ORIGINAL

NATIONAL UNIVERSITY OF SINGAPORE

EE5132 – WIRELESS AND SENSOR NETWORKS

(Semester 2 : AY2018/2019)

Time Allowed: 2 Hours

INSTRUCTIONS TO STUDENTS

1. Please write only your Student Number. Do not write your name.
2. This paper contains **FOUR (4)** questions and comprises **EIGHT (8)** printed pages.
3. Students are required to answer **ALL** questions.
4. Students should write the answers for each question on a new page.
5. This is a **CLOSED BOOK** examination. However, students are allowed to bring ONE self-prepared A4 help sheet into the examination hall.
6. Supplementary Information is provided on Page 7.
7. Programmable calculators are **NOT ALLOWED**.
8. Total Marks is 100.

Q1. (a) A wireless ad hoc network of 8 nodes is shown in Figure Q1.

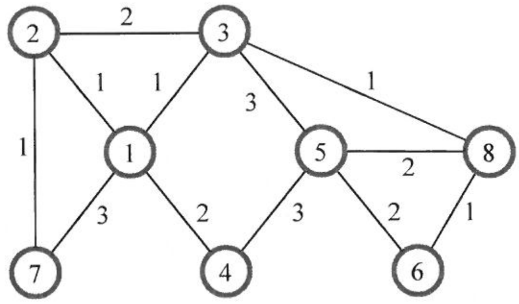

Figure Q1.

i. Determine the link costs from node 1 to all the other nodes using the Dijkstra algorithm.

(7 marks)

ii. Determine the link costs from node 1 to all the other nodes using the Bellman-Ford algorithm.

(7 marks)

(b) A transmitting antenna operates at 1 GHz and is located at a height of 50 m above the ground. The receiving antenna is at a height of 2 m and the refraction correction index is 1.2. What is the maximum radio line-of-sight distance between the transmitter and the receiver?

(5 marks)

(c) A radio communications network operates at 2 GHz at a data rate of 500 kbps, with data packets of size 1000 bits and the speed of radio propagation is 3×10^8 m/s. The relative speed between the transmitter and receiver is 10 m/s and the normalize fade margin, $\frac{A}{\sqrt{2}\sigma}$ is 0.2. The communications modem employs forward error correction (FEC) to mitigate against bit errors caused by adverse channel conditions. Determine the minimum strength of the FEC, in terms of the average number of bits in error per 1000 bits transmitted, that the FEC is capable of detecting and correcting to ensure reliable communication.

(6 marks)

Q2. (a) Four nodes A, B, C and D are arranged as shown in Figure Q2 such that nodes B and D are within range of node C, nodes A and C are within range of node B, but nodes A and B are hidden from node D, and nodes C and D are hidden from node A. The links between the nodes indicate that the attached nodes are able to communicate with each other. The network uses the MACAW-RRTS multiple access protocol. Node C has data to send to node D and initiates a MACAW-RRTS messaging sequence with the launch of an RTS message to node D, and subsequently node D responds with a CTS message and so on. Meanwhile, at the time when node C sends the RTS message, node A also has data to send to node B and, unaware of the communication between nodes C and D, sends an RTS message to node B. Suppose that the propagation delay is denoted by α, DIFS = 5α, SIFS = 2α, RTS = CTS = DS = ACK = RRTS = 8α, and Data = 20α. Determine the total time taken in terms of α from the time that C starts sending its RTS message to node D to the time when node A completes successful delivery of its packet to node B. State clearly any assumptions that you make.

(10 marks)

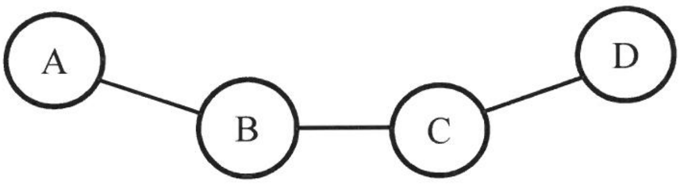

Figure Q2

(b) A wireless network based on Zone Routing Protocol is shown in Figure Q3 illustrating the zones, nodes and neighbour nodes in the network. The dark circles denote the nodes, while the lighter circles denote the zones. Node A has data to transmit to node T. Assume that all nodes have no knowledge of prior routes.

i. Describe the steps involved in discovering a route from node A to node T.

(6 marks)

ii. List the 3 shortest possible routes from node A to node T.

(3 marks)

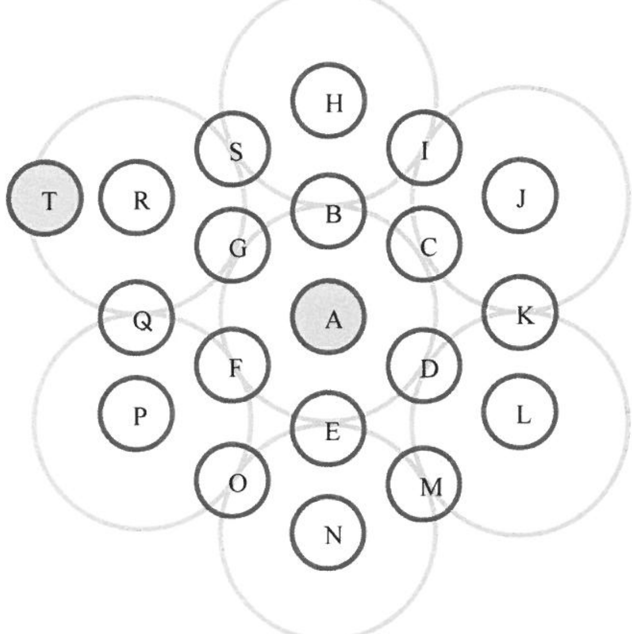

Figure Q2

Question 2 continues on Page 4

(c) A radio receiver with an effective diameter of 100 cm is receiving signals at 10 GHz from a transmitter that transmits at 50 mW and a gain of 25 dB. Assume that the speed of propagation is 3×10^8 m/s.

i. What is the gain of the receiver antenna?

ii. What is the received power if the receiver is 10 km away from the transmitter?

(6 marks)

Q3. (a) The Message Queuing Transfer (MQTT) and the Constrained Application Protocol (CoAP) are well-established Internet of Things (IoT) protocols. Describe the different operating paradigms of the MQTT and CoAP protocols.

(4 marks)

(b) The CoAP protocol enables constrained devices such as wireless sensor nodes to act as Representational State Transfer (REST) clients and servers which support a simplified form of the HyperText Transfer Protocol (HTTP).

A client application wishes to read a measurement from a wireless sensor node that implements the CoAP protocol. Which HTTP-like method should the client application use?

(3 marks)

(c) In another design, wireless sensor nodes that implement the CoAP protocol are required to send their sensor readings to a server. For each communication with the server, a database record may be created or modified. Which HTTP-like method(s) should the wireless sensor nodes use?

(4 marks)

(d) A wireless sensor network measures various parameters of interest in a chemical processing plant and conveys them to a classifier which is firstly trained, and then used, to make classification decisions about whether the plant is operating normally (i.e. *Normal*), or whether one type of anomaly called *Anomaly1* or another type of anomaly called *Anomaly2* is occurring.

The confusion matrix is shown in Table Q3 below.

		Classifier output / Predicted class		
		Normal	*Anomaly1*	*Anomaly2*
Actual class	*Normal*	53	5	2
	Anomaly1	12	42	6
	Anomaly2	15	14	31

Table Q3

Determine the *probability of detection* and the *probability of false alarm* for each of the three classes.

(5 marks)

(e) The management of the chemical processing plant is only interested in whether an anomaly has occurred, which is deemed to be a *positive* detection result, or the situation is normal, which is deemed to be a *negative* detection result.

Using the information in Table Q3, determine the following quantities of interest: *sensitivity* or *recall*, *specificity* and *precision*.
Hint: consider a binary classification task.

Comment on the probability of detection of the *Normal* class and specificity.

(9 marks)

Q.4 (a) In the μAMPS wireless sensor node, there will be a nett energy saving for making a transition from the active state to a lower energy state if the idle time t_i is larger than the transition time threshold T_{th} shown in the fourth column of Table Q4.

State	P_k (mW)	τ_k (ms)	$T_{th,k}$ (ms)
Active	1040	-	-
Ready	400	5	8
Monitor	270	15	20
Look	200	20	25
Sleep	10	50	50

Table Q4. Energy states, power at each state, transition latencies and thresholds at node k.

The sensors of the node remain on for all states except the Sleep state and can cause the node to make a transition from that state to the active state when an event is detected. If the probability that at least one event occurs in duration T_{th} is given by

$$p_{th,k}(T_{th}) = 1 - e^{-\lambda_k T_{th}}$$

where λ_k is the event arrival rate, determine the probability that there will NOT be nett energy saving for each of the Ready, Monitor and Look states. The node has been switched on for 100 seconds and 100 events have been observed.

(11 marks)

(b) What are the similarities and differences in the actions performed by a cluster head versus the actions performed by a normal node during the set-up phase of the Low Energy Adaptive Clustering Hierarchy (LEACH) protocol?
Use a flowchart to show the similar aspects and different aspects.

(7 marks)

(c) How does the LEACH protocol ensure that each sensor node becomes a cluster head exactly once in an interval of $1/P$ rounds, where P is the cluster head probability?

(7 marks)

SUPPLEMENTARY INFORMATION

Relationship between antenna gain and effective area $$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2}$$

Received power $$P_r = \frac{A_e G_t P_t}{4\pi d^2} = \frac{G_r G_t \lambda^2 P_t}{(4\pi d)^2} = \frac{A_r A_t P_t}{(\lambda d)^2} = \frac{f_c^2 A_r A_t P_t}{(cd)^2}$$

Transmitter/Receiver gain $$G_{t/r} = \frac{4\pi A_e}{\lambda^2}$$

Free space loss, isotropic antenna $$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi fd)^2}{c^2}$$

Free space loss, accounting for antenna gains $$\frac{P_t}{P_r} = \frac{(4\pi)^2 (d)^2}{G_r G_t \lambda^2} = \frac{(\lambda d)^2}{A_r A_t} = \frac{(cd)^2}{f^2 A_r A_t}$$

Gaussian distribution: $$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{\left(x-\bar{x}\right)^2}{2\sigma^2}\right]$$

Rayleigh distribution: $$p(x) = \frac{x}{\sigma^2} e^{-\frac{x^2}{2\sigma^2}}$$

Rician distribution: $$p(x) = 2x(1+K_R)\exp\left[-x^2(1+K_R) - K_R\right] I_0\left(\sqrt{4[1+K_R]K_R}\right)$$

Fading – Average level crossing rate: $$N_A = \sqrt{2\pi} f_d \frac{A}{\sqrt{2}\sigma} e^{-\frac{A^2}{2\sigma^2}}$$

Fading – Average fade duration: $$\bar{t}_F = \frac{1}{\sqrt{2\pi} f_d} \frac{\sqrt{2}\sigma}{A}\left[e^{\frac{A^2}{2\sigma^2}} - 1\right]$$

Fading – Average inter-fade duration: $$\bar{t}_{IF} = \frac{1}{\sqrt{2\pi} f_d} \frac{\sqrt{2}\sigma}{A}$$

ALOHA – Probability of successful transmission: $$P(0) = e^{-2T_{txm}\lambda}$$

Slotted ALOHA – Probability of successful transmission: $$P(0) = e^{-T_{txm}\lambda}$$

END OF PAPER