IMPERIAL COLLEGE LONDON

EE3-17
EE9SO8

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2012

MSc and EEE/ISE PART III/IV: MEng, BEng and ACGI

COMMUNICATION NETWORKS

Tuesday, 15 May 2:30 pm

Time allowed: 3:00 hours

There are FIVE questions on this paper.

Answer FOUR questions.

All questions carry equal marks

Any special instructions for invigilators and information for candidates are on page 1.

Examiners responsible First Marker(s) : J.A. Barria
Second Marker(s) : T-K. Kim

Special information for students

1. Mean delay for the M/M/1 system may be taken as

$$t_i = \frac{1}{\mu C_i - \lambda_i}$$

where,

$1/\mu$ = Average length of packet [bit/packet]

C_i = Transmission speed link i [bits/s]

μC_i = Service rate (link i) [packet/ s]

λ_i = Arrival rate (link i) [packet/ s]

2. Optimal Routing Problem (ORP)

$Min\ D(F)$ with respect to $F = \{ F_i \}$

where, $D(F) = \sum_{i=1}^{L} \frac{F_i}{C_i - F_i}$

and,

C_i = Capacity of link l_i.

F_i = Flow carried by link l_i.

The Questions

1.

a) For the selective repeat ARQ protocols applied to the sliding window protocol timing shown in Fig. 1.1 (W < 2a+1), the following utilisation is derived:

$$U_{Selectve\ repeat}(W < 2a+1) = \frac{W(1-P)}{1+a}$$

Explain the meaning of each one of the parameters W, P and a. [3]

Is this a good approximation to the utilisation of the selective repeat ARQ?
State clearly the reason for your answer. [3]

b) Discuss why the media access protocol used by the wireless LAN IEEE 802.11standard is different from the Ethernet (IEEE 802.3) media access control protocol. [6]

c) Explain the usefulness of the Dynamic Host configuration protocol (DHCP) in the Internet. [3]

d) Briefly describe five operations and deployment issues that are unique to mobile ad-hoc networks (MANETs). [5]

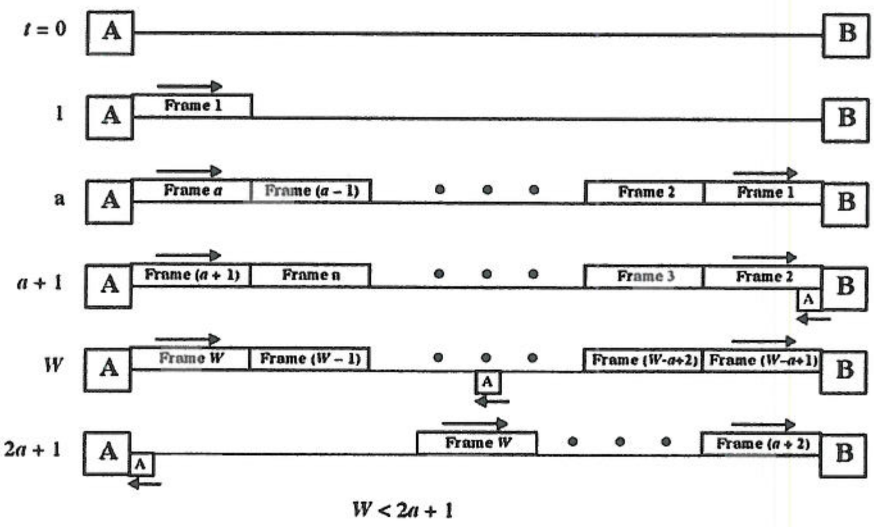

Figure 1.1.

2.

a) For the packet network in Fig. 2.1, assume that:

All external flow streams $R(i, j)$ in [Kbits/s] are given by the following table:

Demand Matrix [Kbits/s]		Destination Node j		
		A	B	C
Origin Node i	A	-	18.0	12.0
	B	-	-	-
	C	-	12.0	-

External arrival streams are Poisson streams,

Each link operates at a rate 20 [Kbits/s],

Packet lengths are exponentially distributed with mean length 6 [Kbits],

Processing time at each node is negligible.

i) Derive a generic expression for mean average network delay. [4]

ii) Solve the optimal routing problem (ORP). [5]

iii) Calculate the mean average delay when the flow inside the network is assigned according to the ORP solution. [3]

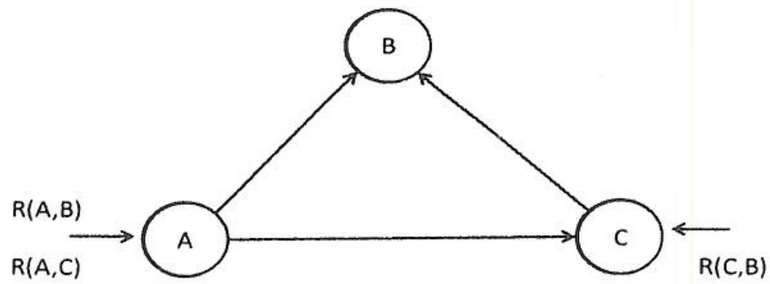

Figure 2.1.

Question 2 continues next page

Question 2 continues from previous page

2. b)

   i) Explain why you need to define a penalty function when stating a combined optimal routing (ORP) and end-to-end flow control problem.

   [4]

   ii) Formally state the combined ORP and flow control problem and suggest a suitable penalty function. Explicitly explain your notations and variables used.

   [4]

3.

a)

i) Consider K TCP connections sharing a single bottleneck link with a transmission rate R bps. Introduce and explain the principle of fairness when allocating transmission rates to all flows sharing the bottleneck link.

[3]

ii) Consider two (2) competing TCP connections sharing a single bottleneck link with a transmission rate R. Using Fig. 3.1. explain how the TCP mechanism would react to the initial flow assignment given by point A.

[3]

iii) In real world networks multiple TCP connections sharing a common link might have different RTT (round trip time). Explain the effect on the allocation of throughput for different connections in this case.

[2]

iv) Explain why from the perspective of a TCP connection, applications running over UDP are not considered to be fair.

[2]

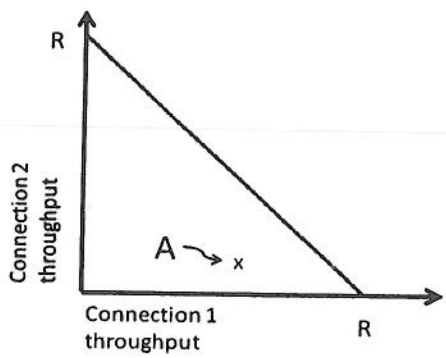

Figure. 3.1.

b)

i) Explain why the Differentiated Service (DiffServ) model has been proposed as an alternative to Integrated Service (IntServ) models in the context of Internet peer models.

[3]

ii) Explain what the traffic conditioning agreement in a DiffServ model is and how this is enforced in an ingress route by the service provider.

[4]

iii) Explain the mechanism that could be implemented at a DiffServ Router to treat different flow streams.

[3]

4.

Figure 4.1 represents the topology of a transportation network.

Demand expressed in terms of [vehicles/hour] is composed of two Origin-Destination (*O/D*) pairs $w_1 = (2,6)$ and $w_2 = (3,7)$.

The user link cost functions, which correspond to travel time in minutes, are of the BRP (Bureau of Public Roads) form and given by:

$$c_a(f_a) = t_a(1 + k(f_a / u_a)^{\beta}); \qquad \forall a \in L,$$

where

L = the set of direct links in the transportation network,

f_a = the flow on link a [vehicles/hour],

u_a = actual capacity of link a in [vehicles/hour] (it also has the interpretation of level-of-service flow rate),

t_a = the free-flow travel time or cost on link a in [minutes],

k and β = the model parameters.

The parameters for the network under analysis are:

k = 0.15 for all links,

β = 4.0 for all links.

Link	t_a [minutes]	u_a [vehicles / hour]
a	8	2000
b	9	2000
c	2	2000
d	6	4000
e	3	2000
f	3	2500
g	4	2500
h	6	4000
i	6	4000
j	6	4000
k	6	4000

Question 4 continues next page

Question 4 continues from previous page

a) Assume that there is no demand in the network. Obtain the shortest path from node 1 to each of the other nodes in the network using the Bellman-Ford or the Dijkstra algorithm. State clearly which algorithm you are using.

~~[6]~~ [5]

b) Using a User-Oriented approach, calculate the maximum flow in terms of [vehicles/hour] that the network can carry for *O/D* pairs $w_1 = (2,6)$ and $w_2 = (3,7)$ without using alternative routes.

~~[6]~~ [8]

c) Discuss the limitations in the above context if the minimum hop criterion is used to select the minimum path length.

[4]

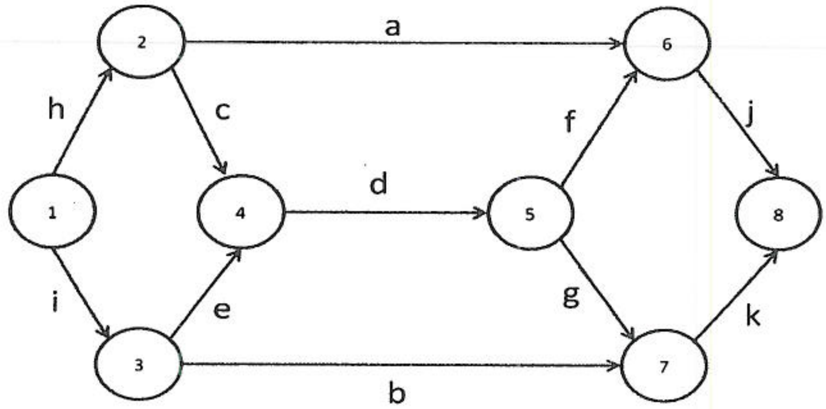

Figure 4.1

5.

An Internet user has the following Utility function:

$$U = q_1 q_2 + 4q_1 + 2q_2$$

where:

q_i = units of time during period i.

Assume also that you know p_i, the period i price.

a) Derive this user's demand function as a function of her budget $M = q_1 p_1 + q_2 p_2$.

[5]

b) Now assume that she is endowed with Internet access to 164 units of time during period 2 ($q_2 = 164$) but no permission to have access during period 1.

i) Derive this users's excess demand function if she can only interchange units of time from period 1 to period 2.

[5]

ii) Discuss the effect on the excess demand in terms of period 1and period 2 prices (p_1 and p_2 respectively).

[5]

c) In respect to Intelligent Infrastructure for Intelligent Transportation Systems (ITS), define and describe five (5) key applications and give at least one example for each application.

[5]

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Q1

a) W = window size

P = probability that a single frame is in error

$a = \frac{\text{propagation Time}}{\text{Transmission Time}}$

note = Transmission of one frame (normalised) = 1

$$U(W < 2a+1) = \frac{W(1-P)}{1+2a} \quad \text{and not} \quad \frac{W(1-P)}{1+a}$$

The time cycle time (until acknowledment) comes back to sender is $1+2a$.

b) IEEE 802.11 wireless LAN use a MAC protocol called Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).
WiFi systems are half duplex shared media. Therefore in a Radio system a station cannot hear while it is sending. Hence not possible to detect a collision.
CA = Distributed Control Function (DCF): A WiFi station will transmit only if it thinks the channel is clear. All tx are ack. If a station does not receive an ack it assumes a collision occurred and retransmit after a random waiting time.

c) Dynamic Host Configuration Protocol (DHCP)
- DHCP automatically configures hosts that connect to a TCP/IP network
- It provides a mechanism for assigning temporary IP network addresses to host
- Used by ISP to maximise the usage of their limited IP address spaces.

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Q1 MANETs design & operational issues

d) Describe the following aspects of MANETs:

- Dynamic topology
- scalability
- power consumption
- security threats
- Data Rates
- Routing.

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Q2 a) i)

$\gamma \rightarrow (N, T)$ $N = \gamma T$ (Little's on Network)

$$\gamma = \sum_{j=1}^{m} \sum_{k=1}^{m} \gamma_{jk}$$

$q_i = \lambda_i t_i$ (Little's in queue i)

$$\sum_{i=1}^{L} \lambda_i t_i = N = \gamma T$$

$$N = \gamma T = \sum_{i=1}^{L} \frac{\lambda_i}{\mu C_i - \lambda_i} \qquad F_i = \frac{\lambda_i}{\mu}$$

$$T = \frac{1}{\gamma} \sum_{i=1}^{L} \frac{F_i}{C_i - F_i}$$

Q2 a) iii) From Q2a) ii) (next page)

$x_1^* = 15.85$, $x_2^* = 2.15$

$$T = \frac{1}{(18+12+12)} \left(\frac{15.85}{20-15.85} + \frac{12+2.15}{20-(12+2.15)} + \frac{12+2.15}{20-(12+2.15)} \right)$$

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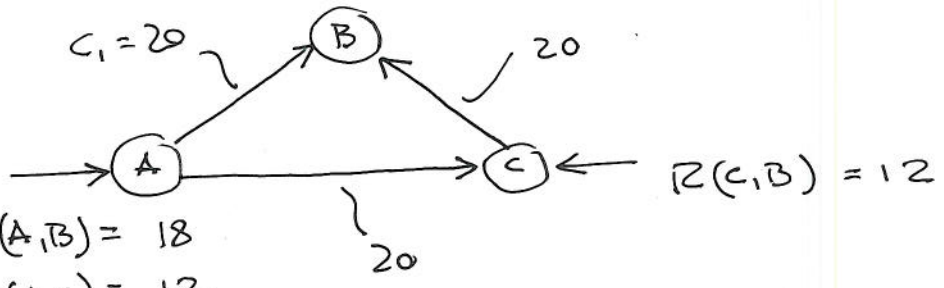
Q2 a) ii)



$R(A,B) = 18$

$R(A,C) = 12$

The only flow that can be optimally assign is $R(A,B)$

$$\frac{C_1}{(C_1 - x_1)^2} = \frac{20}{(20-x_1)^2} = \frac{20}{(20-\underset{R(A,C)}{12}-x_2)^2} + \frac{20}{(20-\underset{R(C,B)}{12}-x_2)^2}$$

$$\frac{20}{(20-x_1)^2} = \frac{40}{(8-x_2)^2} \qquad 18 = x_1 + x_2$$

$$20(8-x_2)^2 = 40(20-x_1)^2$$

$$\sqrt{20}\,(8-x_2) = \sqrt{40}\,(20-x_1)$$

$$\sqrt{20}\cdot 8 - \sqrt{20}\,x_2 = \sqrt{40}\cdot 20 - \sqrt{40}\,x_1$$

$$\sqrt{40}\,20 - \sqrt{20}\cdot 8 = \sqrt{40}\,x_1 - \sqrt{20}\,(18 - x_1)$$

$$\sqrt{40}\cdot 20 - \sqrt{20}\cdot 8 + \sqrt{20}\,18 = \sqrt{40}\,x_1 + \sqrt{20}\,x_1$$

$$\sqrt{40}\,20 + \sqrt{20}\,10 = (\sqrt{40} + \sqrt{20})\,x_1$$

$$x_1^* = \frac{\sqrt{40}\,20 + \sqrt{20}\cdot 10}{\sqrt{40} + \sqrt{20}}$$

$$x_1^* = 15.85$$

$$x_2^* = 2.15$$

5)

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Q2 b)

If we minimise the cost function of an ORP with respect to both the path flow $\{x_p\}$ and the inputs $\{R_w\}$ the optimal solution will be the trivial one ($x_p = 0$, $R_w = 0$) for all paths p and O-D pairs w. R_w = input rate on an OD pair.

This implies that the cost function should include a penalty for input R_w becoming too small

The ORP and flow control problem can be stated:

$$\text{minimise} \quad \sum_{(i,j)} D_{ij}(F_{ij}) + \sum_{w \in W} e_w(R_w).$$

$$\text{subject to} \quad \sum_{p \in P_w} x_p = R_w \quad \forall w \in W$$

$$x_p \geq 0 \quad \forall p \in P_w, \; w \in W$$

$$0 \leq R_w \leq \bar{R}_w \quad \forall w \in W$$

F_{ij} = total flow carried by link (i,j)
x_p = flow of path p
$\bar{R}_w$ = Input rate/flow for a O-D pair (desired)
R_w = carried flow

example of a possible e_w such that

$$e'_w(R_w) = -\left(\frac{a_w}{R_w}\right)^{b_w}$$

a_w, b_w = given positive constants

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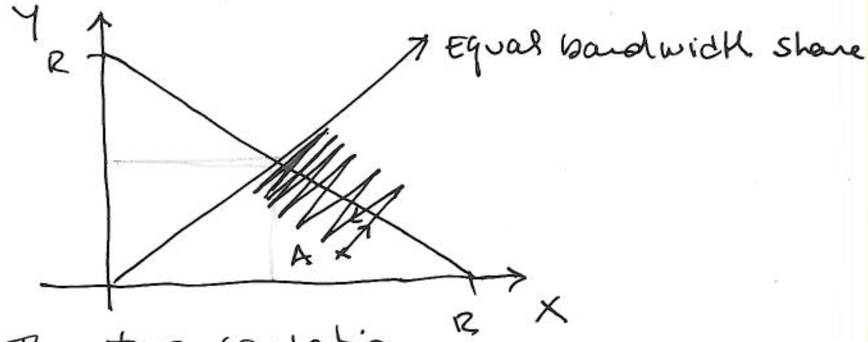
Q3 a) i) If K TCP connections each with a different end-to-end path but all passing through a bottleneck link with transmission rate R bps (and with no UDP traffic passing through the same bottleneck link): A congestion-control mechanism is said to be fair if the average transmission rate of each connection is approximately R/K. That is each connection gets an equal share of the link bandwidth

ii)



The two competing sessions:
- Additive increase give slope (1) as throughput increases
- multiplicative decrease decreases throughput proportionally

iii) The effect of having multiple connections to share a common bottleneck, those sessions with a smaller RTT (Round trip Time) are able to acquire the available bandwidth at the bottleneck link more quickly as it becomes free (enjoying higher throughput than those with longer RTT).

iv)

TCP congestion control will decrease its transmission rate in the face of increasing congestion.
UDP sources need not to react to congestion, hence UDP sources could halt TCP traffic

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Q3 a) i) The DiffServ model is simpler and more scalable than INTSERV model.
- Per flow service is replaced with per aggregate service
- Complex processing is moved from the core of a network to the edge.

The DiffServ model allocates resources to a small number of classes of traffic

ii) A service level agreement (SLA) is required: A user before receiving a service must first have a SLA

A SLA includes a traffic conditioning agreement:
- Service level, traffic profile, marking and shaping
- Users can agree a static or dynamic SLA and may require different services for different packets
- Packet marking is done at the host or customer's access router.

To ensure traffic conformance (TCA) the ingress router performs traffic classification and traffic conditioner (metering, marking, shaping and dropping)

iii) Individual routers' behaviour are called PHB
- Expedite Forwarding: low-loss, low-latency, low-jitter, assured bandwidth, end to end serv.
- Assured Forwarding: Delivers aggregate traffic with high assurance as long as the traffic does not exceed the traffic profile.
  Not intended for low-~~jitter~~, low latency traffic
- Default PHB: best effort treatment

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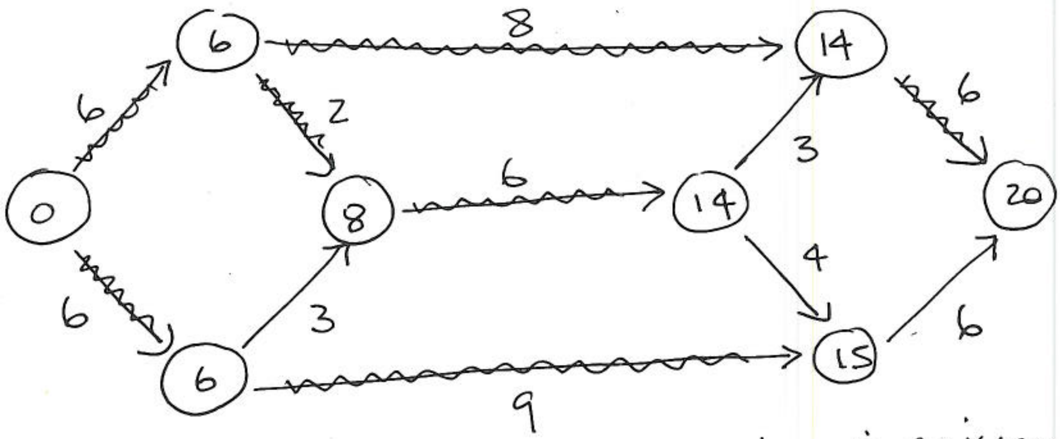
Q4

a)



solution: distance to each node is given in circles.
Show step by step the algorithm used.

b)

$$w(3,7) \Rightarrow 9\left(1+0.15\left(\frac{fb}{2000}\right)^4\right) = 3+6+4$$

$$9 + 1.35\left(\frac{fb}{2000}\right)^4 = 13$$

$$\vdots$$

$$fb = 2623.98$$

$$w(2,6) \Rightarrow 8\left(1+0.15\left(\frac{fa}{2000}\right)^4\right) = \underbrace{3+6+2}_{11}$$

$$8 + 1.2\left(\frac{fa}{2000}\right)^4 = 11$$

$$\vdots$$

$$fa = 2514.86$$

c) Discussion on the limitations of using a path without considering the state of a link in term of e.g. congestion levels.

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Q5

$$U = q_1 q_2 + 4q_1 + 2q_2 \qquad M = q_1 p_1 + q_2 p_2$$

a)

$$L = q_1 q_2 + 4q_1 + 2q_2 + \lambda[M - q_1 p_1 - q_2 p_2]$$

$$\left.\begin{aligned}\frac{\partial L}{\partial q_1} &= q_2 + 4 - \lambda p_1 = 0 \\ \frac{\partial L}{\partial q_2} &= q_1 + 2 - \lambda p_2 = 0\end{aligned}\right\} \quad \frac{q_2+4}{q_1+2} = \frac{p_1}{p_2}$$

$$\frac{\partial L}{\partial \lambda} = M - q_1 p_1 - q_2 p_2 = 0$$

$$(q_2+4)p_2 = (q_1+2)p_1 \longrightarrow p_2 q_2 = (q_1+2)p_1 - 4p_2$$

$$M = q_1 p_1 + (q_1+2)p_1 - 4p_2$$

$$M = 2q_1 p_1 + 2p_1 - 4p_2$$

$$\frac{M + 4p_2 - 2p_1}{2p_1} = q_1 \qquad \boxed{\frac{M}{2p_1} + \frac{p_2}{p_1} - 1 = q_1}$$

$$q_1 p_1 = p_2 q_2 + 4p_2 - 2p_1$$

$$M = q_2 p_2 + p_2 q_2 + 4p_2 - 2p_1$$

$$\frac{M + 2p_1 - 4p_2}{2p_2} = q_2 \qquad \boxed{\frac{M}{2p_2} + \frac{p_1}{p_2} - 2 = q_2}$$

Q5 b)

$$u = q_1 q_2 + 4q_1 + 2q_2$$

$$q_2 = E_2 + 164$$

$$q_1 = E_1$$

$$L = (E_2+164)E_1 + 4E_1 + 2(E_2+164) - \lambda(p_1E_1 + p_2E_2)$$

$$\frac{\partial L}{\partial E_1} = E_2 + 164 + 4 - \lambda p_1 = 0 \qquad \lambda = \frac{E_2+168}{p_1}$$

$$\frac{\partial L}{\partial E_2} = E_1 + 2 - \lambda p_2 = 0 \qquad \lambda = \frac{E_1+2}{p_2}$$

$$\frac{\partial L}{\partial \lambda} = p_1E_1 + p_2E_2 = 0 \rightarrow \frac{p_1}{p_2} = -\frac{E_2}{E_1}$$

$$E_1 = \lambda p_2 - 2 = (E_2+168)\frac{p_2}{p_1} - 2$$

$$E_1 = E_2(-)\frac{E_1}{E_2} + 168\frac{p_2}{p_1} - 2$$

$$\boxed{E_1 = 84\frac{p_2}{p_1} - 1}$$

$$E_2 = \lambda p_1 - 168 = \frac{(E_1+2)}{p_2}p_1 - 168$$

$$E_2 = E_1(-)\frac{E_2}{E_1} + \frac{2p_1}{p_2} - 168$$

$$\boxed{E_2 = \frac{p_1}{p_2} - 84}$$

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Q5 c)

ITS - Intelligent Infrastructure

chose, any five:

- Arterial and freeway management
- crash prevention and safety
- Traffic incident Management
- Energy Management
- electronic payment and pricing
- Road operations
- Transit Management
- Traveller information
- Road weather information
- Information Management
- commercial vehicle operations
- Intermodal freight