Internet of Things, *July 4, 2018* **Total Available time: 1.30 hours**

1 – Exercise (7 points)

A IEEE 802.15.4 network is composed of a PAN Coordinator and four motes. Each mote is assigned 2 slots in the Collision Free Part for uplink traffic, and the PAN coordinator is assigned 8 slots in the CFP for downlink traffic (two slots dedicated to each one of the four motes). Each slot can carry packets of 128 [byte]. The nominal rate is R=125 [kb/s] and the active part is composed of the beacon slot and the CFP only. The network is operated with a duty cycle η=10%. The motes and the PAN coordinator have the following traffic pattern:

- Mote 1 and mote 2 generate packets towards the PAN coordinator according to a Poisson process with parameter λ_1=0.01 [packets/s]
- Mote 3 and 4 generate packets towards the PAN coordinator according to a Poisson process with parameter λ_2 = 0.5 [packet/s]
- The PAN coordinator generates packets toward each one of the four motes according to a Poisson process with parameter λ_3 = 0.1 [packet/s]

Find (i) the duration of the Beacon Interval, (ii) the duration of a slot, (iii) the average energy consumed by the PAN coordinator Mote 1 assuming E_{rx} = 1[uJ], E_{tx},=3 [uJ], E_{idle} = 0.5 [uJ] and E_{sleep} = 1[nJ] to be respectively the energy for receiving, transmitting (circuitry + emitted power) , being idle and sleeping in a slot.

The slot duration is Ts=128[byte]/125 [kb/s]= 8.192[ms].
The CFP is composed of Ncfp = 2 x 4 + 8 = 16 slots.
The active part is Nactive= Ncfp +1 = 17 slots and its duration is Tactive=Nactive x Ts = 139,26 [ms]..
The Beacon Interval is: BI= Tactive/ η =1392,64 [ms].
The number of slots in the inactive part is Ninactive= (BI-Tactive)/Ts = 153.
The probability that Mote 1 and 2 have 0, 1, 2 or more packets ready in a BI are respectively:
$P^1_0= e^{-\lambda 1BI}$
$P^1_1= -\lambda_1 BI\, e^{-\lambda 1BI}$
$P^1_2=1 - P^1_0 - P^1_1$

The probability that Mote 3 and 4 have 0, 1, 2 or more packets ready in a BI are respectively:
$P^2_0= e^{-\lambda 2BI}$
$P^2_1= -\lambda_2 BI\, e^{-\lambda 2BI}$
$P^2_2=1 – P^2_0 – P^2_1$

The probability that the PAN coordinator has 0, 1, 2 or more packets ready in a BI for each one of the mores are respectively:
$P^{PANC}_0= e^{-\lambda 3BI}$
$P^{PANC}_1= -\lambda_3 BI\, e^{-\lambda 3BI}$
$P^{PANC}_2=1 – P^{PANC}_0 – P^{PANC}_1$

The average energy consumed by the PANC in a BI is:
$E = E_{tx} + 2\,[P^1_0\, 2\, E_{idle} + P^1_1\, (E_{rx} + E_{idle}) + P^1_2\, 2\, E_{rx}] + 2\,[P^2_0\, 2\, E_{idle} + P^2_1\, (E_{rx} + E_{idle}) + P^2_2\, 2\, E_{rx}] + 4\,[P^{PANC}_0\, 2\, E_{idle} + P^{PANC}_1\, (E_{tx} + E_{idle}) + P^{PANC}_2\, 2\, E_{tx}] + 153\, E_{sleep}$

2 – Exercise (4 points)

Find the average efficiency of 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.

Applying the recursive formula we get:

$$L_3 = 2 + \sum_{i=0}^{2} P(S=i)L_{3-i}$$

$L_3 = 2 + P(S=0)L_3 + P(S=1)L_2 + P(S=2)L_1$

Knowing that, P(S=0) = ¼, P(S=2) = 0, P(S=1) =3/4, we obtain:

$$L_3 = 2 + \frac{1}{4}L_3 + \frac{3}{4}L_2$$

Iteratively

$$L_2 = 2 + P(S=0)L_2 + P(S=1)L_1$$

P(S=0)=1/2, P(S=1)=0, which leads to L_2=4.
Substituting the value of L2 in the first expression we get:
L_3 = 2 + 1/4L_3 + ¾ x4, that is L_3= 20/3
The efficiency is η = 9/20.

3 – Exercise (6 points)

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

- Client 2 publishes one message on topic /humidity according to a Poisson process with parameter λ = 10 message/minute
- Client 3 publishes one message on topic /humidity according to a Poisson process with parameter λ = 2 message/minute

Find the average energy consumed by the MQTT Client 1 in a time period of 1 hour 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, E_{rx}=10[uJ], energy for sending/receiving MQTT signaling messages (various ACK messages), E_{tx}= 3 [uJ], energy for being idle E_{idle}=0[uJ].

Client 2 and Client 3 generate the following average number of messages per hour:
M2= 10 [message/minute] x 60 [minutes] = 600 messages
M3 = 2 [message/minute] x 60 [minutes] = 120 messages

The energy consumed by client 1 in the cases of QoS 0 and 1 are respectively:
E0 = (M2+M3) E_{rx}
E1 = (M2+M3) (E_{rx}+ E_{tx})

3 – Questions (9 points)

1. Tell if the following statements are true or false. **MOTIVATE THE ANSWER. UNMOTIVATED ANSWER WILL NOT BE CONSIDERED**
   a. The IEEE 802.15.4 MAC layer is based only on random access procedures. **FALSE**
   b. The Schoute's estimate provides an estimate of the total number of already resolved tags. **FALSE**
   c. ZigBee cluster tree routing has higher signaling overhead than ZigBee AODV routing. **FALSE**
   d. The Expected Transmission Time (ETT) is better suited as routing metric in cases where wireless links have different data rate and/or propagation delays **TRUE**
2. Briefly explain the use of the route discovery table in ZigBee-AODV protocol. **SEE SLIDES**
3. Briefly explain the use of DAO messages in RPL. **SEE SLIDES**