GENERAL SIR JOHN KOTELAWALA DEFENCE UNIVERSITY

Faculty of Engineering

Department of Electrical, Electronic and Telecommunication Engineering

BSc. Engineering Honours Degree

Semester 8 Examination – November 2025

(Intake 39 – ET)

ET 4222 – Communication Theory III

Time allowed: 3 Hours | 24 November 2025

ADDITIONAL MATERIAL PROVIDED

1. Queuing Formula
2. Earlang B Table

INSTRUCTIONS TO CANDIDATES

This paper contains 4 questions on 5 pages.

Answer ALL questions

This is a closed book examination.

This examination accounts for 70% of the module assessment. The marks assigned for each question and parts thereof are indicated in square brackets.

If you have any doubt as to the interpretation of the wording of a question, make your own decision, but clearly state it on the script.

Assume reasonable values for any data not given in or provided with the question paper, clearly write such assumptions made in the script.

All examinations are conducted under the rules and regulations of KDU.

DETAILS OF ASSESSMENT

Learning Outcome (LO)	Questions that assess LO	Marks allocated (Total 70)
LO1	Q1	20
LO2	Q2	25
LO3	Q3	15
LO4	Q4	15

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Question 1

[Total 20 marks]

(a) "Teletraffic theory is important for network planning and Network Management control". Explain the statement. QoS, Sys. Cap., Traffic Load [04]

(b) Explain the role of ITU, ETSI and IETF for the communication industry. [03]

International
Telecom. Union

may not meet QoS req.

(c) Explain Normal load, high load and overload with examples. [03]

needs additional inf/resources

(d) Consider a new operator that plans to provide mobile coverage for the following areas.
(i) Highway.
(ii) Urban area
(iii) Airport

Predict the traffic pattern and the services required, along with an explanation. [06]

(e) Explain in what situations the Earlang B table and Earlang C table are used [04]

Question 2

[Total 25 marks]

(a) A cloud-based web server handles incoming API requests. The arrival rate is 120 requests/min, and the service rate of the server is 180 requests/min. Engineers want to evaluate the system's responsiveness during peak traffic. Compute:

(i) Server utilization

(ii) Average number of API requests in the system

(iii) Average response time

(iv) Probability that an incoming user finds the server idle

[08]

(b) An IoT gateway buffers sensor readings before forwarding them to a cloud server. It has a buffer capacity of 10 packets, an arrival rate of 40 packets/sec, and a service rate of 60 packets/sec.

Due to network congestion, engineers are required to find the following:

(i) Probability that the buffer is full

(ii) Effective arrival rate (packets that are NOT dropped)

(iii) Average number of packets in the gateway

[06]

(c) A telecom operator deploys 20 voice channels for a rural area tower. Calls arrive at call arrival time, 8 calls/min, and the average call duration is 180 seconds. The operator wants to evaluate the quality of service.

Compute the following:

(a) Traffic offered

(b) Blocking probability

(c) Carried traffic

[06]

(d) Two ticket counters are opened to issue the train tickets. The station master marked the lines on the ground to indicate the queue positions in front of each counter. Applying the knowledge of queuing theory, illustrate how the queue/ queues should be marked in front of the counters, explaining the reasons.

[05]

Question 3 **[Total 15 marks]**

(a) Determine the Kendall notation for the following scenarios.

(i) Several teller machines located in supermarkets fail to permit withdrawals. Three agents handle the customer service and all the customer complaints regarding the matter once they were unable to withdraw money. [02]

(ii) Customers walk in to repair different electronic items to a repair shop with one technician. [02]

(iii) The automated conveyor brings items periodically to a worker. [02]

(iv) Patients arrive for Vaccination in a given time slot. The vaccination is conducted by an experienced nurse at the government hospital. [02]

(b) Discuss the advantages and disadvantages of having a higher queue length.

[05]

(c) Explain the difference of M/M/1 Queue and M/G/1 Queue in terms of usage and performance

[02]

Question 4 **[Total 15 marks]**

A large smart-city deployment uses multiple IoT access points to collect sensor data across different regions. Each access point receives traffic from hundreds of sensor nodes that transmit packets at irregular intervals. You are asked to model and simulate the network traffic to evaluate congestion levels and end-to-end performance

(a) A student suggests a Monte Carlo simulator for the above simulation. Explain the suitability of the suggested simulator with justification. [04]

(b) Explain how traffic theory can be applied to model the packet arrivals from IoT sensors in this network. Discuss the suitability of models such as Poisson arrival, batch arrivals, or self-similar traffic in representing real IoT traffic patterns. [03]

(c) The access points process packets with known average service times but significant variability due to intermittent backhaul delays. Propose an appropriate queueing model to simulate the behaviour of each access point. Justify your choice based on the traffic and service characteristics. [04]

(d) Explain the performance metrics you will measure to evaluate the network performance. [04]

End of question paper

Symbols

P_n - Steady state probability that there are n customers in the system.

ρ - The traffic intensity or offered load (Utilization) $\rho = \lambda\bar{S}$.

λ - Mean arrival rate of customers into the system

$\bar{\lambda}$ - Actual mean arrival rate into the system, for which some arrivals are turned away, e.q., the M/M/c/c system.

μ - Mean service rate per server, that is, the mean rate of service completions while the server is busy.

N - The steady state number of customers in the system.

$\bar{N}$ - Expected steady state number of customers in the queuing system

Q - Random variable describing the steady state number of customers in the queue.

$\bar{Q}$ – Expected number of customers in the queue (steady state)

$F_T(t)$ - The distribution function of T , $F_T(t) = P[T < t]$

T - the total time a customer spends in the queueing system, $T = W + S$

$\bar{T}$ - Expected steady state time a customer spends in the system, $\bar{T} = E[T] = \bar{W} + \bar{S}$

W - The time a customer spends in the queue before service begins.

$\bar{W}$ – Expected steady state time a customer spends in the queue before service begins.

S - Customer service time

$\bar{S}$ - Expected customer service time. ($1/\mu$)

a - Server utilization

a_i - Utilization of component *i* in a queuing network.

c - Number of servers in a service facility.

K - Maximum number of customers allowed in the queuing system. Also size of the population in finite population models.

M/M/1 Formulas

$$\rho = \lambda\overline{S}, \quad P_n = P[N = n] = (1-\rho)\rho^n, \quad n = 0, 1, \ldots.$$

$$P[N \geq n] = \rho^n, \quad n = 0, 1, \ldots.$$

$$\overline{N} = \mathbf{E}[N] = \overline{\lambda} \cdot \overline{T} = \frac{\rho}{1-\rho}, \quad Var(N) = \frac{\rho}{(1-\rho)^2}.$$

$$\overline{Q} = \lambda\overline{W} = \frac{\rho^2}{1-\rho}, \quad Var(Q) = \frac{\rho^2(1+\rho-\rho^2)}{(1-\rho)^2}.$$

$$\mathbf{E}[Q|Q>0] = \frac{1}{1-\rho}, \quad Var[Q|Q>0] = \frac{\rho}{(1-\rho)^2}.$$

$$F_T(t) = P[T \leq t] = 1 - \exp\left(\frac{-t}{\overline{T}}\right), \quad P[T > t] = \exp\left(\frac{-t}{\overline{T}}\right).$$

$$\overline{T} = \mathbf{E}[T] = \frac{\overline{S}}{1-\rho} = \frac{1}{\mu(1-\rho)}, \quad Var(T) = \overline{T}^2.$$

$$\pi_T[r] = \overline{T}\ln\left(\frac{100}{100-r}\right), \quad \pi_T[90] = \overline{T}\ln 10, \quad \pi_T[95] = \overline{T}\ln 20$$

$$F_T(t) = P[W \leq t] = 1 - \rho\exp\left(\frac{-t}{\overline{T}}\right), \quad P[W > t] = \rho\exp\left(\frac{-t}{\overline{T}}\right).$$

$$\overline{W} = \frac{\rho\overline{S}}{1-\rho}, \quad Var(W) = \frac{(2-\rho)\rho\overline{S}^2}{(1-\rho)^2}.$$

M/M/1/K Formulas

$$P_n = \begin{cases} \dfrac{(1-\rho)\rho^n}{(1-\rho^{K+1})} & \text{if } \lambda \neq \mu \\ \\ \dfrac{1}{K+1} & \text{if } \lambda = \mu \end{cases}$$

$n = 0, 1, \ldots, K$, where $\rho = \lambda\overline{S}$.

$\overline{\lambda} = (1 - P_K)\lambda$, Mean arrival rate into system.

$$\overline{N} = \begin{cases} \dfrac{\rho[1-(K+1)\rho^K + K\rho^{K+1}]}{(1-\rho)(1-\rho^{K+1})} & \text{ha } \lambda \neq \mu \\ \\ \dfrac{K}{2} & \text{ha } \lambda = \mu. \end{cases}$$

$$\overline{Q} = \overline{N} - (1 - P_0), \quad \Pi_n = \frac{P_n}{1 - P_K}, n = 0, 1, \ldots, K-1.$$

$$F_T(t) = 1 - \sum_{n=0}^{K-1} \Pi_n Q[n; \mu t],$$

where

$$Q[n; \mu t] = e^{-\mu t} \sum_{k=0}^{n} \frac{(\mu t)^k}{k!}.$$

$$\overline{T} = \frac{\overline{N}}{\overline{\lambda}}, \quad \overline{W} = \frac{\overline{Q}}{\overline{\lambda}}.$$

$$F_T(t) = 1 - \sum_{n=0}^{K-2} \Pi_{n+1} Q[n; \mu t].$$

$$\mathbb{E}[W | W > 0] = \frac{\overline{W}}{1 - \Pi_0}, \quad a = (1 - P_K)\rho.$$

M/M/c Formulas

$$\rho = \lambda\overline{S}, \quad a = \frac{\rho}{c}$$

$$P_0 = \left[\sum_{n=0}^{c-1} \frac{\rho^n}{n!} + \frac{\rho^c}{c!(1-a)}\right]^{-1} = \frac{c!(1-a)P[N \geq c]}{\rho^c}.$$

$$P_n = \begin{cases} \dfrac{\rho^n}{n!}P_0, & \text{if } n \leq c \\[2ex] \dfrac{\rho^n}{c!c^{n-c}}P_0, & \text{if } n \geq c. \end{cases}$$

$$P[N \geq n] = \begin{cases} P_0\left[\displaystyle\sum_{k=n}^{c-1} \frac{\rho^k}{k!} + \frac{\rho^c}{c!(1-a)}\right] & \text{if } n < c, \\[3ex] P_0\left[\dfrac{a^c a^{n-c}}{c!(1-a)}\right] = P[N \geq c]a^{n-c} & \text{if } n \geq c \end{cases}$$

$$\overline{Q} = \overline{\lambda} \cdot \overline{W} = \frac{\rho P[N \geq c]}{c(1-a)},$$

where

$$P[N \geq c] = C[c, \rho] = \frac{\dfrac{\rho^c}{c!}}{(1 - \dfrac{\rho}{c})\displaystyle\sum_{n=0}^{c-1} \frac{\rho^n}{n!} + \frac{\rho^c}{c!}}.$$

$$Var(Q) = \frac{aC[c,\rho][1 + a - aC[c,\rho]]}{(1-a)^2}.$$

$$\overline{N} = \overline{\lambda} \cdot \overline{T} = \overline{Q} + \rho.$$

$$Var(N) = Var(Q) + \rho(1 + P[N \geq c]).$$

$$\overline{W}[0] = 1 - P[N \geq c], \quad F_T(t) = 1 - P[N \geq c]\exp[-c\mu t(1-a)],$$

$$\overline{W} = \frac{P[N \geq c]\overline{S}}{c(1-a)}.$$

M/M/c/c Formulas

$$\rho = \lambda \overline{S}$$

$$P_n = \frac{\frac{\rho^n}{n!}}{1 + \rho + \frac{\rho^2}{2!} + \ldots + \frac{\rho^c}{c!}} \qquad n = 0, 1, \ldots, c.$$

The probability that all servers are busy, P_c is called Erlang's B formula, $B[c, \rho]$, and thus

$$B[c, \rho] = \frac{\frac{\rho^c}{c!}}{1 + \rho + \frac{\rho^2}{2!} + \ldots + \frac{\rho^c}{c!}}.$$

$\overline{\lambda} = \lambda(1 - B[c, \rho])$ Is the average arrival rate of customers who actually enter the system. Thus, the true server utilization, a, is given by

$$a = \frac{\overline{\lambda}\,\overline{S}}{c}.$$

$$\overline{N} = \overline{\lambda}\,\overline{S}.$$

$$\overline{T} = \frac{\overline{N}}{\overline{\lambda}} = \overline{S}.$$

$$F_T(t) = 1 - \exp\left(\frac{-t}{\overline{S}}\right).$$

M/M/c/K Formulas

$$\rho = \lambda \overline{S}.$$

$$P_0 = \left[\sum_{n=0}^{c} \frac{\rho^n}{n!} + \frac{\rho^c}{c!} \sum_{n=1}^{K-c} \left(\frac{\rho}{c} \right)^n \right]^{-1}.$$

$$P_n = \begin{cases} \dfrac{\rho^n}{n!} P_0 & \text{if } n = 1, 2, \ldots, c, \\ \dfrac{\rho^n}{c!} \left(\dfrac{\rho}{c} \right)^{n-c} P_0 & \text{if } n = c+1, \ldots, K. \end{cases}$$

The average arrival rate of customers who actually enter the system is $\overline{\lambda} = \lambda(1 - P_K)$.

The actual mean server utilization, a, is given by:

$$a = \frac{\overline{\lambda}\,\overline{S}}{c}.$$

$$\overline{Q} = \frac{\rho^c r P_0}{c!(1-r)^2} \left[1 + (K-c) r^{K-c+1} - (K-c+1) r^{K-c} \right],$$

where

$$r = \frac{\rho}{c}.$$

$$\overline{N} = \overline{Q} + \mathbb{E}[N_s] = \overline{Q} + \sum_{n=0}^{c-1} n P_n + c \left(1 - \sum_{n=0}^{c-1} P_n \right).$$

By Little's Law

$$\overline{W} = \frac{\overline{Q}}{\overline{\lambda}}, \qquad \overline{T} = \frac{\overline{N}}{\overline{\lambda}}.$$

$$\Pi_n = \frac{P_n}{1 - P_K}, \quad n = 0, 1, 2, \ldots, K-1,$$

Erlang B Traffic Table

Maximum Offered Load Versus B and N

B is in %

N/B	0.01	0.05	0.1	0.5	1.0	2	5	10	15	20	30	40
1	.0001	.0005	.0010	.0050	.0101	.0204	.0526	.1111	.1765	.2500	.4286	.6667
2	.0142	.0321	.0458	.1054	.1526	.2235	.3813	.5954	.7962	1.000	1.449	2.000
3	.0868	.1517	.1938	.3490	.4555	.6022	.8994	1.271	1.603	1.930	2.633	3.480
4	.2347	.3624	.4393	.7012	.8694	1.092	1.525	2.045	2.501	2.945	3.891	5.021
5	.4520	.6486	.7621	1.132	1.361	1.657	2.219	2.881	3.454	4.010	5.189	6.596
6	.7282	.9957	1.146	1.622	1.909	2.276	2.960	3.758	4.445	5.109	6.514	8.191
7	1.054	1.392	1.579	2.158	2.501	2.935	3.738	4.666	5.461	6.230	7.856	9.800
8	1.422	1.830	2.051	2.730	3.128	3.627	4.543	5.597	6.498	7.369	9.213	11.42
9	1.826	2.302	2.558	3.333	3.783	4.345	5.370	6.546	7.551	8.522	10.58	13.05
10	2.260	2.803	3.092	3.961	4.461	5.084	6.216	7.511	8.616	9.685	11.95	14.68
11	2.722	3.329	3.651	4.610	5.160	5.842	7.076	8.487	9.691	10.86	13.33	16.31
12	3.207	3.878	4.231	5.279	5.876	6.615	7.950	9.474	10.78	12.04	14.72	17.95
13	3.713	4.447	4.831	5.964	6.607	7.402	8.835	10.47	11.87	13.22	16.11	19.60
14	4.239	5.032	5.446	6.663	7.352	8.200	9.730	11.47	12.97	14.41	17.50	21.24
15	4.781	5.634	6.077	7.376	8.108	9.010	10.63	12.48	14.07	15.61	18.90	22.89
16	5.339	6.250	6.722	8.100	8.875	9.828	11.54	13.50	15.18	16.81	20.30	24.54
17	5.911	6.878	7.378	8.834	9.652	10.66	12.46	14.52	16.29	18.01	21.70	26.19
18	6.496	7.519	8.046	9.578	10.44	11.49	13.39	15.55	17.41	19.22	23.10	27.84
19	7.093	8.170	8.724	10.33	11.23	12.33	14.32	16.58	18.53	20.42	24.51	29.50
20	7.701	8.831	9.412	11.09	12.03	13.18	15.25	17.61	19.65	21.64	25.92	31.15
21	8.319	9.501	10.11	11.86	12.84	14.04	16.19	18.65	20.77	22.85	27.33	32.81
22	8.946	10.18	10.81	12.64	13.65	14.90	17.13	19.69	21.90	24.06	28.74	34.46
23	9.583	10.87	11.52	13.42	14.47	15.76	18.08	20.74	23.03	25.28	30.15	36.12
24	10.23	11.56	12.24	14.20	15.30	16.63	19.03	21.78	24.16	26.50	31.56	37.78
25	10.88	12.26	12.97	15.00	16.13	17.51	19.99	22.83	25.30	27.72	32.97	39.44
26	11.54	12.97	13.70	15.80	16.96	18.38	20.94	23.89	26.43	28.94	34.39	41.10
27	12.21	13.69	14.44	16.60	17.80	19.27	21.90	24.94	27.57	30.16	35.80	42.76
28	12.88	14.41	15.18	17.41	18.64	20.15	22.87	26.00	28.71	31.39	37.21	44.41
29	13.56	15.13	15.93	18.22	19.49	21.04	23.83	27.05	29.85	32.61	38.63	46.07
30	14.25	15.86	16.68	19.03	20.34	21.93	24.80	28.11	31.00	33.84	40.05	47.74
31	14.94	16.60	17.44	19.85	21.19	22.83	25.77	29.17	32.14	35.07	41.46	49.40
32	15.63	17.34	18.21	20.68	22.05	23.73	26.75	30.24	33.28	36.30	42.88	51.06
33	16.34	18.09	18.97	21.51	22.91	24.63	27.72	31.30	34.43	37.52	44.30	52.72
34	17.04	18.84	19.74	22.34	23.77	25.53	28.70	32.37	35.58	38.75	45.72	54.38
35	17.75	19.59	20.52	23.17	24.64	26.44	29.68	33.43	36.72	39.99	47.14	56.04
36	18.47	20.35	21.30	24.01	25.51	27.34	30.66	34.50	37.87	41.22	48.56	57.70
37	19.19	21.11	22.08	24.85	26.38	28.25	31.64	35.57	39.02	42.45	49.98	59.37
38	19.91	21.87	22.86	25.69	27.25	29.17	32.62	36.64	40.17	43.68	51.40	61.03
39	20.64	22.64	23.65	26.53	28.13	30.08	33.61	37.72	41.32	44.91	52.82	62.69
40	21.37	23.41	24.44	27.38	29.01	31.00	34.60	38.79	42.48	46.15	54.24	64.35
41	22.11	24.19	25.24	28.23	29.89	31.92	35.58	39.86	43.63	47.38	55.66	66.02
42	22.85	24.97	26.04	29.09	30.77	32.84	36.57	40.94	44.78	48.62	57.08	67.68
43	23.59	25.75	26.84	29.94	31.66	33.76	37.57	42.01	45.94	49.85	58.50	69.34