Internet of Things, *July 22, 2020* **Total Available time: 2.00 hours**

1 – Exercise (7 points)

A IEEE 802.15.4 network is composed of a PAN Coordinator and two motes. Each mote is assigned 2 slots in the Collision Free Part for uplink traffic, and the PAN coordinator is assigned 4 slots in the CFP for downlink traffic (two slots dedicated to each one of the two 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 generates packets towards the PAN coordinator according to a Poisson process with parameter λ_1=0.01 [packets/s]
- Mote 2 generates 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 two 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 2 + 4 = 8 slots.
The active part is Nactive= Ncfp +1 = 9 slots and its duration is Tactive=Nactive x Ts = 73.728 [ms]..
The Beacon Interval is: BI= Tactive/ η =737.28 [ms].
The number of slots in the inactive part is Ninactive= (BI-Tactive)/Ts = 81.
The probability that Mote 1 are respectively:

$P_0 = e^{-\lambda_1 BI}$

$P_1 = -\lambda_1 BI\, e^{-\lambda_1 BI}$

$P_{>=2} = 1 - P_{10} - P_{11}$

The average energy consumed by the Mote 1 in a BI is:

$E = E_{rx} + 6E_{idle} + P_0\, 2\ E_{idle} + P_1\, (E_{tx} + E_{idle}\,) + P_{>=2}\, 2\, E_{tx}\,] + 81\, E_{sleep}$

A IEEE 802.15.4 network is composed of a PAN Coordinator and two motes. Each mote is assigned 2 slots in the Collision Free Part for uplink traffic, and the PAN coordinator is assigned 4 slots in the CFP for downlink traffic (two slots dedicated to each one of the two motes). 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 η=1%. The motes and the PAN coordinator have the following traffic pattern:

- Mote 1 generates packets towards the PAN coordinator according to a Poisson process with parameter λ_1=0.01 [packets/s]
- Mote 2 generates 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 two motes according to a Poisson process with parameter λ_3 = 0.1 [packet/s]

The slot duration is Ts=128[byte]/250 [kb/s]= 4.096[ms].
The CFP is composed of Ncfp = 2 x 2 + 4 = 8 slots.
The active part is Nactive= Ncfp +1 = 9 slots and its duration is Tactive=Nactive x Ts = 36.864 [ms]..
The Beacon Interval is: BI= Tactive/ η =368.64 [ms].
The number of slots in the inactive part is Ninactive= (BI-Tactive)/Ts = 891.
The probability that Mote 1 are respectively:

$P_0 = e^{-\lambda_1 BI}$

$P_1 = -\lambda_1 BI\, e^{-\lambda_1 BI}$

$P_{>=2} = 1 - P_{10} - P_{11}$

The average energy consumed by the Mote 1 in a BI is:

$E = E_{rx} + 6E_{idle} + P_0\, 2\ E_{idle} + P_1\, (E_{tx} + E_{idle}\,) + P_{>=2}\, 2\, E_{tx}\,] + 891\, E_{sleep}$

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.

Find the average efficiency of Dynamic Frame ALOHA collision resolution protocol with an initial population of n=4 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:

$L_4 = 2 + P(S=0)L_4 + P(S=1)L_3 + P(S=2)L_2 + P(S=3)L_1$

P(S=3)=P(S=2)=0

P(S=1)=P(S=0)=1/2

$$L_4 = 2 + 1/2L_4 + 1/2L_3$$

Iterating

$L_3 = 3 + P(S=0)L_3 + P(S=1)L_2 + P(S=2)L_1$

P(S=2)=0

P(S=0)=$(1/3)^3$ 3 =1/9

P(S=1)= $(1/3)^3$ 3 3 2 = 6/9

$$L_3 = 3 + 1/9L_3 + 6/9L_2$$

L_2=4

L_3=3+1/9L_3+6/9 4

L_3=9/8 (3+24/9)=51/8

L_4=2+1/2L_4 + ½ 51/8

L_4=2 (2+51/4)=59/2 83/8

Eta=8/59 32/83

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:
$E0 = (M2+M3)\ E_{rx}$
$E1 = (M2+M3)\ (E_{rx}+ E_{tx})$

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 1 and 2. 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 1 and 2 are respectively:
$E1 = (M2+M3)\ (E_{rx}+ E_{tx})$
$E1 = (M2+M3)\ (E_{rx}+ 3E_{tx})$

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. RPL uses a reactive approach. **FALSE**

A wireless link is characterized by the following parameters: packet error rate in both directions, p = 0.01, packets size, L=100[byte], acknowledgment size= 10[byte], data rate, R=100[kb/s], propagation delay, t=5[us]. Find the Expected Transmission Time (ETT) for the link.

2 alternatives considered correct
$ETX=1/(1-p)$
$ETX=1/(1-p)^2$

$RTT=L/R+l_{ack}/R+2t$
$ETT=ETX \times RTT$

A wireless link is characterized by the following parameters: packet error rate in both directions, p = 0.05, packets size, L=100[byte], acknowledgment size= 5[byte], data rate, R=200[kb/s], propagation delay, t=5[us]. Find the Expected Transmission Time (ETT) for the link.

2 alternatives considered correct
$ETX=1/(1-p)$
$ETX=1/(1-p)^2$
$RTT=L/R+l_{ack}/R+2t$
$ETT=ETX \times RTT$