Network traffic

- Request for resources
  - Rate of requests = Arrival rate = \( \lambda \)
  - Average resource hold time = \( T_h \)
  - Common Assumptions
    - Time between arrivals ~ exponentially
    - Holding time ~ exponentially

- Load
  - \( \lambda \) = packet/sec or calls/sec or files/sec...
  - \( T_h \) = average holding time sec/call
  - Service rate \( \mu = 1/T_h \)
  - Load = \( \lambda * T_h \) Erlangs = \( \lambda / \mu \)
Network traffic

Packet Voice
- Constraint: limit on end-to-end delay
- Packetization time (ms/packet)
- Role of the Jitter buffer
  - Compensate for random network delays
  - Jitter buffer size in bytes (or bits) or ms
  - Too small: lose packets
  - Too large: increase delay

VoIP Rate calculation

Data
- Burstyness = (Peak rate)/(Average rate)
- Large Burstyness leads to effective statistical multiplexing.
Performance Analysis

- **Given**
  - Traffic
  - QoS

- **Design system**
  - For M/M/1 → Find C
  - For M/M/1/N → Find C and System size=N
  - For M/M/N/N → Find Number of Servers

- **Assumptions**
  - Service time ~ Exponentially distributed
  - Interarrival time ~ Exponentially distributed

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**M/M/1**

*Average Number in System =*

\[
E[K] = \frac{\rho}{1 - \rho}
\]

*Variance of Number in System =*

\[
\text{Var}[K] = \frac{\rho}{(1 - \rho)^2}
\]

\[
E[D] = \frac{1}{\mu(1 - \rho)} = \frac{E[L]}{C} = E[TH] = \frac{1}{(1 - \rho)} = \frac{1}{\mu - \lambda}
\]

← Given on Test
M/M/1/K and M/M//N/N

- **M/M/1/K**
  
  $P_{\text{Blocking}} = P[K = S] = \frac{(1 - \rho)^S}{1 - \rho^{S+1}}$  
  
  - Given on Test

  - Full Table Given on Test

- **M/M/N/N** → **Erlang B**  
  - Table Given on Test

**MAC**

- Scaling & trade-offs WRT: rate (b/s), number of users, and size (km)
- Deterministic (Polling)
  - Operation (why called deterministic)
  - Calculate effective rate & efficiency

$$a = \frac{r'}{L} \quad \text{where} \quad r' = \text{Ring Latency}$$

$$C'$$

As $a \uparrow$, $S_{\text{Max}} \downarrow$
MAC

Random Access
- Collision process
  - Time vulnerable to collision
  - Detecting Collisions
- Time
  - Unslotted
  - Slotted
- Role of backoff process

MAC (Random Access-continued)

- Types (all can be slotted/unslotted)
  - ALOHA (for unslotted $S_{max} = 18\%$, for slotted $S_{max} = 36\%$)
  - CSMA
    - p-persistent (1-persistent)
    - Non-persistent
    - CSMA/CD
      \[
      a = \frac{r}{L} \quad \text{where} \quad r = \text{End-to-End Propagation Time}
      \]
      \[
      \text{As} \quad a \uparrow \quad S_{Max} \downarrow \text{ and as} \quad a \rightarrow 1, \quad S_{Max} \rightarrow ALOHA
      \]
- Leads to specification of Min/Max Packet size
MAC

- Collision Free Protocols
- Random Access and Reservation Systems
  - In upstream send requests to transmit
    - Use part of frame (contention slots) to send requests
    - Use random access to share contention slots
  - Receive grants in the downstream
  - No contention in downstream
  - If no grant in downstream then assume collision for the request, backoff and resend request in upstream

MAC- Ethernet

- IEEE 802.3
  - Evolution
    - Bus
    - Hub
    - Switch
      - 10 Mb/s → 100 Gb/s
  - Role of CSMA/CD
Network Elements

- Repeater
- Bridge
- Switch
- Router
  - Layer 2 Switch
  - Layer 3 Switch
  - Layer 4 Switch
  - Layer “Any” Switch

MAC- Wireless Networks

- Issues
  - Noise
  - Signal Fading
  - Hidden terminal
- RTS/CTS
MAC- Cable Networks

- DOCSIS
- Access protocol
- CM, Headend, CMTS

DLC

- Goal → point-to-point error free link
- Functions
  - Framing → Flags & bit stuffing
  - Error recovery
  - Flow control
DLC

- Sliding window flow control
  - n bits/SN in packet header
  - Max window $\Rightarrow N = 2^n - 1$
  - $N=1 \Rightarrow$ Stop and Wait
  - When to retransmit?
    - Timeout
    - RNR (NACK)
  - What to retransmit?
    - SN
    - Go-back-N
    - Selective Repeat

DLC

- Piggybacking
- Frame structure
  - Components of the packet overhead
- HDLC
DLC

- Performance
  \[ \eta = \frac{R_{\text{ef}}}{R} \]
  \[ R_{\text{ef}} = \frac{\# \text{bits}}{\text{Time to tx \# bits}} \]

* Understand assumptions behind these equations

- Stop&Wait*
  \[ \eta_{\text{Stop\&Wait}} = \frac{1}{1 + \frac{2\tau R}{n_f}} \]

- Sliding window*
  \[ \eta_{\text{SlidingWindow}} = \begin{cases} 
  1 & \text{if } N \geq \frac{2\tau R}{n_f} + 1 \\
  \frac{N}{1 + \frac{2\tau R}{n_f}} & \text{if } N < \frac{2\tau R}{n_f} + 1
\end{cases} \]

Small Window Case

\[ N_{\text{RTT}} = \# \text{Frames in RTT} \]

\[ = \frac{1}{1 + N_{\text{RTT}}} \]

DLC

- Open Loop Control
  - DE bit
  - Methods
    - CIR, B_c, B_e
    - Token bucket
      - Average rate
      - Maximum burst size
Transport Layer

- Port & sockets
- UDP
- TCP
  - Error free end-to-end communications
  - Connection oriented
  - Header checksum → covers data and header
  - SN in Bytes

Transport Layer - TCP continued

- Session setup/teardown
- Estimate RTT → set time out
- Window management for flow control
- Adaptive window for congestion control
  - Action on loss (timeout or duplicate ACKS)
  - Phases
    - Slow start
    - Congestion avoidance
    - Threshold
- RED
MPLS

- Internet mechanism to support VC for aggregate flows
- Language of MPLS
  - Label
  - FEC
  - LDP
  - LSR
  - LSP
- Enables
  - Traffic Engineering
  - QoS for FEC
- GMPLS

At the conclusion of this class the students are expected to:

- Understand the basics of network protocols, including,
  - MAC
  - Data link control,
  - Transport protocols
- Understand the nature of network traffic
- Understand the tradeoffs involved in network design in a variety of environments - LAN and WAN, diverse link rates, and varied error and delay conditions
- Perform simple analytic performance and design trade-off studies
- Be fluent in the language of communication networks, i.e., understand the meaning of networking terms and abbreviations