Name:	**Student Number**:

THE UNIVERSITY OF MELBOURNE

Department of Electrical and Electronic Engineering

ELEN90061 Communication Networks

Mid-Semester Test 2016

Time allowed: 45 minutes

This paper has 8 pages

Authorised materials:

Approved electronic calculators are permitted.

Mobile phones, tablets, or any other computing devices are NOT permitted!

This is a closed book and notes test!

Instructions to students:

Please write your answers clearly and legibly to the provided boxes. *Show all your work to receive full credit!* You can use the back of the pages for intermediate steps when needed.

The marks for each question are indicated in brackets after the question.

The total marks for this test is **30**.

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Question 1 [10 marks]:

Explain your answers for full credit. No explanation receives no credits!

1.1) Four active wireless nodes A, B, C, D attempt to transmit to a base station in a **slotted ALOHA** system. Assume that each node has always a packet to send. The slots are numbered as 1, 2, 3, …. Each node attempts to transmit in each time slot with a probability ***p***.

Find the probability that *Node A* *<u>or</u>* *Node B succeeds for the first time in Slot 3*. **[6 marks]**
Hint: the solution will be a polynomial in terms of p. You <u>do not</u> need to simplify your answer.

Very similar to Question 4 in Week 2!

P(A succeeds in any slot) $= p(1-p)^3$; Same for B!

P(A succeeds first time in slot 3) $= \underbrace{p(1-p)^3}_{3^{rd}\text{ slot}} \underbrace{\left[1 - p(1-p)^3\right]^{2}}_{\text{A fails in first 2 slots}}$

Again, this is same for B, i.e. P(B succeeds first time in slot 3).

Note, that these events are mutually exclusive since only one node can succeed (at a time) in slot 3. Add the probabilities!

$\Rightarrow$ P(A first time in slot3 or B first time in slot 3)

$= 2p(1-p)^3\left[1-p(1-p)^3\right]^2$

I have accepted the answer below as well but it is NOT really correct!
Why? Think of the successful transmission sequences (events) B,B,A or A,A,B. Those are not taken into account by the calculation below**.**

P(A or B succeeds in any slot) = P(A succeeds) + P(B succeeds)

$\Rightarrow$ P(A or B any) $= p(1-p)^3 + p(1-p)^3 = \underline{2p(1-p)^3}$

P(A or B succeeds first time in slot 3) $= (1 - P(\text{A or B any}))^2 \cdot P(\text{A or B any})$

Substitute in $= \underline{(1 - 2p(1-p)^3)^2 \cdot 2p(1-p)^3}$

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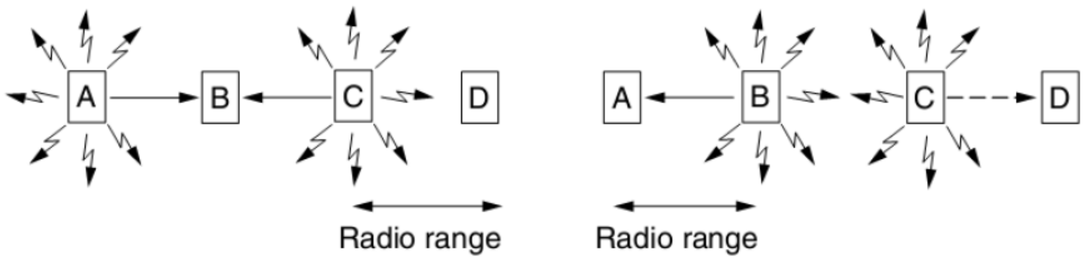
1.2) Describe the **hidden terminal problem** in wireless networks with diagrams and a few sentences using your own words. **[4 marks]**

See Week 3 slides (v2), slide 21



(a) (b)

A wireless LAN.
(a) A and C are **hidden terminals** when transmitting to B.
(b) B and C are exposed terminals when transmitting to A and D .

The problem of a station not being able to detect a potential competitor for the medium because the competitor is too far away is called the **hidden terminal problem**.

Note: it is expected here that you discuss the range/distance between nodes A and C!

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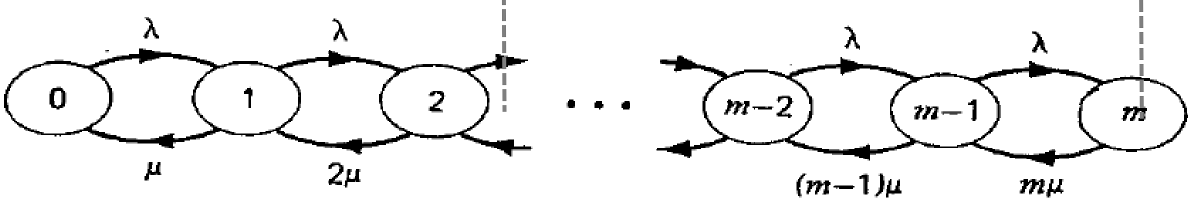
Question 2 [10 marks]:

Explain your answers for full credit. No explanation receives no credits!

2.1) Consider the birth-death process with the state transition diagram shown below. What type of a queueing system can this birth-death process model *assuming* Poisson arrivals and exponentially distributed service times with the respective rates? *Clearly explain your answer and reasoning.*

[2 marks]



Answer: this can be an **M/M/x/x** system due to the assumptions made. There are only m+1 states, so it has to be **M/M/x/m**, i.e. only m spaces in the queueing system. Since the service rates scale proportional to states with max of mμ, it has to have m servers, i.e. **M/M/m/m** queueing system.

2.2) Write the set of **detailed balance equations** for the queuing system in Part 2.1 above and provide a general expression in terms of **p_0**. *Hint: consider the flows across barriers such as the example two shown above using dashed lines.* **[8 marks]**

$$\left.\begin{aligned} p_0\lambda &= p_1\cdot\mu \\ p_1\lambda &= p_2(2\mu) \\ &\vdots \\ p_{m-1}\lambda &= p_m\cdot(m\mu) \end{aligned}\right\} \Rightarrow p_{k+1}(k+1)\mu = p_k\cdot\lambda\,,\quad k=0,\dots,m-1$$

$$p_{k+1} = \frac{\lambda}{(k+1)\mu}\cdot p_k \;;\; \text{recursively substitute until } p_0!$$

$$p_k = \prod_{i=0}^{k-1}\frac{\lambda}{(i+1)\mu}\cdot p_0 \iff p_k = \begin{cases} p_0\left(\frac{\lambda}{\mu}\right)^k\frac{1}{k!}, & 0\le k\le m \\ 0, & k>m \end{cases}$$

$$k=0,\dots,m$$

Note: detailed balance equations are not the same as global balance ones… See Wk4v2 slides 64-65….

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Question 3 [10 marks]:

The company you are working for gives you the task of *designing a simple communication network*. After some experimentation you decide that the incoming packet traffic to the network from outside can be modelled as a Poisson process with an average arrival rate of $\lambda= 6$ per second. For simplicity, you also decide to model the routers having exponentially distributed service times and infinite buffers.

Your budget allows you to buy either **(1)** a single fast router with a service rate of $\mu=8$ per second **or** **(2)** two routers each having service rate of $\mu=4$ per second with a simple load balancer in front of them that forwards each incoming request randomly to one of the routers with 50% probability.

Explain your answers for full credit. No explanation receives no credits!

3.1) Identify the queueing systems and **calculate** *the average number of total customers* as well as *the time they spend in the system* ***for each option*** described above. **[8 marks]**

Answer: This is very similar to the question in Workshop 2!

1. M/M/1 queue. $\rho=\lambda/\mu=6/8=0.75$.
2. Two M/M/1 queues with $\lambda= 3$ and $\mu=4$, $\rho=\lambda/\mu=0.75$ same!

$\Rightarrow N_{serv} = \frac{\lambda}{\mu} = \rho$

Hence $N = \bar{N}_q + N_{serv} = \frac{\rho^2}{1-\rho} + \rho = \frac{\rho}{1-\rho} = 3$

From Little's Law: $T = N/\lambda = 3/6 = 0.5$ secs

(2) ρ is same, so $N_1 = 3$, $N_2 = 3$ $N_{total} = 6$

$\lambda_1 = \lambda_2 = \lambda/2 = 3$

$T_1 = T_2 = \frac{N_1}{\lambda_1} = \frac{N_2}{\lambda_2} = \frac{3}{3} = 1$ second.

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3.2) Based on your calculations in Part 3.1, which of the two options would you choose? Are there other engineering considerations which are not taken into account by the model above?
Clearly explain your answers and reasoning. **[2 marks]**

Answer: Clearly option 1 is more desirable due to less amount of delay. [1 mark]

However, there may be other considerations such **cost**, **robustness** (potential equipment failures) or **additional complexity** issues due to load balancer. Taking into account some of these considerations may make option 2 more appealing.

I have given full one mark here to any meaningful discussion since it is an open-ended question.

END OF EXAM

$\boxed{\textbf{Useful formulas}}$

$$General: \quad N = \lambda T$$

$$P(X = x) = \frac{\lambda^x e^{-\lambda}}{x!} \quad (Poisson)$$

$$f_X(x) = \lambda e^{-\lambda x}, \; x \geq 0 \quad (Exponential)$$

$$p_k = p_0 \prod_{i=0}^{k-1} \frac{\lambda_i}{\mu_{i+1}} \quad (General\ balance)$$

$$M/M/1: \quad \rho = \frac{\lambda}{\mu}$$

$$p_k = (1-\rho)\rho^k$$

$$\bar{N}_q = \frac{\rho^2}{1-\rho}$$

$$P[\geq k\ in\ system] = \rho^k$$

$$M/M/m: \quad \bar{N}_q = \left(\frac{(m\rho)^m \rho}{m!(1-\rho)^2}\right) p_0$$

$$p_0 = \left[\sum_{k=0}^{m-1} \frac{(m\rho)^k}{k!} + \frac{(m\rho)^m}{m!} \frac{1}{1-\rho}\right]^{-1}$$

$$\rho = \frac{\lambda}{m\mu}$$

$$p_k = p_0 \frac{(m\rho)^k}{k!}, \quad k \leq m, \; \rho < 1$$

$$p_k = p_0 \frac{(m\rho)^k}{m! m^{k-m}}, \quad k > m, \; \rho < 1.$$

$$P[queueing] = \frac{\frac{(m\rho)^m}{m!} \frac{1}{1-\rho}}{\left[\sum_{k=0}^{m-1} \frac{(m\rho)^k}{k!} + \frac{(m\rho)^m}{m!} \frac{1}{1-\rho}\right]} \; (Erlang\, C)$$

$$M/M/\infty: \quad \bar{N} = \frac{\lambda}{\mu}$$

$$M/M/1/K: \quad \bar{N}_q = \frac{\lambda/\mu}{1-\lambda/\mu} - \frac{(\lambda/\mu)\left[K(\lambda/\mu)^K + 1\right]}{1-(\lambda/\mu)^{K+1}}$$

$$M/M/1/K: \quad p_k = \frac{1-\rho}{1-\rho^{K+1}}\rho^k,\ 0 \le k \le K, \rho \ne 1.$$

$$p_k = 0,\ \text{otherwise.}$$

$$M/M/m/m: \quad p_m = \frac{(\lambda/\mu)^m/m!}{\sum_{k=0}^{m}(\lambda/\mu)^k/k!}\ (Erlang\ B)$$

$$M/G/1: \quad W = \frac{\lambda\overline{X^2}}{2(1-\rho)} = \frac{\lambda\overline{X^2}}{2(1-\lambda\bar{X})}$$

$$W = \frac{\lambda\overline{X^2}}{2(1-\rho)} + \frac{\overline{V^2}}{2\overline{V}}\ (with\ vacations)$$

$$\text{Non-preemptive priority}: \quad W_k = \frac{R}{(1-\rho_1-\cdots-\rho_{k-1})(1-\rho_1-\cdots-\rho_k)}$$

$$R = \frac{1}{2}\sum_{i=1}^{n}\lambda_i\overline{X_i^2}$$

$$\text{Preemptive resume priority}: \quad T_k = \frac{\frac{1}{\mu_k}(1-\rho_1-\cdots-\rho_k)+R_k}{(1-\rho_1-\cdots-\rho_{k-1})(1-\rho_1-\cdots-\rho_k)}$$

$$R_k = \frac{1}{2}\sum_{i=1}^{k}\lambda_i\overline{X_i^2}$$

$$G/G/1: \quad W \le \frac{\lambda(var^2_{intarrival} + var^2_{service})}{2(1-\rho)}$$