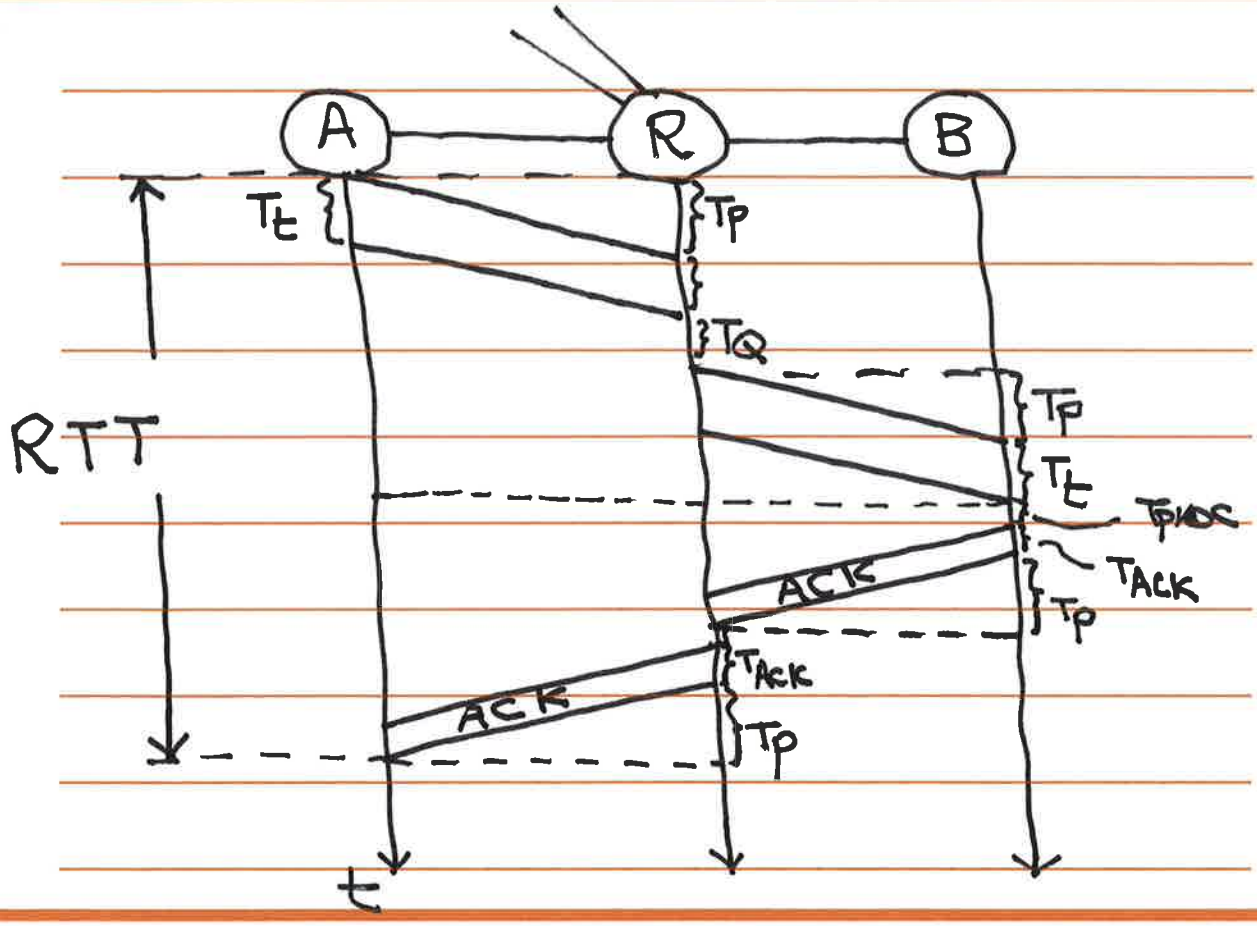
$$T_p = \frac{\text{length of the Link (m)}}{\text{velocity of propagation (m/sec)}}$$

$\approx$ speed of Light $\simeq 3 \times 10^8$ m/sec



Random Delay components

- Processing Delay T_{proc}
- Queuing Delay (T_Q)



End_to_End Delay (Transfer Time)

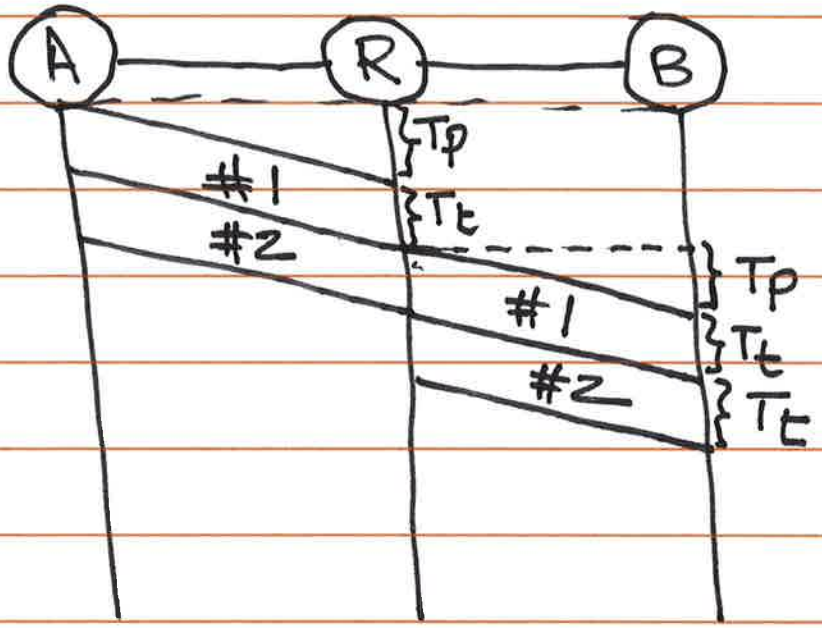
$$= T_{p_1} + T_{t_1} + T_Q + T_{p_2} + T_{t_2}$$

RTT = Round Trip Time

↑

Response Time

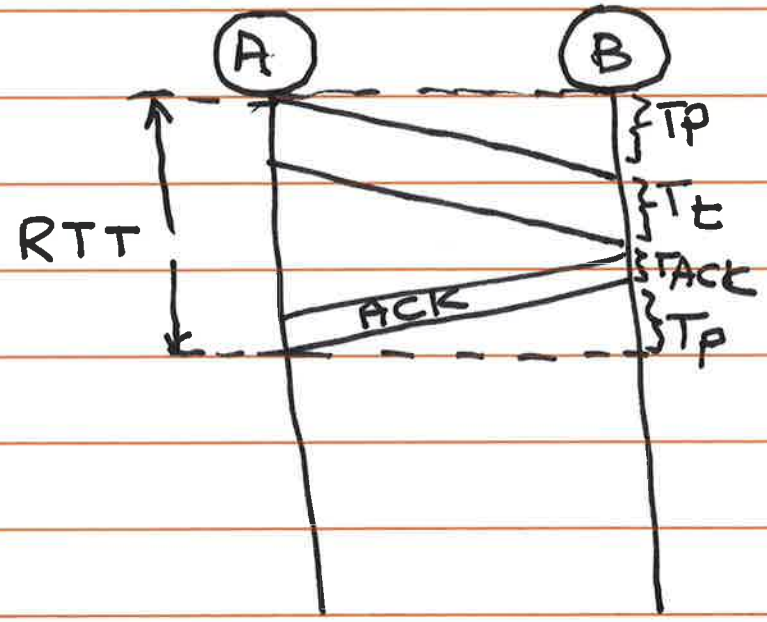
ignore T_Q



End-to-End delay = $3T_t + 2T_p$

Throughput (bps): The rate at which the bits are delivered "reliably" to the receiver.

Data Rate (bps) = the rate at which the bits are transmitted.

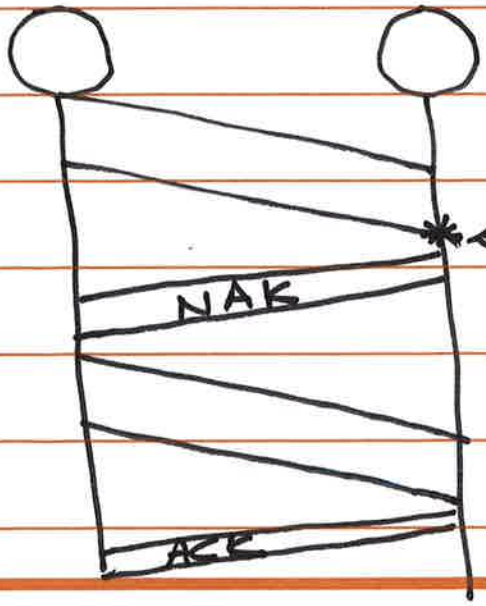


$$\text{Data Rate} = \frac{\text{Message length (bits)}}{T_t \text{ (sec)}}$$

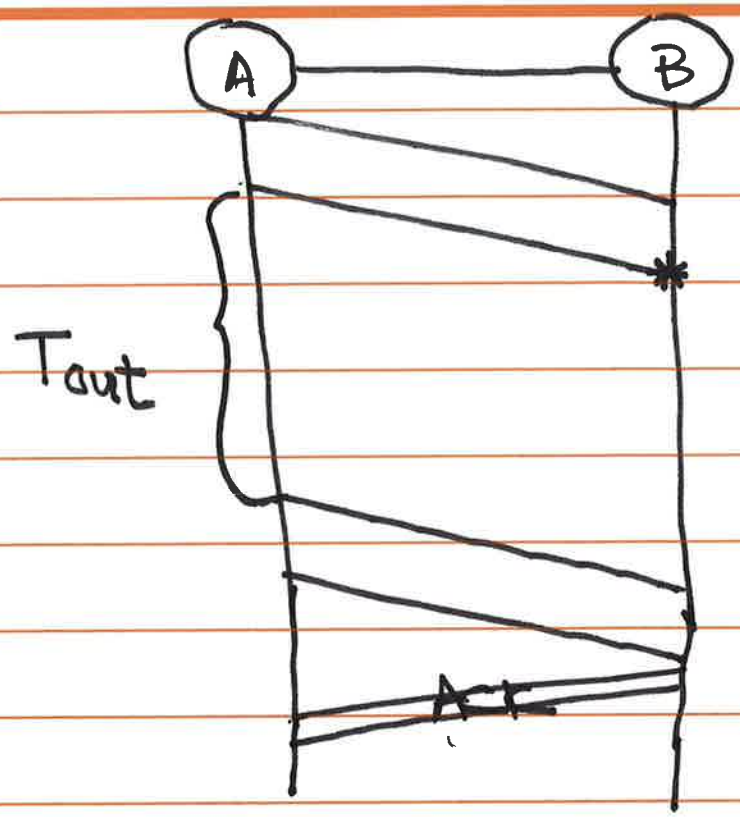
$$\text{Throughput} = \frac{\text{message length (bits)}}{\text{RTT (sec)}}$$

Same Data Rate

$$\text{Throughput} = \frac{\text{message length}}{2\,\text{RTT}}$$



* ← message was found to be in error


A
B
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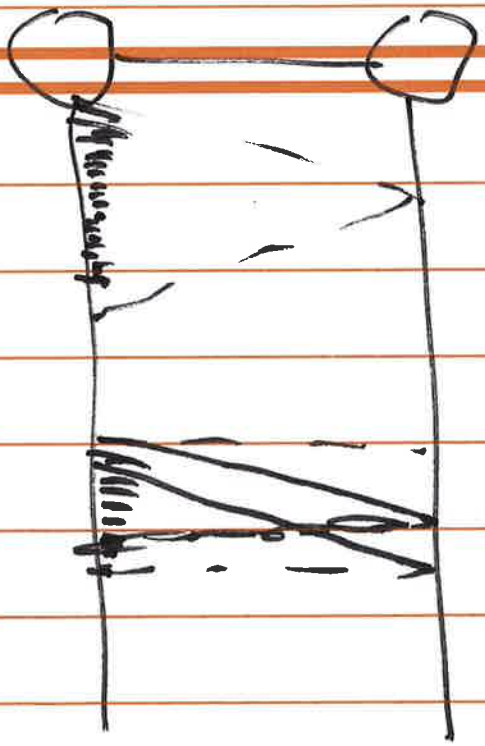


Network Performance Measures

- The two most important network performance measures are Delay/Latency & Throughput (bps)
- End-to-end delay consists of several components
  - Transmission time
  - Propagation delay
  - Nodal processing
  - Queuing delay (Random, depends on network loading, link capacities, disciplines, etc..)

Transmission Time

- Transmission Time (t_{trans})
  - The time it takes to transmit a group of bits (e.g., a Message/Packet/Frame) of bits into a network

$$t_{tran} = \frac{\text{Number of Message (Packet) bits}}{\text{Data rate [bps]}}$$

Propagation Delay

- Propagation time (t_{prop})
  - The time it takes for a bit to traverse the link

$$t_{prop} = \frac{\text{link length[m]}}{v_{prop}\,[m/s]}$$

- Example propagation velocities:
  - Air/Free space: c = 3×10^8 meters/sec
  - Cat 5 UTP: 2~2.5x10^8 meters/sec
  - Optical Fiber: 2~2.5x10^8 meters/sec

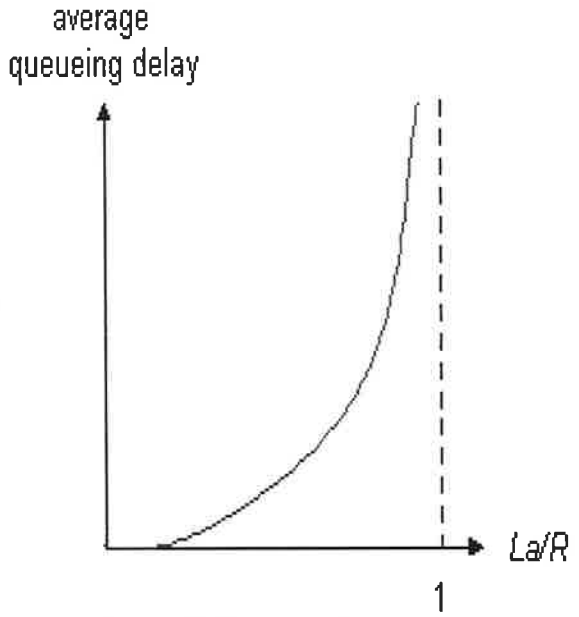
Nodal Processing/Queueing

- Nodal processing:
  - Check bit errors
  - Determine output link (Routing decision)
- Queuing
  - Time waiting at output link for transmission
  - Depends on congestion level of router

More on Queueing Delay

- *R:* link bandwidth (bps)
- *L:* packet length (bits/Packet)
- λ: average packet arrival rate (In Packets/sec)

  - λL/*R* ~ 0: avg. queueing delay small
  - λL/*R* ≤ 1: avg. queueing delay large
  - λL/*R* > 1: more "work" arriving than can be serviced, average delay in

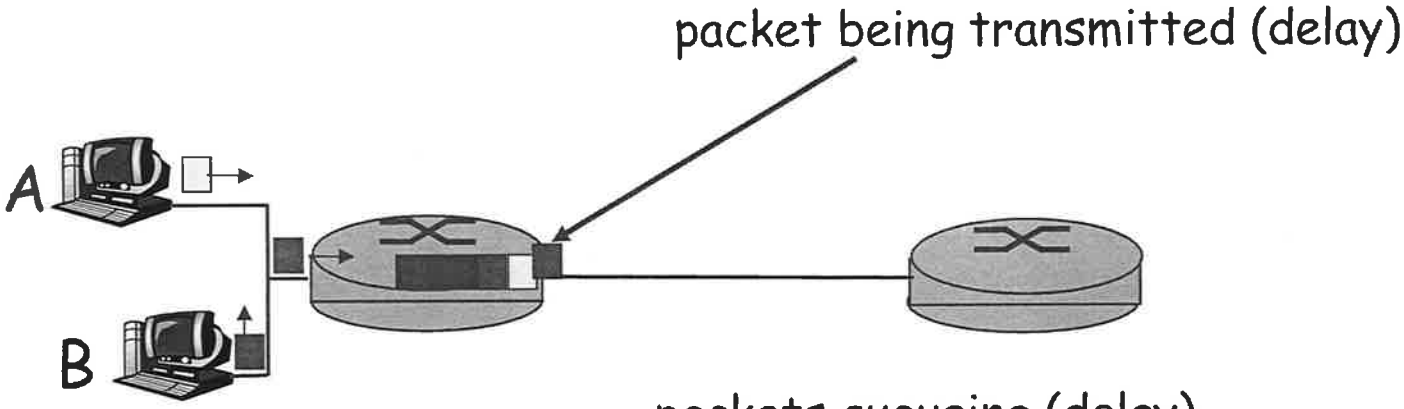


λL/R ~ 0

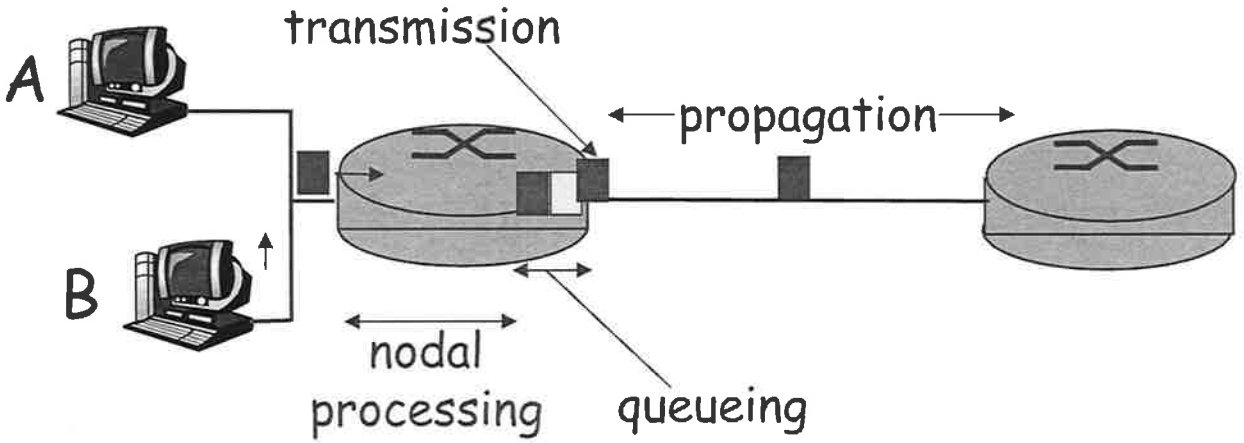
λL/R → 1

Loss and Delay: Why?

- packets *queue* in router buffers
- packet arrival rate to link exceeds output link capacity
- packets queue, wait for turn



Summary of Delay Components



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

d_{proc}: nodal processing

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

d_{queue}: queueing delay

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

Message Transfer Time

- Message Transfer Time (t_{xfr}) = Message latency
  - Time for sender to transmit message to the receiver and for the receiver to receive the entire message. Also known as the end-to-end delay

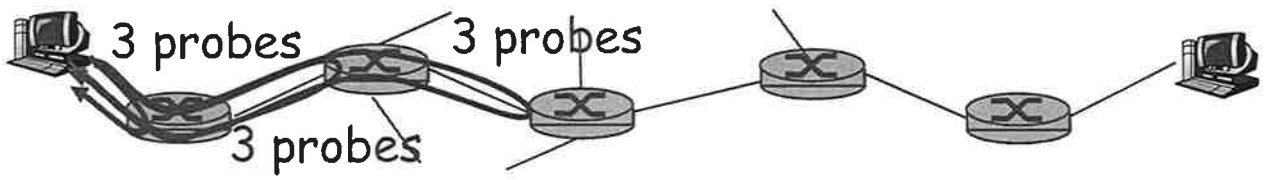
$$t_{xfr} = t_{trans} + t_{prop} + t_{queuing/processing}$$

Round Trip Time (RTT)

- Round Trip Time: The time to send a message from a sender to the receiver and receive a response back
- RTT depends on message size, length of link, direction of propagation, propagation velocity, network node processing, network loading, etc...
- For simplicity, RTT is normally assumed to be twice the end-to-end propagation delay although this might not be true if the message and the response traverses different links

Real Internet Delays & Routes

- What do "real" Internet delay & loss look like?
- 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
  - router *i* will return packets to sender
  - sender times interval between transmission and reply.

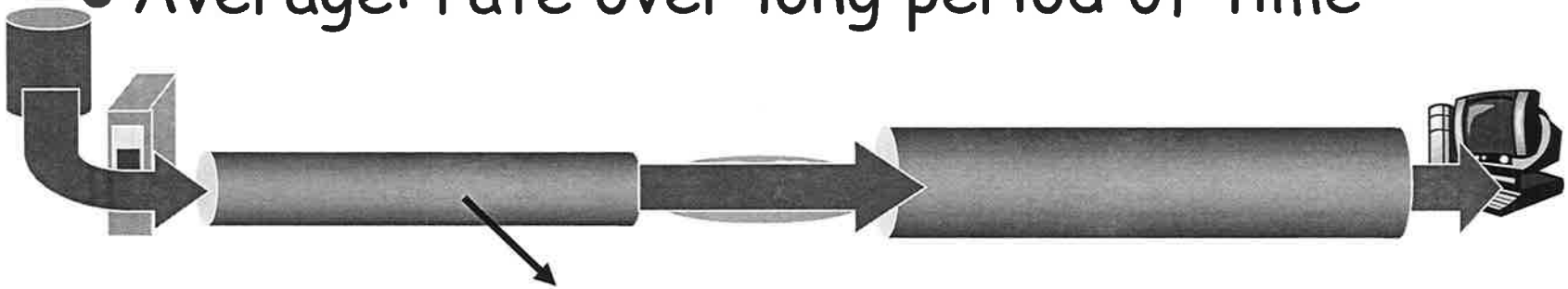


Throughput

- The Throughput is defined as the number of information bits that can be transferred reliably over a certain period of time. It is measured in "bps"
- The throughput is the carried load and it is not equal to the offered load
- Protocols add overhead bits and time delays in addition to the transmission time of the actual information bits. That would result in reduced throughput.
- Link errors are result in reduced throughput

Instantaneous vs. Average Throughput

- Throughput: rate (bits/time unit) at which bits transferred between sender/receiver
  - Instantaneous: rate at given point in time
  - Average: rate over long period of time



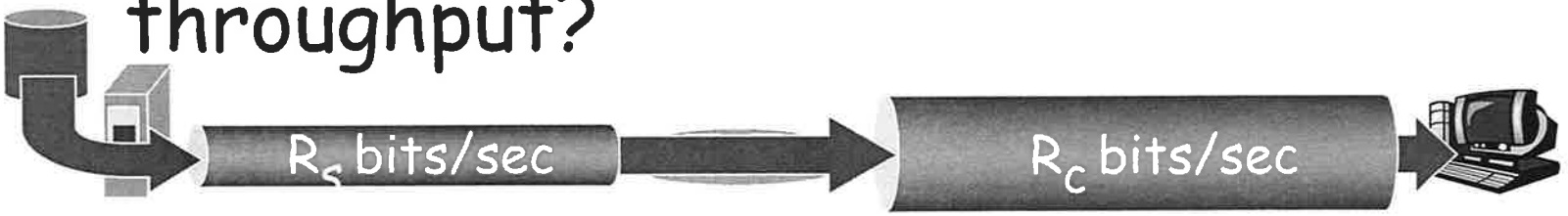
Server sends bits (fluid) into pipe

Pipe that can carry fluid at rate R_s bits/sec)

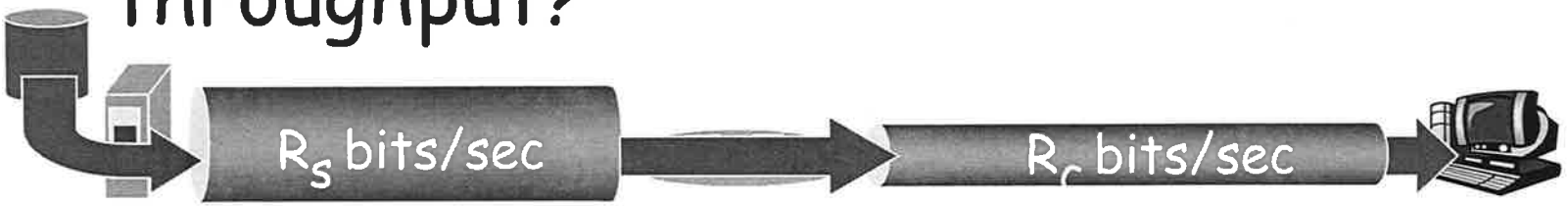
Pipe that can carry fluid at rate R_c bits/sec)

More on Throughput

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



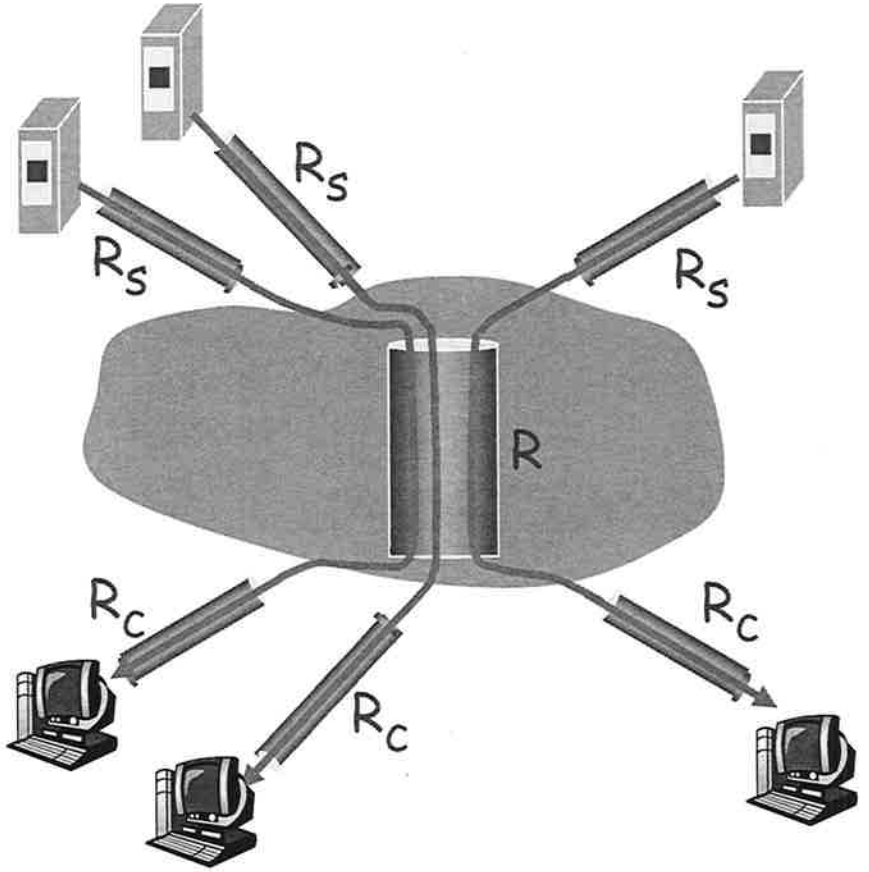
- $R_s > R_c$ What is average end-end throughput?



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

Example on Throughput

- per-connection end-end throughput: $\min(R_c, R_s, R/3)$
- In practice: R_c or R_s is often bottleneck
- Trunks have huge BW (i.e. R is v. Large)



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

Bandwidth/Capacity

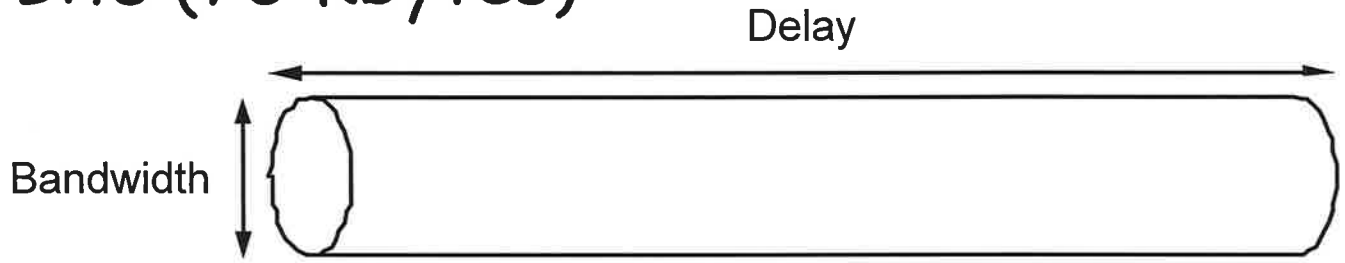
- The bandwidth or the data rate is the number of bits that can be transmitted over a certain period of time.
  - For example, 10 Mbps means that 10 million bits are transmitted every seconds.
- Link Capacity is the maximum data rate possible on the link with negligible error rate (Shannon Theorem, to be discussed later)

Hertz

~~Hurts~~

Bandwidth X Delay Product

- Pipe Size: The maximum amount of data present on the line, usually in an interval of RTT
- Example: If the line bandwidth (data rate) is 10 Mbps and the end-to-end delay is 30 msec, the amount of data found on the line is 600K Bits (75 Kbytes)



Networking Perspective

- Application Programmer / End User
  - Guaranteed timely, reliable and recognizable delivery of message/information
- Network Designer
  - Cost-effective design. Resources (Bandwidth, Memory and CPUs) must be used efficiently and are fairly allocated
- Network Provider
  - Administration & management effort, fault detection/fault isolation, easy to account for usage

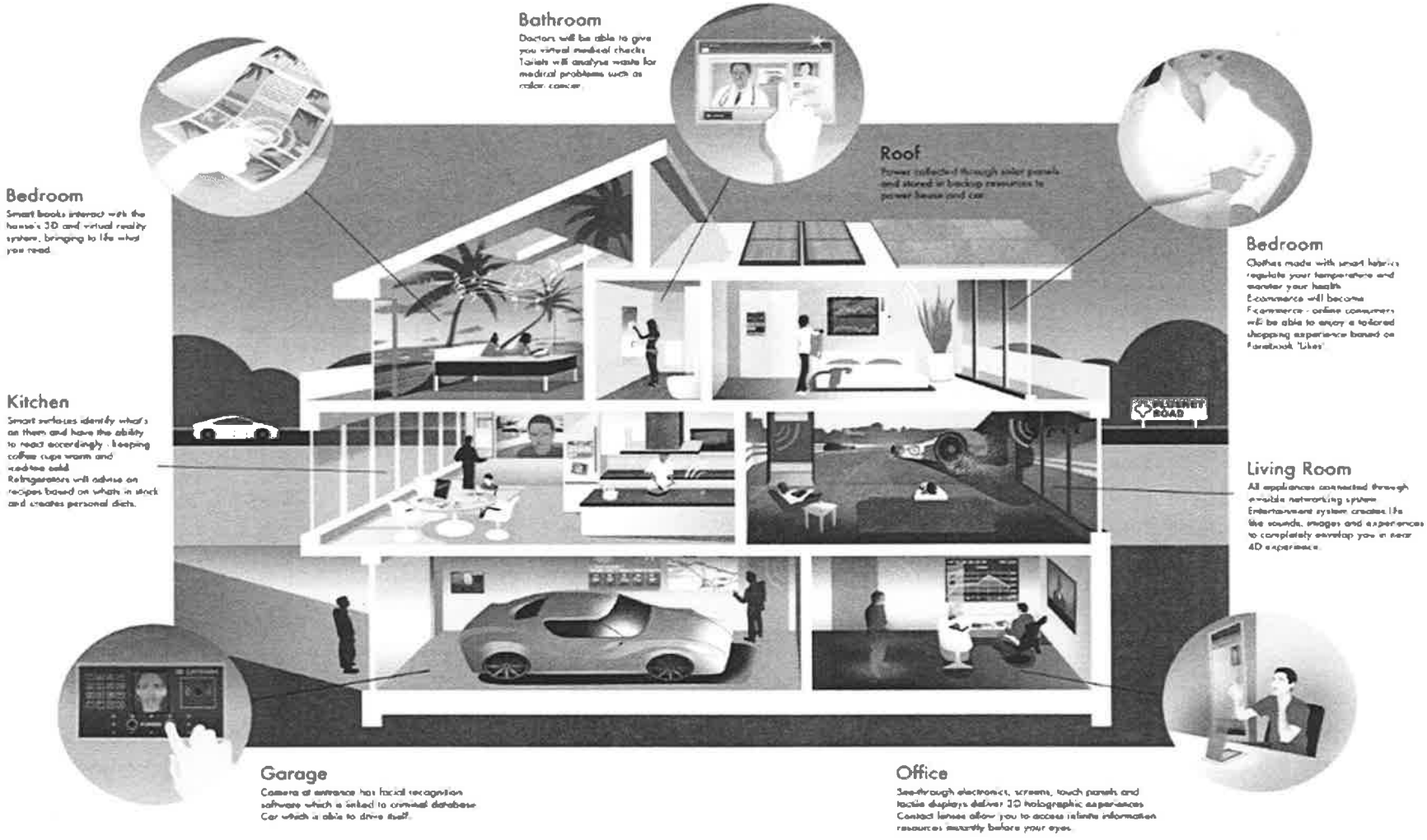
The Internet Today

- ~ 1 Billion Web Sites
- ~ 3 Billion Internet users
  - Number of Internet-ready devices exceeding number of users. Smart Phones, Tablets, etc…
- Aggressive deployment of broadband access
- Increasing ubiquity of high-speed wireless access
- Emergence of online social networks:
  - Face book ~ One billion users
- Service providers (Google, Microsoft) create their own networks
  - Bypass Internet, providing "instantaneous" access to search, email, etc.
- E-commerce, universities, enterprises running their services in "cloud" (e.g. Amazon)

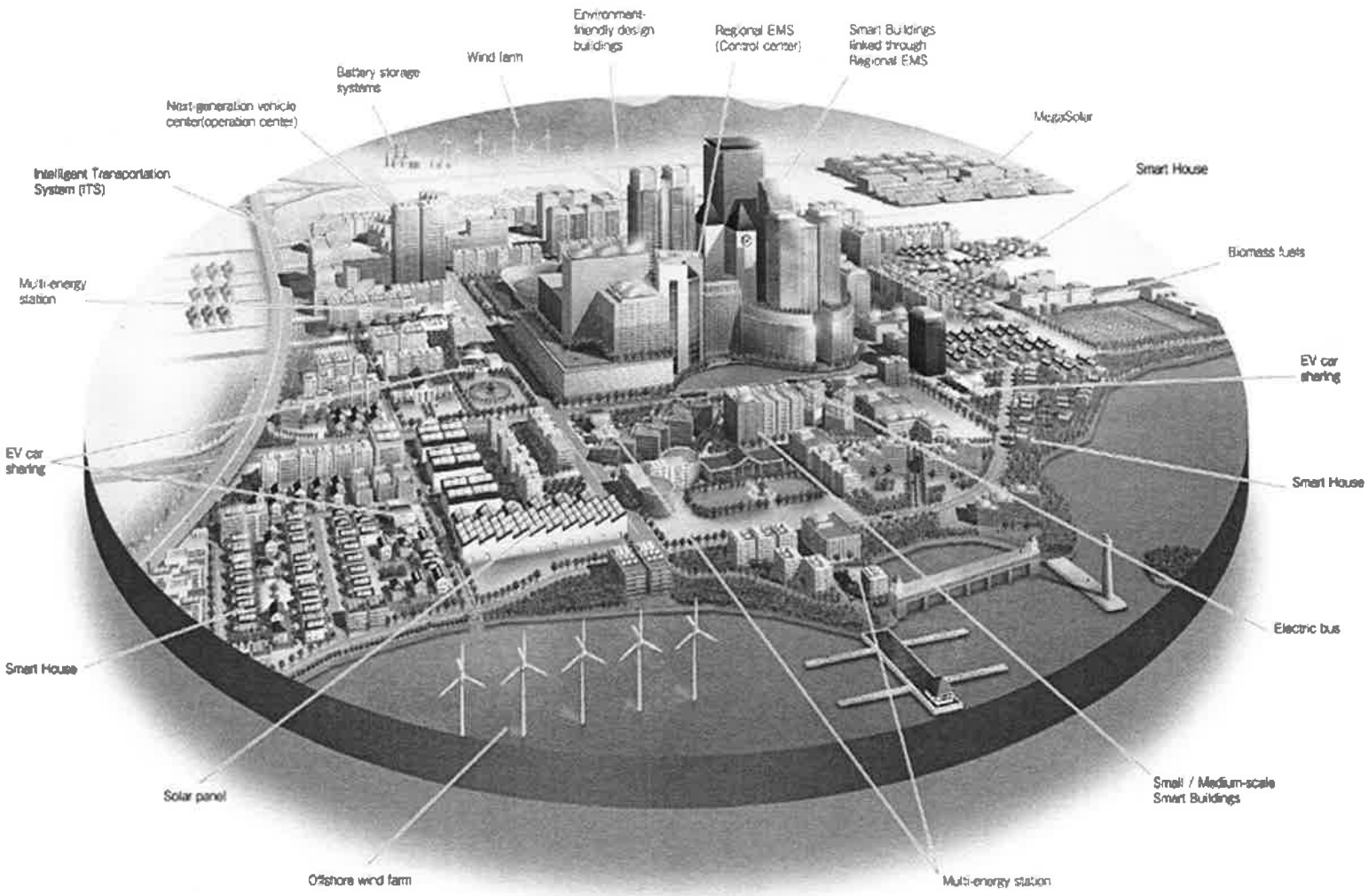
Emergence of the Internet of Things

- Extending the traditional "IP-over-everything, everything-over-IP" paradigm to smart objects, sensors, actuators, control systems, etc..
- IoT is enabled by the latest developments in RFID, Smart Sensors, embedded devices, communications Technologies, Internet Protocols and of course applications
- Emerging new applications: Smart Homes, Smart Buildings, eHealth, Smart Grid, Smart Cities, Industrial Automation, Transportation, etc...

Smart Home


Bathroom
Doctors will be able to give you virtual medical checks. Toilets will analyse waste for medical problems such as colon cancer.
Roof
Power collected through solar panels and stored in backup resources to power house and car.
Bedroom
Smart books interact with the home's 3D and virtual reality system, bringing to life what you read.
Bedroom
Clothes made with smart fabrics regulate your temperature and monitor your health.
E-commerce will become F-commerce - online consumers will be able to enjoy a tailored shopping experience based on Facebook 'Likes'.
Kitchen
Smart surfaces identify what's on them and have the ability to react accordingly - keeping coffee cups warm and roasting cold.
Refrigerators will advise on recipes based on what's in stock and creates personal diets.
Living Room
All appliances connected through a mobile networking system.
Entertainment system creates life like sounds, images and experiences to completely envelop you in near 4D experience.
Garage
Camera at entrance has facial recognition software which is linked to criminal database.
Car which is able to drive itself.
Office
See-through electronic screens, touch panels and tactile displays deliver 3D holographic experiences.
Contact lenses allow you to access infinite information resources instantly before your eyes.

Smart City


Environment-friendly design buildings
Regional EMS (Control center)
Smart Buildings linked through Regional EMS
Wind farm
Battery storage systems
Next-generation vehicle center(operation center)
MegaSolar
Intelligent Transportation System (ITS)
Smart House
Biomass fuels
Multi-energy station
EV car sharing
EV car sharing
Smart House
Electric bus
Smart House
Solar panel
Small / Medium-scale Smart Buildings
Offshore wind farm
Multi-energy station