**Question 1**

 2m

4m

Sink

3m

**Figure 1**

Figure 1 shows motion sensor mote deployed in a secluded server room to monitor human movement. Node S1 can either forward the motion data to node S2 or node S3 depending on the residual energy of the nodes or its energy harvesting capability. S1 to S2 and S1 to S3 have the same energy consumption for every packet being delivered and it takes one packet to be delivered in 1 second. Both S2 and S3 have the same battery capacity Eb and residual energy on both nodes is Eb-3 and Eb-5 respectively. And energy harvesting rates at 3 and 2 units per second respectively. S2 and S3 both consume 4 energy units to relay a packet to the A.

1. Calculate the remaining battery of the sensor nodes S1 and S2 after 10 seconds imagining that the same amount of data is sent to both nodes.
2. Given a scenario of remaining energy in both nodes when a) S2 is relaying the data to the sink b) S3 is relaying the data to the sink
3. Give a scenario for energy aware routing, whereby the nodes with the highest remaining energy will be selected as the next hop.

**Answer**

 2m

4m

Sink

3m

EH = 3/s

ER = Eb - 3

Ec = 4/s

EH = 2/s

ER = Eb - 5

Ec = 4/s

1. After 10 seconds, 10 packets delivered by each node.

 2m

4m

Sink

3m

EH = 30/s

ER = Eb - 13

Ec = 40/s

EH = 20/s

ER = Eb -25

Ec = 40/s

1. a) when S2 relays packets S3 maybe fully charged whereby EH cannot be more than Eb

 2m

4m

Sink

3m

EH = 30/s

ER = Eb - 13

Ec = 40/s

EH = 20/s

ER = Eb + 20 -5 = Eb + 15

Ec = 0/s

ii. b) when S3 relays packets, S2 maybe fully charged whereby EH cannot be more than Eb

 2m

4m

Sink

3m

EH = 30/s

ER = Eb – 3+ 30 = Eb +27

Ec = 40/s

EH = 20/s

ER = Eb -25

Ec = 40/s

1. in energy aware routing, node S2 will be selected first as it has more remaining energy than S3 (Eb – 3 and Eb – 5) and after 10 seconds, remaining energy of node S2 is Eb – 5 and node S3 is fully charged by then. So after 10 seconds node S3 will be chosen to relay packets and node S2 will harvest energy and the process will continue by taking turn by each nodes.

**Question 2**

 2m

4m

Sink

3m

 3m

**Figure 2**

Referring to Figure 2, now imagine that a cluster head can be chosen at random in which node S1 becomes cluster head and S2 and S3 forward the data to S1 and S1 takes the average of the sensor data forwards to node A and in the next rounds node S2 becomes cluster head whereby S1 and S3 forwards to S2 and S2 forwards the average to A and the next round S3 becomes cluster head the process happens in the same manner. (consider how many cycles of cluster head rotation can take place). Calculate the lifetime with the parameters given below:

Energy to send/receive per packet Ec = 3 µJ

Energy required for transmit amplifier Et = 0.1 µJ

Energy for calculating average EA = 2 µJ

Initial energy network = EI  = 45 µJ

Distance between S2 and S3 is 8m

Hint : (Et X d)

**Answer**

**Energy required for one round when S1 is the cluster head**

 = 2Ec+Etx(√13)+Etx(3)+2Ec+EA+Ec+Etx(4) = 20.8[µJ]

Lifetime = 45 / 20.8 = 2.16

**Energy required for one round when S2 is the cluster head**

 = 2Ec+Etx(√13)+Etx(8)+2Ec+EA+Ec+Etx(√13) = 19.6[µJ]

Lifetime = 45 / 19.6 = 2.29

**Energy required for second round when S3 is the cluster head**

= 2Ec+Etx(3)+Etx(8)+2Ec+EA+Ec+Etx(5) = 26.8[µJ]

Lifetime = 45 / 26.8 = 1.67

**The actual lifetime is 45 / 26.8 = 1.67 because S3 is the bottleneck here. Consumes the highest energy**

When S1 and S2

Total energy is 20.8[µJ] + 19.6[µJ] = 40.0 = 2 cycles

When S1 and S3

Total energy is 20.8[µJ] + 26.8[µJ]= 47.6 = 1 cycle

When S2 and S3

Total energy is 19.6[µJ]+ 26.8[µJ]= 46.4 = 1 cycle

**Question 3**

d= 5m

**Figure 3**

Figure 3 shows a simple deployment of sensor nodes in a home environment to detect elder movement. The 3 sensor nodes (n) are deployed in a linear manner with equal distance between each other.

energy required for TX/RX circuitry, Ec=100 [nJ/bit],

energy required for transmission power Etx(d) = kd2 [nJ/bit], being k=1 [nJ/bit/m2],

packets size a =1000 [bits],

1. Is it more energy efficient to use direct transmission (from S1 to S3) or minimum per-transmission energy routing or multihop (S1 to S3).
2. How many nodes are required so that direct transmission consumes the same amount of energy as multihop
3. Discuss the situation in b and explain under what circumstances that direct transmission is suitable.
4. As we know, energy consumption is directly proportional to data packet size. Calculate to show that how doubling the packet size can increase the total energy consumption. Compare the results with the previous. (you may just use direct transmission only). Suggest one way how data size can be reduced?

Energy consumption = *Energyelec X a + Energyamp X d2 X a*

Energy consumption α a

Energy consumption α d

1. Energy consumption is directly proportional to the distance. Calculate to show that how doubling the distance d can increase the total energy consumption. Compare the results with the previous. (you may just use direct transmission only).

**Answer**

a.

The total consumed energy under direct transmission (S1 to S3) is:

Edirect = Eca + Etx(2d)a + Eca = 0.3[mJ]

The total consumed energy under minimum per-transmission energy routing (A-B-C-D-E) is:

Eminenergy = 2a(2Ec + Etx(d)) = 0.45[mJ]

b.

Edirect = 2Eca + Etx((n-1)d)a

Eminenergy = (n-1)a(2Ec + Etx(d))

Therefore,

2Eca + Etx((n-1)d)a = (n-1)a(2Ec + Etx(d))

n =2

c.

2Eca + Etx((n-1)d)a > (n-1)a(2Ec + Etx(d))

We can see that n <= 2, which mean that when there are densely populated network with a lot of nodes, direct transmission will incur higher energy than multihop communication and this is also depending on the transmission distance d because transmission power is directly proportional to d2 and d4 and in this example we can see that Etx((n-1)d) whereby transmission power of n-1 times of distance between nodes and in multiop it is (n-1) Etx(d). There is a big difference in these two cases.

**Question 4**

Sink

 2m

4m

2m

**Figure 4**

A linear personal area network (PAN) (see Figure 4) is composed of 3 close-by motes and a distant Gateway. The communication is performed by electing a cluster head among the three motes which collects the traﬃc from the other motes and sends it remotely to the gateway.

energy required for TX/RX circuitry, Ec=100 [nJ/bit],

energy required for transmission power Etx(d) = kd2 [nJ/bit], being k=1 [nJ/bit/m2],

packets size a =1000 [bits],

Initial energy of each node = EI  = 150 nJ

1. Find the total energy consumption for three cases a) when S1 is the cluster head, b) when S2 is the cluster head and c) when S3 is the cluster head.

2. Which setup would give the most efficient energy consumption, a, b or c?.

3. What is the total energy consumption when direct transmission is used without cluster head election. Which setup is better?

4. Calculate the lifetime under all these cases.

5. Calculate the lifetime when cluster head election follows the following sequence S1-S1-S2-S3-S3

**Answer**

1a) When S1 is cluster head, it receives one packet from S2 and one packet from S3 and sends 3 packets to the sink.

Energy consumed by S1:

E(S1) = 2Eca + 3(Eca + Etx(4)a)

Energy consumed by S2 and S3:

E(S2) = Eca + Etx(2)a

E(S3) = Eca + Etx(2)a

**Total Energy Consumption** is E(S1) + E(S2) + E(S3) = 7Eca + 2 Etx(2) + Etx(4)

The bottleneck in this case is Node S1 and therefore lifetime = EI / E(S1)

1b) When S2 is cluster head, it receives one packet from S1 and one packet from S3 and sends 3 packets to the sink.

2

4

√20

Energy consumed by S2:

E(S1) = 2Eca + 3(Eca + Etx(√20)a)

Energy consumed by S1 and S3:

E(S2) = Eca + Etx(2)a

E(S3) = Eca + Etx(4)a

**Total Energy Consumption** is E(S1) + E(S2) + E(S3) = 7Eca + 2 Etx(2) + Etx(4) + Etx(√20)

The bottleneck in this case is Node S2 and therefore lifetime = EI / E(S2)

1c) When S3 is cluster head, it receives one packet from S1 and one packet from S2 and sends 3 packets to the sink.

2

4

√20

Energy consumed by S3:

E(S3) = 2Eca + 3(Eca + Etx(√20)a)

Energy consumed by S1 and S3:

E(S1) = Eca + Etx(2)a

E(S2) = Eca + Etx(4)a

**Total Energy Consumption** is E(S1) + E(S2) + E(S3) = 7Eca + 2 Etx(2) + Etx(4) + Etx(√20)

The bottleneck in this case is Node S3 and therefore lifetime = EI / E(S3)

2. Obviously S(2) = S(3) and S(1) is definitely more than S(2) and S(3). So it is best to elect S(1) as the cluster head in this case.

3. Energy consumption when direct transmission is used =

 3Eca + Etx(4)a) + Etx(√20) + Etx(√20)

 Obviously direct transmission consumes less energy in this case.

**Question 5**

4m

D=15m

Sink

**Figure 5**

Figure 5 shows a simple personal area network (PAN) that consists of n number of sensor motes and a Pan coordinator that collects periodical humidity data from the motes and finally conveys the messages to the sink.

Calculate total energy consumption in i) when 4 motes send the humidity data to the coordinator and coordinator just relay the received data to the sink. ii) coordinator performs average of the humidity and only then sends the average data to the sink. iii) Is there a possibility that energy consumption using averaging is less efficient than without averaging?

Energy to send/receive per packet Ec = 3 µJ

Energy required for transmit amplifier Et = 100 µJ

Energy for calculating average EA = 2 µJ

Initial energy of each node = EI  = 105 µJ

~~Packet size b = 100 byte~~

Hint : (Et X d)

**Answer**

1. Total energy consumption is : E(i) = 4 (2 Ec + Et (d)) + 4( Ec + Et (D))
2. Total energy consumption is : E(ii) = 4 (2 Ec + Et (d)) + 4EA + ( Ec + Et (D))

General Term

1. Total energy consumption is : E(i) = n (2 Ec + Et (d)) + n( Ec + Et (D))
2. Total energy consumption is : E(ii) = n (2 Ec + Et (d)) + nEA + ( Ec + Et (D))
3. When E (i) < E (ii)

n (2 Ec + Et (d)) + n( Ec + Et (D)) < n (2 Ec + Et (d)) + nEA + ( Ec + Et (D))

when n = 1

**Question 6**

In a simple WSAN network, temperature measurement has to be taken every 250ms whereby every reading takes 10ms and sending is required only once per second. When a node sends a packet, it is expected that the node receives a packet as well. The packet size is 250 bytes and the radio bandwidth is 6400 bits/s. More properties of energy consumption is given below:

 Idle mode : 0,05mA

CPU computation: 9mA

Sending of wireless data: 10mA

Receiving of wireless data: 5Ma

1. Calculate the lifetime of each node?
2. There are several factors not considered here which might affect the overall energy consumption. List down FOUR (4) factors that may increase or decrease the energy consumption calculated in Q2.(c ).(i).

**Answer :**

Energy for CPU processing and computation

4 samples/second x 0,01 seconds (for each measurement) x 9mA = **0.36mAs**

Energy for radio transmission (involves both sending and receiving)

(250 bytes x 8 bit)/(6400 bits/s) x (9mA (basic consumption) + 10 mA (for sending)) + (250 bytes x 8 bit)/(6400 bits/s) x (9mA (basic consumption) +5mA (for receiving)) = **0.3125s x19mA + 0.3125s x 14mA = 5.9375 + 4.375 = 10.312 mAs**

Energy consumption in idle mode

First, ﬁnd out the idle time within 1 second. Active time includes 0.04s for computation and processing, and 0.625s for radio transmission within 1 second. Therefore, idle time is (1-0.04-0.625) = 0.335. Idle energy consumption is: **0.335s x 0.01 mA = 0,00335 mAs**

Total energy consumption per second

**0.36mAs + 10.312mAs + 0.00335 mAs = 10.675 mAs**

**Question 7**

****

**More exercises**

**Question 8**

A

Event

**Figure 6**

13 Sensors are equally deployed in a forest area for fire detection and an actuator is placed nearby the sensors for immediate action. When the fire triggers (event) the data is firstly detected by the closest nodes which is node 3 and node 4. Distance between node 10,11 and 13 to the actuator is 5m. Assume that the distance between each sensor node is 2m. Based on this answer the following questions.

Energy to send/receive per packet Ec = 3 µJ

Energy required for transmit amplifier Et = 100 µJ

Energy for calculating average EA = 2 µJ

Initial energy of each node = EI  = 105 µJ

Packet size b = 100 byte

Hint : (Et X d)

1. Identify a multihop (flooding) route from node 3 or node 4 until the final node which is the actuator A. Calculate total energy consumption in this scenario.
2. Identify few other alternative routes that you may find as shortest route and calculate the total energy consumption.
3. Identify the shortest route based on your calculations above.
4. If the routes that you have selected in a and b have been used which particular node or nodes becomes the routing hole (i.e the node dies first)
5. Calculate the energy consumption for node 3 and node 4 using direct transmission. Distance between node 3 to the actuator is 9m and node 4 to the actuator is 10m.
6. Calculate the energy consumption if node 2 and node 4 detects the event and forwards the data to the cluster head node 5 and node 5 forwards the data directly to the actuator. Distance between node 5 to the actuator is 7m.
7. What if node 4 is a mobile relay that collects the event data moves closer to the actuator at the distance of 2m and forwards the data. Calculate the energy consumption assuming that energy consumed for mobility is neglectable as node 4 is already a mobile entity such as an animal or train. Is this scenario suitable for the event given? Justify.

**Question 9**

A

Event

For the network shown explain how the following works. Use suitable table to show or you may re draw the diagram.

1. SPIN
2. Directed Diffusion
3. Rumor Routing
4. Clustering

**Question 10**

A border tracking system system is to be developed for detecting human intrusion or movement within the border of countries. For this you need to identify the following

1. Aspects
2. Sensor modality
3. How to detect presence of human
4. System and experiment

**Answer**

Aspects of the illegal immigrant detection problem

* Environment (where satellite view is not feasible, for example forests)
* Application constraints (purpose, cost, integrity violation, security)
* Platform
* Communication
* Sensor system
* Pattern recognition
* Decision making
* Actuation
* Experiment / Collect data

One can argue that border monitoring is a suitable starting point (line vs area).

Similar problems requiring area monitoring

* Illegal logging (monitor large area instead of border)
* Illegal hunting / harvesting (monitor large area instead of border)
* Safety and security in urban environments

Problem statement

* Application constraints (coverage, cost, energy, communication, …)
* What sensors to use?
	+ Are multiple sensors needed?
	+ Integration of information from multiple motes is necessary?
	+ Motion detectors
	+ Sound analysis
	+ Chemical, electronic nose, CO2, moisture, microbial cloud
	+ Seismic, Vibration
	+ Magnetic (metals)
	+ IR imaging, low-resolution, eye reflection (requires line-of-sight conditions?)
	+ Neuromorphic vision
	+ Bio-inspiration (how do prey detect predators):
	Sound increases awareness / attention,
	Smell makes them run off / escape,
	Vision works differently, sometimes makes them run off, sometimes not.
* How to detect the presence of humans, and categorize their activities / behaviour?
	+ Pattern recognition
	+ Limited resources (energy, processing, communication)
	+ Appropriate hardware
	+ Local or distributed
* How to build such a system?
	+ Energy management
	+ Communication
	+ Pattern recognition
	+ Decision making
* How to design an appropriate experiment?
	+ Collect realistic data
	+ Train the system to detect presence and categorize behaviour