Internet of Things, Exam– June 30, 2014

Family Name	
Given Name	
Student ID	

Total Available time: 2 hours

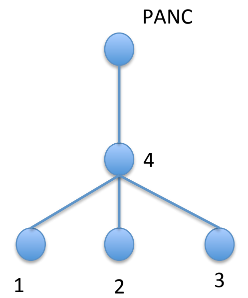
1 – Exercise (7 points)

The two-hop personal area network (PAN) in the figure is composed of 4 motes and a PAN Coordinator. The PAN works in beacon-enabled mode.

- Mote 1 and Mote 2 have statistical (non-deterministic) traffic towards the PAN coordinator characterized by the following probability distribution: P(required rate=50 [bit/s])=0.5, : P(required rate=250 [bit/s])=0.25, P(required rate=0 [bit/s])=0.25.
- Mote 3 and Mote 4 have deterministic traffic towards the PAN coordinator with a required rate of 500 [bit/s].

Assuming that:

- the active part of the Beacon Interval (BI) is composed of Collision Free Part only
- The collision free part is divided in two: the first part is dedicated to the transmissions from Motes 1,2 and 3 towards Mote 4, the second part is used by Mote 4 to deliver its own traffic and the relayed one to the PANC.
- the motes use b=128 [bit] packets to communicate with the PANC which fit exactly one slot in the CFP
- the nominal rate is 250 [kb/s]
- Mote 4 is 10 [m] away from the PANC



Find

1. The duration of the single slot, the duration of Beacon Interval (BI), the duration of the CFP and the duration of the inactive part, a consistent slot assignment for the four motes, and the duty cycle
2. The energy consumption in a BI for Mote 4 if the energy required to operate the TX/RX circuitry is E_c=50 [nJ/bit], the energy required to support sufficient transmission output power $E_{tx}(d)$= k d^2 [nJ/bit], being k=1 [nJ/bit/m2], the energy of being idle in a slot is E_{idle} = 20 [uJ] and the energy for sleeping is E_{sleep} = 5 [nJ].

Solution

The minimum rate required by all the four motes is 50 [bit/s]. The beacon interval can be dimensioned such that one slot in the CFP per beacon interval corresponds to 50 [bit/s].

Thus, BI = 128 [bit] / 50 [bit/s] = 2.56 [s].

Mote 1 and 2 in the worst case require a bitrate of 250 [kb/s] which corresponds to 5 slots in the CFP
Mote 3 requires a rate of 500 [bit/s] which corresponds to 10 slots in the CFP
Mote 4 requires a rate of 500 [bit/s] which corresponds to 10 slots for its own traffic and then it must be able to relay also the traffic from the other 3 motes. In total, mote 4 requires 10+5+5+10=30 slots

The total number of slots in the CFP is thus: 5 (Mote 1) + 5 (Mote 2) + 10 (Mote 3) + 30 (Mote 4) = 50 slots.

The slot duration can be calculated as: Ts=128 [bit] /250 [kb/s] = 512 [us]
The duration of the CFP is Tcfp=50 x Ts = 25.6 [ms]
The duration of the inactive part is: Tinactive = BI – Tcfp – Ts= 2.56 [s] – 25.6 [ms] – 512 [us] = 2.533 [s]
The duty cycle is d=Tactive / BI = 0.01

The energy consumption of Mote 4 is due to:
1-the traffic mote 4 receives from mote 1, 2 and 3
2-the traffic mote 4 sends to the PANC

1- Mote 4 receives for 10 slots the traffic coming from Mote 3: 10 Ec b
    Mote 4 receives traffic form mote 1 and mote 2: 0.25 5 Eidle + 0.25 5 Ec b + 0.5 (4 Eidle + Ec b)
2 mote 4 sends its own traffic to the PANC: 10 (Etx b +Ec b)
mote 4 relays traffic from mote 3 to the PANC: 10 (Etx b +Ec b)
Mote 4 relays traffic from Mote 1 and 2 to the PANC: 0.25 5 Eidle + 0.25 5 (Etx b + Ec b) + 0.5 (4 Eidle + Etx b + Ec b)

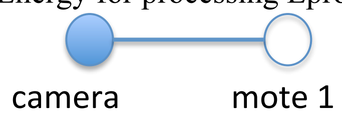
The overall energy consumption is:
Emote4 = 10 Ec b + 2(0.25 5 Eidle + 0.25 5 Ec b + 0.5 (4 Eidle + Ec b)) + 20 (Etx b +Ec b) + 2(0.25 5 Eidle + 0.25 5 (Etx b + Ec b) + 0.5 (4 Eidle + Etx b + Ec b)) + Ec b + 4947 Esleep

<u>2 – Exercise (7 points)</u>

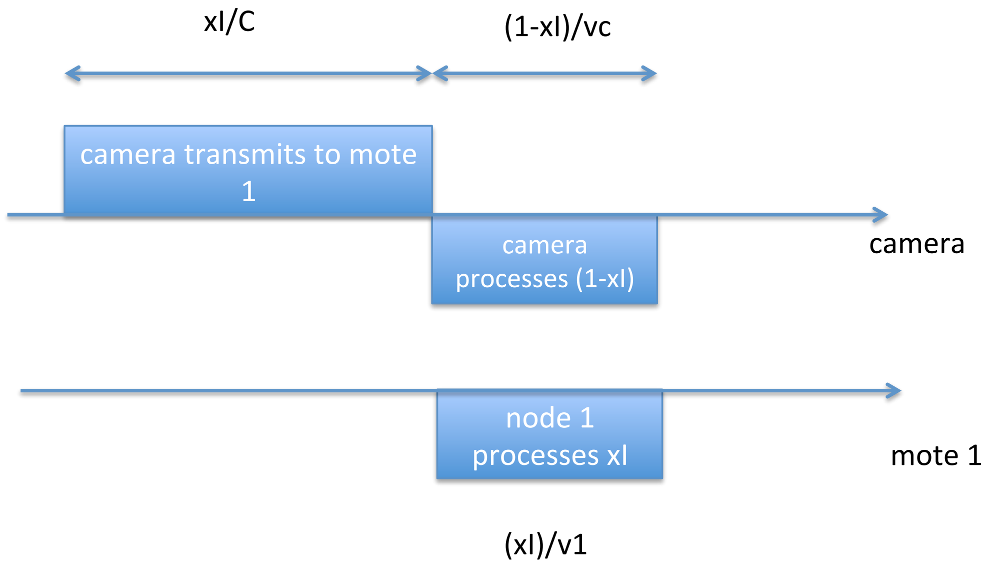
A visual sensor network is composed of a camera node and a plain mote (see figure). The camera node acquires an image of I=10 [Mbyte] which needs to be processed. The camera node sends a fraction of the image, xI, to Mote 1 for processing and processes locally the remaining part. In this case, the camera node first sends xI to Mote 1 and, upon completion of the transmission, starts processing the remaining part. Mote 1 starts processing its part as soon as it has received it.
Find out the value of x for which the camera node and the plain mote stop processing at the same time (initial time is the time the camera node sends out the first bit of xI to the plain mote).

- Capacity of the link camera-Mote 1, C= 1[Mb/s]
- Processing rates of the camera and Mote 1 respectively, vc= 100 [kb/s], v1= 500[kb/s]

Find out the corresponding total energy consumption under the following parameters
Energy for transmitting/receiving: $E_{tx/rx}$=50 [nJ/bit] (including circuitry and transmission energy)
Energy for processing Eproc = 100 [nJ/bit]



Solution



The camera node and mote 1 stop processing at the same time if the following holds (see figure): xI / v1 = (1-x)I /vc which leads to x= v1/(v1+vc)=0.83

The camera node consumes energy for trasmitting xI [bits] and for processing (1-x)I [bits]. In details,
Ecamera=Etx/rx xI + Eproc (1-x)I = 3.32 [Joule] + 1.36 [Joule] = 4.68 [Joule]
The mote 1 consumes energy for receiving xI bits and for processing xI bits
Emote1 =xI (Erx + Eproc) =9.96 [Joule]

3 – Exercise (5 points)

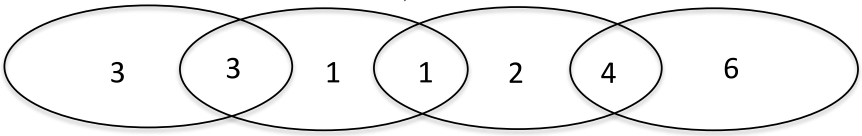
A tree-based ZigBee network topology is used to collect traffic from a monitoring application. The topology has the following parameters: maximum number of ZigBee routers per tree-level Rm=2, maximum number of ZigBee end-devices per tree level Dm=2. Assuming that the first level of the three (nodes directly connected to the PANC) share the same link capacity, C=100[kb/s], find out the maximum tree-depth, Lm, which does not exceed C under the following traffic conditions:

- ZigBee end devices generate 2 [kb/s] of traffic
- ZigBee routers, besides relaying simple nodes' traffic, generate additional 2 [kb/s] of traffic

Solution
The capacity of the link between the devices at level 1 and the PANC is 100 [kb/s]. Each of the four devices requires 2 [kb/s] for its own traffic. Thus, the remaining capacity for the two zigBee routers at level 1 is 100[kb/s] – 8[kb/s] =92[kb/s].
Each one of the two routers can thus relay traffic up to 46 [kb/s].
In turn, the tree sub-branch rooted at each router at level 1 cannot exceed 46 [kb/s] of collected traffic. The four devices connected to the routers at level 1 require 2[kb/s] each. Thus, the remaining capacity for routers at level 2 is 46[kb/s] – 8[kb/s] = 38[kb/s]. Each one of the routers at level 2 can thus relay traffic from devices at level 3 up to 19 [kb/s]. To conclude, the maximum depth of the tree is Lm=3.

3 – Questions (9 points)

1. Given the network topology in the figure, what is the minimum number of slots in the signaling subframe and in the data subframe under SPARE MAC (numbers represents the numbers of motes within each area of the topology, ovals represent the coverage range: motes in the same oval can hear each other, motes in the intersection between two ovals can hear the motes in both the ovals)? EXPLAIN WHY.



The number of slots in the signaling subframe must be equal to the cardinality of the biggest two-hop cluster of nodes, thus N=13 (the two-hop cluster at the very right in the figure).
The number of slots in the data subframe must be at least equal to the cardinality of the biggest one hop cluster of nodes, thus M=10 (the one-hop cluster at the very right in the figure).

2. A sensor node performs channel access according to the CSMA/CA scheme of the IEEE 802.15.4 standard. Assuming that the probability of finding the channel busy is p=0.01 at each backoff period, what is the probability that the sensor node does actually access the channel within the first two tries.

The probability that the sensor access the channel at the first attempt is (1-p)x(1-p) (remember that in order for the sensor to access the channel it must "see" the channel idle in two consecutive backoff periods).

The probability that the sensor access the channel at the second attempt is (1-(1-p)x(1-p)) (1-p)x(1-p) (remember that in order for the sensor to access the channel it must "see" the channel idle in two consecutive backoff periods).

The required probability is the sum of the probabilities of the two events, P=0.999

3. A Dynamic Frame ALOHA system is used to arbitrate 5 tags. What is the average throughput after the first two frames of the arbitration process knowing that the respective frame lengths are $r_1=2$, $r_2=3$?

After the firs frame, either 1 tag or 0 tags are resolved.
The probability that 1 tag is resolved during the first frame is: 5 ½ $(1/2)^4$ 2= 0.3125
The probability that 0 tags are resolved during the first frame is: 0.6875

If 1 tag has been resolved after the first frame, the average number of tags resolved during the second frame is: 4 $(1-1/3)^3$=1.185

If 0 tags were resolved during the first frame, the average number of tags resolved during the second frame is: 5 $(1-1/3)^4$=0.98

The average number of tags resolved after two frames is: 0.3125 (1+1.185) + 0.6875 0.98 = 1.35