Internet of Things, ***July 3, 2019*** **Total Available time: 1.30 hours**

1 – Exercise (6 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=5%. 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.

SOLUTION
N_{cfp}= 2x 4 +8 = 16, N_{active} =17, Ts=128[byte]/125[kb/s] = 8.192 ms
T_{active}= N_{active} x Ts = 139.26 ms
BI=Tactive/η=2.789s
The probabilities that a generic node or the PAN coordinate generates 0, 1 or >= 2 packets per beacon interval are:
$Pi(N=0) = e^{-\lambda_i BI}$, $Pi(N=1)= -\lambda_i BI\, e^{-\lambda_i BI}$, Pi(N>=2)=1-Pi(N=0)-Pi(N=1) with i=1,2,3

The average energy consumed by the PANC is:
$E_{panc} = E_{tx} + 2[P_1(N=0)\ 2\ E_{idle} + P_1(N=1)(E_{idle}+E_{rx})+P_1(N>=2)2E_{rx}] + 2[P_2(N=0)\ 2\ E_{idle} + P_2(N=1)(E_{idle}+E_{rx})+P_2(N>=2)2E_{rx}] + 4\,[P_3(N=0)\ 2\ E_{idle} + P_3(N=1)(E_{idle}+E_{tx})+P_3(N>=2)2E_{tx}] + N_{sleep}\ E_{sleep}$

2 – Exercise (6 points)

At the end of a frame of Dynamic FRAME ALOHA 3 collided slots are observed. What is the size of the next frame is Shoute's estimate is used? ***(2 points)***
Assuming that the number of tags transmitting in one slot is distributed according to a Poisson point process with parameter λ=3 tags, find the average backlog ***(4 points)***

SOLUTION
N = round(2.39 c)= 7
The probability that I tags transmit in a collided slot is:

$$P(N=i/N\geq 2)=\frac{P(N\geq 2/N=i)P(N=i)}{P(N\geq 2)}=\frac{\lambda}{i!}e^{-\lambda}\frac{1}{1-\lambda e^{-\lambda}-e^{-\lambda}} \qquad i=2,3,4,\ldots$$

The average number of tags transmitting in a collided slots is:

$$E[N/N\geq 2]=\sum_{i=2}^{\infty} i\frac{\lambda}{i!}e^{-\lambda}\frac{1}{1-\lambda e^{-\lambda}-e^{-\lambda}}=\frac{3-3e^{-3}}{1-3e^{-3}-e^{-3}}=3.55$$

The backlog is:
3.55 x 3 = 10.67

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 $\lambda = 2$ message/minute

Find the average energy consumed by the MQTT Client 1 in a time period of 1 hour in the two cases where 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 two 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].

SOLUTION

Client 2 generates on average 600 messages per hour
Client 3 generates on average 120 messages per hour

The average energy consumption is:
QoS0
$E= 720\ E_{rx}$

QoS1
$E=720(E_{rx}+E_{tx})$

3 – Questions (8 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. In LoRaWAN, Class B devices consumes (on average) more energy than Class A TRUE
   c. RPL is a reactive routing protocol FALSE
   d. Expected Transmission Time (ETT) and Expected Transmission Count (ETX) can be interchangeably used as routing metrics when wireless links in the network have different data rate and/or propagation delays FALSE
2. What is the content of route discovery table in ZigBee-AODV protocol. See slides
3. Briefly explain the use of DAO messages in RPL. See slides