EEEN20060 Communication Systems

Analysis of MAC Protocols

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Scoil na hInnealtóireachta Leictrí, Leictreonaí agus Cumarsáide UCD

What do we want to know?

- Network Throughput
  - total rate of data transfer through system
  - bit/s or data block/s, from all users
  - or normalise: efficiency, block/frame time
- Average Transfer Delay
  - time from data block ready for transmission to final delivery at destination
  1. queuing time at sender
     - waiting behind other blocks that were ready earlier
  2. access delay, waiting for turn or permission
  3. contention delay, collisions & re-transmissions
  4. transmission time, actually sending frame
  5. propagation delay, sender to destination

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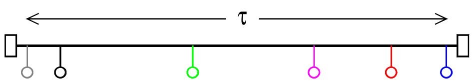
Scenario



- N devices share a channel
  - e.g. bus network, all in parallel on cable
- Blocks of data become ready at random times
  - often assume Poisson random process
  - queue to be transmitted
  - eventually sent as frame on channel
  - average time to transmit bits of frame is $\overline{T_F}$
- Propagation delay on channel
  - end-to-end (worst case) τ
  - average delay between two devices $\bar{\tau}$
- Ignore errors – short cable, separate problem

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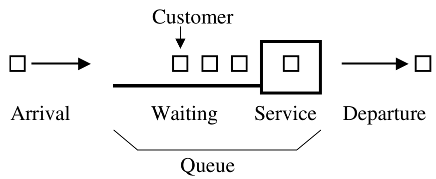
Queuing Theory



- In general, *customers*, here, data blocks
  - *arrive* into queue at random
    - here, Poisson random process
    - average rate of arrival λ (data block/s)
  - *wait* for some *service*, according to queue rule
    - here, service is transmission on channel
  - spend some time being served (service time)
    - here, frame transmission time – fixed or variable
    - average service rate is $\mu = \frac{1}{\overline{T_F}}$ (while busy)
  - then *depart* from the system

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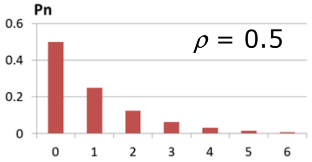
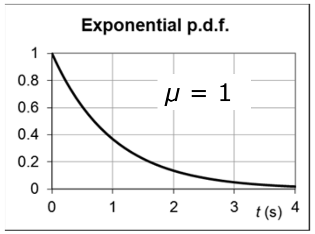
Queuing Theory





- For stable queue, need λ < μ
  - arrival rate < service rate
  - define ratio $\rho = \frac{\lambda}{\mu}$ as *link utilisation*, want < 1
- Consider random service times (frame size)
  - assume exponential prob. density function
    - as shown above – long frames less likely…
  - then prob. *n* customers in queue $P_n = \rho^n(1-\rho)$
    - assumes no limit on queue size…

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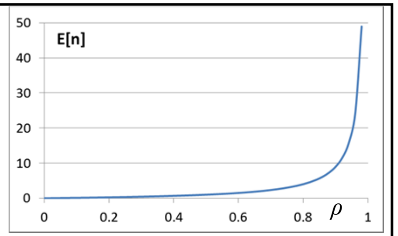
Queue Size



- Average number of customers in queue
  - know probability of *n* customers…
  - average: $\mathrm{E}[n] = \sum_{n=0}^{\infty} nP_n = \sum_{n=0}^{\infty} n\rho^n(1-\rho)$
  - get $\mathrm{E}[n] = \frac{\rho}{1-\rho}$ grows rapidly as $\rho \to 1$
- Assumptions (not always realistic):
    - arrivals are Poisson random process
    - service time (frame size) exponential p.d.f.
    - infinite queue (no limit on size)
  - but similar shape for other cases

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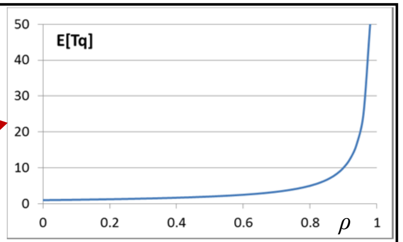
Queuing Time

Normalised: time in units of average service time



- Average time in system (incl. service)
  - Little's formula: $\mathrm{E}[n] = \lambda \mathrm{E}[t_Q]$
  - so $\mathrm{E}[t_Q] = \frac{\rho}{\lambda(1-\rho)} = \frac{1}{\mu(1-\rho)}$
- Average time waiting: subtract service time
  - $\mathrm{E}[t_W] = \mathrm{E}[t_Q] - \frac{1}{\mu} = \frac{\rho}{\mu(1-\rho)}$
- Fixed service time, this becomes
  - $\mathrm{E}[t_W] = \frac{\rho}{2\mu(1-\rho)}$ only half as long

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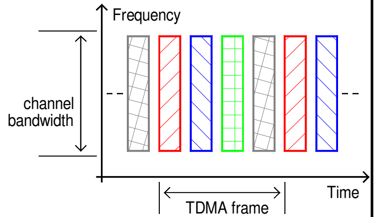
Example: Fixed TDMA



- Assume fixed-length link-layer frames
  - length T_F, chosen to fit in one time-slot
- Fixed and equal allocations to *N* devices
  - so *N* independent queues, arrival rates λ_i
  - service rate fixed, one block per cycle, $\mu = \frac{1}{T_C}$
  - so $\rho_i = \frac{\lambda_i}{\mu} = \lambda_i T_C$ and $\mathrm{E}[t_W] = \frac{\rho_i}{1-\rho_i}\frac{T_C}{2}$
- Cycle time is TDMA frame time, $T_C > NT_F$,
  - with overhead, let $T_C = (N+O)T_F$

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Fixed TDMA...

- Access delay – waiting for turn
  - average = half cycle time
  - but no contention delay
- Average transfer delay: $T_i = \frac{\rho_i}{1-\rho_i}\frac{T_C}{2} + \frac{T_C}{2} + T_F + \bar{\tau}$
- Total throughput: $\lambda = \sum_{i=1}^{N} \lambda_i$
  - assuming all queues stable, $\lambda_i < \mu$
  - max throughput needs frame in every time-slot
- Note:
  - *if* equal traffic from all, $\rho_i = \frac{\lambda}{N} T_C = \lambda T_F \frac{N+O}{N}$
  - *if* could combine all data into one queue...
  - service rate (on same channel) $\frac{1}{T_F}$, so $\rho = \lambda T_F$
  - average transfer delay: $T = \frac{\rho}{1-\rho}\frac{T_F}{2} + T_F + \bar{\tau}$

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Example: Polling, independent devices

- Devices generate traffic as in TDMA
  - queue, wait for poll before transmitting
- Cycle time now variable
  - depends on who has data, and how much...
- Cycle time has fixed component, *latency*, *L*
  - minimum cycle time, time to poll all devices
  - centralised polling: $L \approx N(T_{poll} + T_{response} + 2\bar{\tau})$
    - for each device, send poll, received after prop. delay
    - device sends response, received after prop. delay
    - times depend on bits in messages and channel bit rate
  - token passing: $L \approx N(T_{token} + \bar{\tau})$
    - for each device, time to transmit token, prop. delay
- Access delay = half average cycle time

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Polling...

- Waiting time in queue?
  - difficult to calculate in general, often simulate...
- Example:
  - device may send one frame when polled
  - so service rate is one frame per cycle
- How many devices will send frame in cycle?
  - device will send if queue not empty
  - prob. queue empty = $P_0 = 1 - \rho$
  - prob. of device i sending = ρ_i
  - expected no. frames in cycle = $\sum_{i-1}^{N} \rho_i$
- Average cycle time: $\bar{t_c} = L + \overline{T_F} \sum_{i=1}^{N} \rho_i$
  - hence average service rate...

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Example: Polling, master driven

- Devices generate data when polled
  - e.g. sensors in fire detection system
    - report status when asked, assume ask regularly
    - never want to transmit independently
  - assume equal priority, all polled at same rate
- Throughput depends on polling rate
  - design question is: how often can we poll?
- Cycle time: $T_C = N(T_{poll} + T_{response} + 2\bar{\tau})$
  - for each device, send poll, including data
  - device sends response, with data for master
    - times depend on bits in messages and channel bit rate
  - no queue at devices, no real access delay
    - nothing random in this system
  - so throughput is *N* blocks per cycle...

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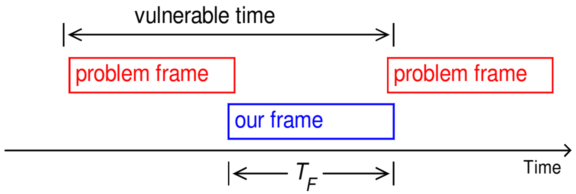
Example: Aloha



- Devices transmit frame when ready
  - collision if two (or more) frames overlap
- Assume data blocks fixed length (to simplify)
  - giving frame time T_F
- Vulnerable time $2T_F$
  - collision with our frame if any other device becomes ready in this interval…

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Aloha…

- After collision, back-off, re-transmit…
- To simplify analysis, assume:
  - data blocks arrive for transmission (across all devices) as Poisson random process
  - average arrival rate (new data blocks) λ
  - back-off algorithm makes total transmission attempts a Poisson random process also
  - average rate of attempts $\lambda' > \lambda$
- Probability of success
  - P_S = prob. no transmit attempts in time $2T_F$
  - for Poisson random process, $P_S = e^{-\lambda' 2T_F}$
  - or P_S = fraction of attempts that succeed: $P_S = \frac{\lambda}{\lambda'}$
  - equating these: $\lambda = \lambda' P_S = \lambda' e^{-\lambda' 2T_F}$

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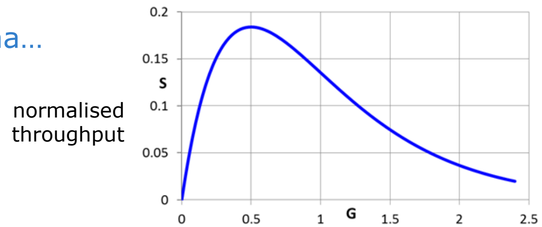
Aloha…



- Usually normalise to frame time
  - normalised throughput $S = \lambda T_F$ block/frame time
  - normalised attempt rate $G = \lambda' T_F$ attempt/fr. time
- Then $S = Ge^{-2G}$
  - differentiate: $\frac{dS}{dG} = e^{-2G}(1-2G)$ zero for max…
  - max throughput at G = 0.5 attempt/frame time
  - and $S_{max} = \frac{1}{2e} \approx 0.184$ block/frame time

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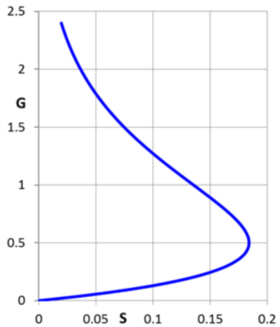
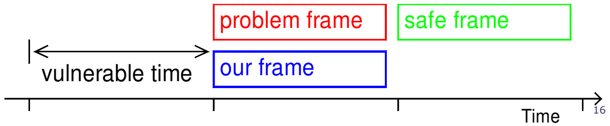
Aloha…



- Alternative view
  - desired throughput on X-axis
  - see two ways to get it
  - one with many collisions and long delays…
- Back-off algorithm vital!
  - want to stay on lower part of curve…
- Slotted Aloha
  - vulnerable time T_F
  - analysis similar…



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