Exam September 20, 2016

September 23, 2016

Exercise–1 (*September 22, 2016*)

A personal area network (PAN) 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($r_{1,2}$=75[bit/s])=0.6, P($r_{1,2}$=225 [bit/s])=0.2, P($r_{1,2}$=0 [bit/s])=0.2. Mote 3 and Mote 4 have deterministic traffic towards the PAN coordinator with a required rate, $r_{3,4}$ of 525 [bit/s]. The PAN coordinator has to deliver downlink traffic towards the four nodes according to the following pattern: traffic towards Mote 1 and Mote 2 P($r_{1,2}^{PANC}$=75[bit/s])=0.5, P($r_{1,2}^{PANC}$ =225 [bit/s])=0.1, P($r_{1,2}^{PANC}$ =0 [bit/s])=0.4; traffic towards Mote 3 and Mote 4 deterministic with required rate $r_{3,4}^{PANC}$ 300 [bit/s].

Assuming that: (i) the active part of the Beacon Interval (BI) is composed of Collision Free Part only; (ii) the motes and the PAN coordinator use b=128 [bit] packets for their transmissions which fit exactly one slot in the CFP, (iii) the nominal rate is 250 [kb/s], find the duration of the single slot, the duration of Beacon Interval (BI), the duration of the CFP, the duration of the inactive part, a consistent slot assignment for all the transmissions (UPLINK AND DOWNLINK), and corresponding the duty cycle. Assuming that the energy consumption parameters are the following ones, find the average energy consumption in a beacon interval for the PAN coordinator; energy for receiving a packet E_{rx} =4[μJ], energy for transmitting a packet E_{tx} =7[uJ], energy for being idle in a slot E_{idle}= 3[μJ], energy for sleeping in a slot E_{sleep}= 3[nJ].

Solution of Exercise–??

Let's dimension the Beacon Interval with respect to the sensor nodes with the "slowest" required channel rate, that is 75 [bit/s]. We have $75[bit/s] = \frac{b}{BI}$, and then $BI = \frac{128[bit]}{75[bit/s]} \approx 1.7[s]$..

In the worst cases (maximum required rate), the four motes need the following number of slots in each beacon interval:

$$N_{mote1} = N_{mote2} = 225[bit/s]/75[bit/s] = 3$$

$$N_{mote3} = N_{mote4} = 525[bit/s]/75[bit/s] = 7$$

Along the same lines, we need to assign bunch of slot to the PAN coordinator for the downlink traffic. Namely, in the worst cases, the PAN coordinator will need 3 slots for Motes 1 and 2 and 4 slots for Motes 3 and 4.

The total number of slots in the Collision Free Part is then: $N_{CFP} = 3+3+7+7+3+3+4+4 = 34$

The slot duration is $T_s = \frac{b}{R} = 512[\mu s]$.

The total duration of the active part is: $T_{active} = T_s \times (N_{CFP} + 1) = 17.92[ms]$ and consequently:

$$T_{inactive} = BI - T_{active} = 1.682[s]$$

$$N_{inactive} = T_{inactive}/T_s \approx 3285$$

The duty cycle is:

$$\eta = \frac{T_{active}}{BI} = 0.9\%$$

The average energy consumed by the PAN coordinator can be written as:

$$\begin{aligned} E_{PANC} = E_{tx} + 3285E_{sleep} + 3E_{tx} + 4E_{tx} + 2[0.2 \times 3E_{idle} + 0.2 \times 3E_{rx} + 0.6 \times (E_{rx} + 2E_{idle})] \\ +2 \times 7E_{rx} + 2[0.4 \times 3E_{idle} + 0.1 \times 3E_{tx} + 0.5 \times (E_{tx} + 2E_{idle})] \end{aligned}$$

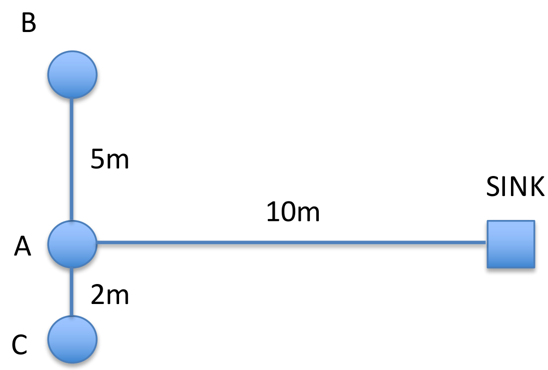

Figure 1: Reference topolgy

Exercise–2 (*September 22, 2016*)

Nodes A, B and C in the figure periodically collect and send temperature samples to the remote sink. The transmission phase is managed through a dynamic clustering approach which works as follows: two nodes send their samples to the cluster head which then takes the average out of all the sample (two received + one obtained locally) and sends a single packet to the SINK. The cluster head role is assigned repeating the following pattern A-A-B-B-C-C (when cluster head is C, B sends its message directly to C, and viceversa not through A).

Find the energy consumed by A, B and C in one round and the network lifetime (time to the first death) with the following parameters: energy required to operate the TX/RX circuitry E_c=6 [μJ/packet], energy required to support sufficient transmission output power E_{tx}(d)= k d^2 [nJ/packet], being k=120 [nJ/packet/m^2], energy for taking the average of 3 samples E_p= 4 [μJ], initial energy budget E_b=150[μJ] for all the three nodes.

Solution of Exercise–??

When mote A plays the cluster head, the energy consumed by the three motes is:

$$E_A = 2E_c + E_p + E_{tx}(10[m]) + E_c = 34[\mu J]$$

$$E_B = E_C = E_c + E_{tx}(5[m]) = 6[\mu J] + 3[\mu J] = 9[\mu J]$$

$$E_C = E_c + E_{tx}(2[m]) = 6[\mu J] + 0.48[\mu J] = 6.48[\mu J]$$

When it's Mote B turn:

$$E_B = 2E_c + E_p + E_{tx}(11.1[m]) + E_c = 12[\mu J] + 4[\mu J] + 6[\mu J] + 15[\mu J] = 37[\mu J]$$

$$E_A = E_c + E_{tx}(5[m]) = 6[\mu J] + 3[\mu J] = 9[\mu J]$$

$$E_C = E_c + E_{tx}(7[m]) = 6[\mu J] + 12[\mu J] = 11.88[\mu J]$$

When it's mote C's turn:

$$E_C = 2E_c + E_p + E_{tx}(\sqrt{104}[m]) + E_c = 12[\mu J] + 4[\mu J] + 6[\mu J] + 15[\mu J] = 34.48[\mu J]$$

$$E_A = E_c + E_{tx}(2[m]) = 6[\mu J] + 3[\mu J] = 6.48[\mu J]$$

$$E_B = E_c + E_{tx}(7[m]) = 6[\mu J] + 12[\mu J] = 18[\mu J]$$

The total energy consumed by A, B and C after one full round is:

$$E_A^{tot} = 98.96[\mu J]$$

$$E_B^{tot} = 115.76[\mu J]$$

$$E_C^{tot} = 105.68[\mu J]$$

The lifetime (measured in full rounds) is: $\frac{E_b}{E_B^{tot}} \approx 1.2$

Exercise–3 (*September 22, 2016*)

A RFID system based on Dynamic Frame ALOHA is composed of 3 tags. Assuming that the initial frame size is r=1, find the overall collision resolution efficiency η (assume that after the first frame, the frame size is correctly set to the current backlog size).

Solution of Exercise–??

The first frame is composed of 1 slot with three transmitting tags, thus throughput after the first frame is null.

The second frame, by assumption, is set to the correct backlog size, that is, $r_2 = 3$. We can then write:

$$L_3 = r_2 + \sum_{i=0}^{2} L_{3-i} P(S = i),$$

being $P(S = 0) = 3\frac{1}{3}^3$, $P(S = 1)$=2/3, $P(S = 2)$=0, $P(S = 3) = 6\frac{1}{3}^3$. We can the write:

$$L_3 = 3 + \frac{1}{9} L_3 + \frac{2}{3} L_2.$$

Iterating, we get:

$$L_2 = 2 + \sum_{i=0}^{1} L_{2-i} P(S = i),$$

being $P(S = 0) = 2\frac{1}{2}^2$, $P(S = 1)$=0, $P(S = 2)$=1/2, thus we get:

$$L_2 = 2 + 1/2 L_2,$$

which leads to $L_2 = 4$. Substituting the value of L_2 in the expression of L_3 we get:

$$L_3 = 3 + 1/9 L_3 + 8/3 = 6.375.$$

We finally have to add the single slot of the initial frame, thus the efficiency is:

$$\eta = \frac{3}{7.375} \approx 0.4.$$

Exercise–4 (*September 22, 2016*)

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=0.1 at each backoff period, find: (i) the probability that the sensor node does actually access the channel within the first two tries, (ii) the average time after which the sensor node does actually access the channel (assume infinite backoff attempts are allowed).

Solution of Exercise–??

The probability that the channel is sensed idle in two consecutive backoff periods is $P_{idle} = (1-p)(1-p) = 0.81$. The probability that the mote does access the channel within the first two tries is:

$$P = P_{idle} + (1 - P_{idle})P_{idle} \approx 0.96$$

The average number of attempts before the sensor nodes accesses the channel is given by $\frac{1}{P_{idle}} \approx 1.23$; The average number of backoff periods (slots) to access the channel can be written as:

$$E[T] = 2P_{idle} + \sum_{i=2}^{\infty}(1 - P_{idle})^{i-1}P_{idle}[2 + (i-1)1.5 + \sum_{k=2}^{i}\frac{2^k - 1}{2}]$$

Exercise–5 (*September 22, 2016*)

Briefly describe COAP Observation mode

Solution of Exercise–??

See slides.

Exercise–6 (*September 22, 2016*)

Sensor nodes 1, 2 and 3 run the SPARE MAC protocol; sensor 2 has two available slots in the Data Sub-Frame. Sensor 1 and 3 have traffic towards Sensor 2 characterized by a Poisson point process with intensity $\lambda_1 =$ 2[packet/frame], $\lambda_3 = 1$[packet/frame], respectively. Find out the probability that the transmissions of Sensor 1 and Sensor 3 (i) collide in exactly one slot of sensor 2 (ii) collide in at least one slot assigned to Sensor 2.

Solution of Exercise–??

There is a collision when:

- sensor 1 and 3 have one packet for sensor 2 and they choose the same slot to transmit the packet (collision in one slot);
- one sensor (1 or 3) has one packet for sensor 2 and the other one has two or more packets for sensor 2 (collision in one slot);
- sensor 1 and 3 have two or more packets for sensor 2 (collision in both slots);

The first event above happens with probability: $\frac{1}{2}\lambda_1\lambda_3 e^{-(\lambda_1+\lambda_3)}$.

The second event above happens with probability: $\lambda_1 e^{-\lambda_1}(1 - e^{-\lambda_3} - \lambda_3 e^{-\lambda_3}) + \lambda_3 e^{-\lambda_3}(1 - e^{-\lambda_1} - \lambda_1 e^{-\lambda_1})$.

The third event above happens with probability: $(1 - e^{-\lambda_3} - \lambda_3 e^{-\lambda_3})(1 - e^{-\lambda_1} - \lambda_1 e^{-\lambda_1})$.