Transport Layer
(Part 2)

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Transport Layer

- Process-to-process delivery §23.1
- User Datagram Protocol (UDP) §23.2
- Transmission Control Protocol (TCP) §23.3
- Network performance §3.6
- Congestion control §24.1-4
- Quality of Service (QoS) §24.5-6
- Real-time interactive audio/video §29.5

Performance

- Bandwidth
  - Hertz (frequency band)
  - Bits per second (capacity)
- Throughput
  - Efficiency
  - Always less than capacity
- Latency (Delay)
  - Transmission, propagation
  - Processing, queueing
- Jitter → real-time data!
Bandwidth-delay product

- How much data can fill the link
- Important for congestion avoidance
  - Delay = Round Trip Time (RTT)
  - Burst = 2 * bandwidth * delay

Bandwidth-delay product

**Traffic descriptors**

- Effective bandwidth
Traffic profiles

- Data rate vs. time
  - Constant bit rate
  - Variable bit rate
  - Bursty

Congestion

- Result of waiting
- When load > capacity
  - Arrival rate > processing rate
  - Processing rate > departure rate

Delay and throughput

- Delay as a function of load
- Throughput as a function of load
**Congestion control**

- Avoiding and eliminating congestion
  - Open-loop = proactive
  - Closed-loop = reactive

**Closed-loop congestion control (1)**

- Backpressure

**Closed-loop congestion control (2)**

- Choke packet
### Congestion Control in TCP

- **Congestion window**
  - size = \( \min(rwnd, cwnd) \)
- **Slow start (state)**
  - Exponential increase
- **Congestion avoidance (state)**
  - Additive increase
- **Congestion detection (event - to act upon)**
  - Multiplicative decrease

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#### Slow start: Exponential increase

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#### Congestion avoidance: Additive increase
Reaction to congestion detection

Detection by time-out
- Probably both channels congested
- New slow start phase

Detection by three ACK
- Probably sending channel congested only
- New congestion avoidance phase

TCP congestion policy: Summary

TCP congestion policy: Example
See you in 15’ :) 

After the break
- Quality of Service
- Real-time data

Quality of Service (QoS)
- Maintaining an appropriate environment
  - Meeting applications’ demands
  - Deals with flow characteristics

How to improve QoS
- Admission control
- Resource reservation
- Scheduling
- Traffic shaping
Scheduling: **FIFO queuing**

![Diagram for FIFO queuing]

Scheduling: **Priority queuing**

![Diagram for Priority queuing]

Scheduling: **Weighted fair queuing**

![Diagram for Weighted fair queuing]
Traffic shaping: **Leaky bucket**

![Diagram of Leaky bucket](image)

Traffic shaping: **Token bucket**

![Diagram of Token bucket](image)

Traffic shaping: **Two approaches**

- **Leaky bucket**
  - Input flow
  - Output flow after LB

- **Token bucket**
  - Input flow
  - Output flow after TB
Real-time interactive audio/video

- Two-way communication in real time
  - Internet telephony
  - Voice over IP
  - Video conferencing
- Sensitive to delay and jitter
  - TCP not suitable
- Not so sensitive to lost and corrupted packets
  - TCP not suitable

Real-time data: *Time relationship*

![Time relationship diagram]

Real-time data: *Jitter*

![Jitter diagram]
Real-time data: **Timestamping**

- Why?
  - Packets can be delivered out of order.
  - Packets can be dropped on their way.
  - Time stamps do not detect lost packets.
- Order in the playback buffer