***Internet of Things,  June 8, 2021***

## ***1 – Exercise (6 points)***

A IEEE 802.15.4 network is composed of a PAN Coordinator and five motes. Each mote is assigned 2 slots in the Collision Free Part, and each slot can carry packets of 128 [byte]. The nominal rate is R=250 [kb/s] and the active part is composed of the beacon slot and the CFP only. The network is operated with a duty cycle $\eta$=1%. The motes have the following traffic pattern: mote 1 and mote 2 generate packets according to a Poisson process with parameter $\lambda_1$=0.2 [packets/s], mote 3 and mote 4 generate packets according to a Poisson process with parameter $\lambda_2$ = 0.5 [packet/s], mote 5 generates packets deterministically at a rate r=2[packets/s]
Find: the duration of the Beacon Interval, the duration of a slot, the equivalent rate defined as "one slot per Beacon Interval", the average energy consumed by one mote 1 assuming that it is not in range of the other motes.

## ***Solution***

The total number of slots in the active part is Nactive=5 x 2 + 1= 11.
The slot duration is Ts = 128[byte] / 250[kb/s] = 4.096[ms]
The beacon interval can be written as: BI = (Nactive x Ts)/ $\eta$ = 4,505[s].
The equivalent rate defined as "one slot per Beacon Interval" is r = 128[byte] / = 227,2[bit/s].

The probabilities that mote 1 and 2 have 0, 1, >=2 packets available in a BI are:

P01 = P(k=0) = e-$\lambda$1 BI
P11 = P(k=1)= $\lambda$1 BI e-$\lambda$1 BI
P21= 1- P01 - P11

The energy consumed by mote 1 is:

E = Erx (beacon reception) + 8 Eidle (idle in the 8 slots of the other 4 motes) + 2Eidle P01 + (Eidle + Etx) P11 + 2Etx P>=2 + Esleep xNsleep

## ***1 – Exercise (6 points)***

A IEEE 802.15.4 network is composed of a PAN Coordinator and five motes. Each mote is assigned 2 slots in the Collision Free Part, and each slot can carry packets of 128 [byte]. The nominal rate is R=250 [kb/s] and the active part is composed of the beacon slot and the CFP only. The network is operated with a duty cycle $\eta$=2%. The motes have the following traffic pattern: mote 1 and mote 2 generate packets according to a Poisson process with parameter $\lambda$1=0.2 [packets/s], mote 3 and mote 4 generate packets according to a Poisson process with parameter $\lambda$2 = 0.5 [packet/s], mote 5 generates packets deterministically at a rate r=2[packets/s]
Find: the duration of the Beacon Interval, the duration of a slot, the equivalent rate defined as "one slot per Beacon Interval", the average energy consumed by one mote 1 assuming that it is not in range of the other motes

## ***Solution***

The total number of slots in the active part is $N_{active}$=5 x 2 + 1= 11.
The slot duration is $T_s$ = 128[byte] / 250[kb/s] = 4.096[ms]
The beacon interval can be written as: BI = ($N_{active}$ x $T_s$)/ $\eta$ = 2,252[s].
The equivalent rate defined as "one slot per Beacon Interval" is r = 128[byte] / = 454,5[bit/s].

The probabilities that mote 1 and 2 have 0, 1, >=2 packets available in a BI are:

$P_0^1$ = P(k=0) = $e^{-\lambda 1 \text{ BI}}$
$P_1^1$ = P(k=1)= $\lambda_1$ BI $e^{-\lambda 1 \text{ BI}}$
$P_2^1$= 1- $P_0^1$ - $P_1^1$

The energy consumed by mote 1 is:

E = Erx (beacon reception) + 8 Eidle (idle in the 8 slots of the other 4 motes) + 2Eidle $P_0^1$ + (Eidle + Etx) $P_1^1$ + 2Etx $P_{>=2}$ + Esleep xNsleep

## *2 – Exercise (6 points)*

Find the average efficiency of multi-frame Dynamic Frame ALOHA collision resolution protocol with an initial population of n=3 tags and an initial frame size r=2. Assume that the size of the frames after the first one is "optimally" set to the current backlog..

Solution
See exercise 2, RFID chapter

## *2 – Exercise (6 points)*

Find the average efficiency of multi-frame Dynamic Frame ALOHA collision resolution protocol with an initial population of n=3 tags and an initial frame size r=3. Assume that the size of the frames after the first one is "optimally" set to the current backlog.

Solution
L3=P(S=0)L3+P(S=1)L2+P(S=2)L1
P(S=2)=0
P(S=0)=(1/3)33=1/9
P(S=1)=(1/3)3 3 3 2=2/3
P(S=3)= (1/3)33!=2/9

L3=3+1/9 L3 + 2/3 L2
L2=4

8/9L3= 17/3

L3=51/8

\eta=24/51

## *3 – Exercise (4 points)*

A MQTT client (Client 1) is subscribed to the topic /lumen. The MQTT broker is connected to 2 additional MQTT clients which publish messages on the topic /lumen according to the following traffic processes:

- Client 2 publishes one message on topic /lumen according to a Poisson process with parameter \lambda_2 = 0.5 message/second
- Client 3 publishes one message on topic /lumen according to a Poisson process with parameter \lambda_3 = 1 message/second

Find the average energy consumed by the MQTT Client 1 in a time period of 15 minutes in the two cases where the all the publish messages require QoS level 0 and 1. Clearly describe the message exchange session between the MQTT broker and Client 1 in the three cases.
Use the following parameters: energy for sending/receiving MQTT publish messages, Erx=10[uJ], energy for sending/receiving MQTT signaling messages (various ACK messages), Etx= 3 [uJ], energy for being idle Eidle=0[uJ].

Solution
Case 1: QoS0
E1=(\lambda_2+\lambda_3)x 120[s] Erx
Case 1: QoS1
E1=(\lambda_2+\lambda_3) x 120 [s] (Erx+Etx)

## *3 – Exercise (4 points)*

A COAP client (Client 1) is interested in retrieving the resource /motex/temperature.txt available at a COAP server. The resource reflects temperature readings at the COAP server which get updated with frequency f=2[Hz]. Find the average energy consumed by the COAP client Client 1 in a time period of 15 minutes in the two cases where COAP Observe

mode is not adopted, and COAP Observe mode is adopted with the option of receiving every new sample of temperature reading.
Use the following parameters: energy for sending/receiving COAP requests messages, Ereq=10[uJ], energy for sending/receiving COAP response messages, Eresp=15[uJ].

Solution
Case 1: no observe mode
E1= f x 900[s] (Ereq+Eresp)

Case 2: observe mode
E1= f x 900 [s] Eresp
Accepted also
E1=(f x 900[s]) Eresp + Ereq

## *4 – Questions (9 points)*

1. Three RFID tags are arbitrated by Dynamic Frame ALOHA. Tell if the following statements are true or false. **MOTIVATE THE ANSWER. UNMOTIVATED ANSWER WILL NOT BE CONSIDERED**
   a. The lower the dimension of the first frame the higher the efficiency of the arbitration process. TRUE
   b. The optimal size of the first frame is 2 FALSE
      In LoraWAN the lower the Spreading Factor the higher the receiver sensitivity FALSE

2. What is the average throughput of a single frame Frame-ALOHA with N=2 tags and r=4 slots?
E[S] = N (1-1/4) = 3/2

2bis. What is the average throughput of a single frame Frame-ALOHA with N=2 tags and r=5 slots?
E[S] = N (1-1/5) = 8/5

3. A MQTT Broker receives a subscription message with the following content: what is the action of the Broker (choose among the following, motivate the answer)?

| | |
|---|---|
| packeId | 2 |
| topicName | “matteo/temp” |
| QoS | 1 |
| retainFlag | false |
| Payload | “temperature:30” |
| dupFlag | false |

The broker relays the PUB message to all the clients subscribed to topic "matteo/temp" and send back a PUB ACK"