GLASGOW COLLEGE UESTC

Exam paper

Wireless Sensor Networks (UESTC4020)

Date: 31st Dec. 2019
Time: 14:30-16:30

Attempt all PARTS. Total 100 marks

Use one answer sheet for each of the questions in this exam.
Show all work on the answer sheet.

Make sure that your University of Glasgow and UESTC Student Identification Numbers are on all answer sheets.

An electronic calculator may be used provided that it does not allow text storage or display, or graphical display.

All graphs should be clearly labelled and sufficiently large so that all elements are easy to read.

The numbers in square brackets in the right-hand margin indicate the marks allotted to the part of the question against which the mark is shown. These marks are for guidance only.

DATA/FORMULAE SHEET IS PROVIDED AT THE END OF PAPER

Continued overleaf

Q1 (a) Give description of two types of sensor networks:

(i) Infrastructure supported wireless sensor network [2]

(ii) Ad-hoc wireless sensor network [2]

(b) Provide a short answer:

(i) Eight wireless nodes are placed on a unit disc, and each node has a capacity of 1.8Mbps. What is the upper bound on the network capacity? [2]

(ii) How much 5-hop links will bring loss rate when a single hop has wireless connection loss rate -10dBm? [2]

(iii) Two types of sensor nodes operating at 433MHz and 916 MHz. In a straight hallway, which type of sensor can be deployed further apart? [2]

(c) Explain in concise English sentences:

(i) Why does the Transmission Control Protocol (TCP) not work well in sensor networks? [4]

(ii) Which methods can be used to save power consumption in wireless sensor network? [4]

(iii) Why have the Nordic nRF51 system-on-chip include a shutdown function? [2]

(iv) Why does wireless sensor network localisation need clock synchronisation? [2]

(d) Draw a typical block diagram of sensor node. [3]

Continued overleaf

Q2 (a) Assume a timer function for contention-based greedy forwarding: $T = 0.0015D_f$ where D_f is the distance from the forwarding node candidate to the target in metres and T is the resulting timer value in seconds, as shown in Figure Q2. What will be the delay due to waiting for the contention timers to expire in the following network, with the source and target as labelled? Please include your working. [5]

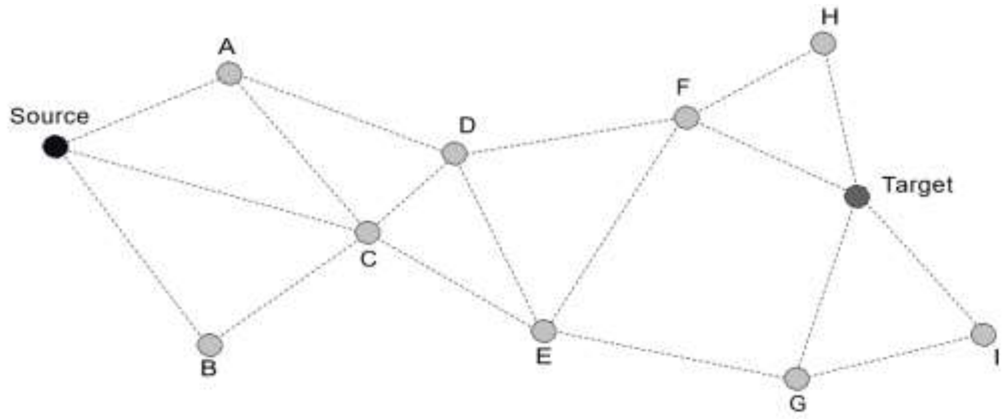

Figure Q2: Dashed lines indicate nodes which are within transmission range of each other.

Node	Distance to target (m)
A	355
B	380
C	290
D	270
E	190
F	120
G	130
H	85
I	175

(b) Suppose that packets arrive at a link at a Poisson rate of 250 packets/second, and the packet lengths are exponentially distributed with mean length 1000 bits/packet. Assume that the buffer length is sufficiently large that it can be assumed to be effectively infinite. Find the required capacity of the link in bits/second so that the following criteria are satisfied:(1) Mean delay <= 10ms; (2) Pr{delay >= 20ms} < =0.10.

[10] (Apply correct formula[5], demonstration of solving [3] and calculation [2])

(c) In a cinema eight displays in each room have been connected using the stream server. Each networked display with transmission probability 0.4 and propagation time equal 0.05 . In order to check the best video quality what is the upper boundary link usage (assume there are no packet collision sensing method)? [10]

(Apply correct formula [5], demonstration of solving [3], and calculation [2])

Continued overleaf

Q3 For the scenarios below, choose the most appropriate protocol or algorithm from the options given, and justify your choice.

(a) 100 wireless stations are connected to an access point. The access point wishes to receive data from the stations periodically. In each data collection period only a small number of them have data to send.

Which MAC protocol (Polling and code-division multiple access) would you choose for this network and why? [5]

(b) Farmer Joe wants to set up a wireless sensor network to monitor his wheat field to collect data such as soil quality, rainfall and temperature. The sensor nodes will be placed in 3m x 3m over 120 acres(1 acre is around 4000m^2) and will relay data (multihop) back to a gateway. Since Farmer Joe's farm is out in the country there is little to no interference from other networks. The sensor nodes will be powered by solar cells with current consumption to less than 400 nA per Hz . Importantly farmer Joe needs accurate data and can't afford for any sensor readings to be lost.

How would you design the queueing method for this sensor network to monitor Farmer Joe's wheat field and why? [5]

(c) Now consider a wireless network where the nodes (aside from the base station) are monitoring a factory floor. Every 500ms, each node sends a data packet to the base station reporting the status of the piece of machinery it is attached to. The time taken to transmit the packet is only a few milliseconds. The network needs to have high reliability and low latency for receiving the status packets. The total number of nodes is about 50.

Which kind of medium access protocol would you choose for this network and why? [7]

(d) Consider a wireless network which is used for tracking moose in a forest. Each node spends most of its time in sleep mode to save energy, but when a moose is detected nearby, the node wakes up and sends data about the animal and its movements to the base station. The amount of data sent is 2Mbps/s. On average, 3 nodes are within sensing range of each moose, and the number of moose typically seen at a time is 4mints — only one or two in the entire network area. In total, there are 200 nodes in the network.

Which kind of resource reservation protocol would you choose for this network and why? [8]

Continued overleaf

Q4 (a) A sensor network is depicted in Figure Q4. In the network are six nodes (A, B, C, D, E, and F), and two end hosts (G and H). Propagation delays on each of the links (δ, in milliseconds) are shown in the figure Q4, as are arrival rates for some of the links (λ, in packets per second), with unknown arrival rates marked with “??”. All the input traffic to the network (λA and λB) consists of Markovian packet arrivals, and each of the routers has sufficient memory such that the space in their buffers can effectively be regarded as infinite. The service rates at each router are also Markovian, and the average values (μ, in packets per seconds) are shown in the figure. After passing through the network, the traffic reaches the two end hosts (shown on the right-hand side of the figure). The end hosts each have limited memory such that they can each only hold up to 6 packets at a time, including the packet currently being processed.

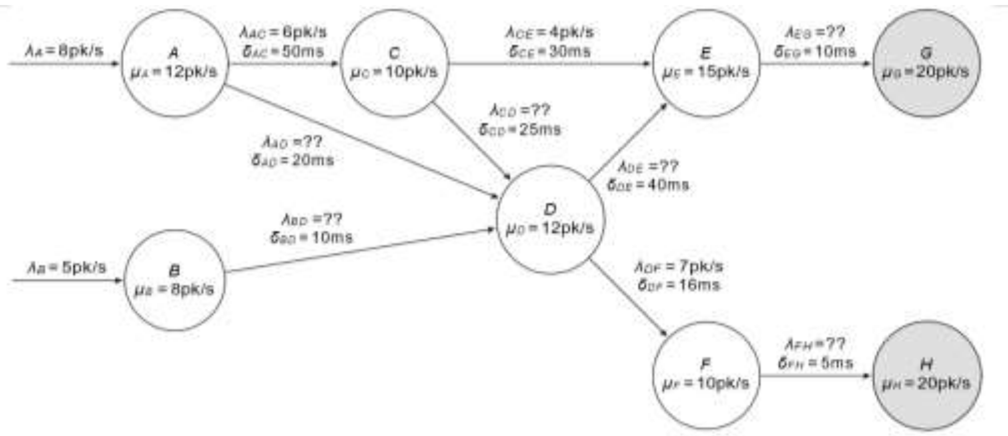

Figure Q4

(i) Calculate the total arrival rates at router D [2]

(ii) Calculate the probability of packet loss at the end hosts H. [3]

(ii) Calculate the total average time each (non-blocked) packet spends in end host G . [5]

(Apply correct formula [3], and calculation [2])

(iii) Calculate the average total delay for a single transmission of a packet using the following route through the network: A, D, E, G. Include all delays: service time at all nodes, link propagation, and queueing delays. [5]

(Apply correct formula [3], and calculation [2])

(b) To improve road monitoring through wireless sensor networks, several sensors are distributed along a road to detect traffic flows, speed, and the continued occupation of the road. This probability of road is used by large container truck is p. Those trucks can create serious barriers for wireless signal. The wireless sensor need design a media access control in link layer. For simplicity assume acknowledgements are never lost, what is the expected number of transmission to successfully send a frame? (Apply correct formula [5], demonstration of solving [3], and calculation [2]) [10]

Continued overleaf

Stochastic Processes

Autocorrelation:

$$R(t_1, t_2) = E[x(t_1)x(t_2)]$$

Autocovariance:

$$C(t_1, t_2) = Cov(x(t_1), x(t_2))$$

Sampling and random numbers

Sample mean:

$$\bar{z} = \frac{1}{n}\sum_{i=1}^{n} z_i$$

Sample variance:

$$\hat{V} = \frac{1}{n}\sum_{i=1}^{n}(z_i - \bar{z})^2$$

Unbiased sample variance (Bessel's correction):

$$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(z_i - \bar{z})^2$$

Confidence intervals:

$$\text{Confidence} = Pr(|\bar{z} - \mu| \leq \alpha \times \frac{\sigma}{\sqrt{n}}$$

$\alpha = 1.96$ gives confidence of 95%. Inverse method:

$$X = F^{-1}(Y)$$

Medium Access Control

FDMA/TDMA rate of work:

$$\eta = \frac{1}{n \times \nu}\sum_{i=1}^{n} \rho_i$$

Polling efficiency:

$$E = \frac{T_t}{T_t + T_{idle} + T_{poll}}$$

ALOHA throughput:

$$S = Ge^{-G}$$

Slotted ALOHA throughput:

$$S = Ge^{-2G}$$

1-persistent CSMA throughput:

$$S = \frac{Ge^{-G}(1+G)}{G + e^{-G}}$$

Non-persistent CSMA throughput:

$$S = \frac{G}{1+G}$$

CSMA utilisation:

$$A = kp(1-p)^{k-1}$$

$$E[w] = \frac{1-A}{A}$$

$$U = \frac{1}{1 + 2a + a(1-A)/A}$$

Queueing Systems

Kendall Notation parameters:

1. Arrival distribution
2. Service distribution
3. Number of servers
4. Total capacity (default: infinite)
5. Population size (default: infinite)
6. Service disciplien (default: FIFO)

Little's Law:

$$E[R] = \lambda E[T_R]$$

Occupancy:

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

M/M/1

Queue length:

$$E[R] = \frac{\rho}{1-\rho}$$

Total time in system:

$$E[T_R] = \frac{1}{\mu(1-\rho)}$$

Waiting time:

$$E[T_W] = \frac{\rho}{\mu(1-\rho)}$$

Delay bound:

$$Pr(T_R \leq t) = 1 - e^{-\mu(1-\rho)t}$$

M/M/1/n

Blocking probability:

$$P_B = \frac{1-\rho}{1-\rho^{n+1}}\rho^n$$

Carried traffic:

$$\gamma = \lambda(1 - P_B)$$

Little's Law:

$$E[R] = \gamma E[T_R]$$

Queue length:

$$E[R] = \frac{1-\rho}{1-\rho^{n+1}}\sum_{i=0}^{n} i\rho^i$$

Continued overleaf

Erlang (M/M/n/n)

Offered traffic:

$$A = \lambda h$$

Service rate:

$$\mu = \frac{1}{h}$$

Erlang loss function:

$$E_n(A) = P_B = \frac{\frac{A^n}{n!}}{\sum_{j=0}^{n} \frac{A^j}{j!}}$$

Carried traffic:

$$A_c = A(1 - P_B)$$

Lost traffic:

$$A - A_c$$

Jackson Networks

Probability a packet leaves the network from node i:

$$1 - \sum_{j=1}^{n} r_{ij}$$

Total arrival rate to node i:

$$\lambda_i = \gamma_i + \sum_{j=1}^{n} \lambda_j r_{ji}$$

Queueing Disciplines

Kleinrock Conservation Law:

$$\sum_{n=1}^{N} \rho_n q_n = C$$

Processor Sharing:

$$F_i^\alpha = S_i^\alpha + P_i^\alpha$$

$$S_i^\alpha = \max\{F_{i-1}^\alpha, A_i^\alpha\}$$

Generalised Processor Sharing:

$$F_i^\alpha = S_i^\alpha + \frac{P_i^\alpha}{w_\alpha}$$

Packet reception rate:

$$PRR = \frac{S}{T}$$

Cellular frequency re-use:

$$D = R\sqrt{3K}$$

Congestion Control

Token bucket:

$$R = \rho T + \beta$$

TCP

Max bandwidth:

$$BW_{max} = \frac{MSS \times C}{RTT \times \sqrt{p}} \qquad C = \sqrt{\frac{3}{2}}$$

Normalised throughput:

$$S = \begin{cases} 1 & W \geq 2RD \\ \frac{W}{2RD} & W < 2RD \end{cases}$$

Expected (average) round trip time:

$$ERTT(K+1) = \frac{K}{K+1} ERTT(K) + \frac{1}{K+1} RTT(K+1)$$

Smoothed round trip time:

$$SRTT(K+1) = \alpha \times SRTT(K) + (1-\alpha) \times RTT(K+1)$$

Retransmission timeout with SRTT:

$$RTO(K+1) = \min\{UB, \max\{LB, \beta \times SRTT(K+1)\}\}$$

Van Jacobson's algorithm:

$$DRTT(K+1) = (1-\alpha) \times DRTT(K) + \alpha \times (SRTT - ERTT)$$

$$RTO = ERTT - 4 \times DRTT$$

Exponential backoff:

$$RTO_{i+1} = q \times RTO_i$$

End of question paper