Exam July 1, 2016

July 4, 2016

Exercise–1 (*July 1, 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])=0.5, P($r_{1,2}$=225 [bit/s])=0.1, P($r_{1,2}$=0 [bit/s])=0.4. Mote 3 and Mote 4 have deterministic traffic towards the PAN coordinator with a required rate, $r_{3,4}$ of 450 [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 $r_{3,4}^{PANC}$ 225 [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–1

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:

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

$$N_{mote3} = N_{mote4} = 450[bit/s]/75[bit/s] = 6$$

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 each one of the four motes.

The total number of slots in the Collision Free Part is then: $N_{CFP} = 3+3+6+6+3+3+3+3 = 30$

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

The total duration of the active part is: $T_{active} = T_s \times (N_{CFP} + 1) = 15.8[ms]$ and consequently:

$$T_{inactive} = BI - T_{active} = 1.684[s]$$

$$N_{inactive} = T_{inactive}/T_s \approx 3289$$

The duty cycle is:

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

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

$$\begin{aligned} E_{PANC} = E_{tx} + 3289E_{sleep} + 2 \times 3E_{tx} + 2[0.4 \times 3E_{idle} + 0.1 \times 3E_{tx} + 0.5 \times (E_{tx} + 2E_{idle})] \\ +2 \times 6E_{rx} + 2[0.4 \times 3E_{idle} + 0.1 \times 3E_{rx} + 0.5 \times (E_{rx} + 2E_{idle})] \end{aligned}$$

Exercise–2 (*July 1, 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=0.3 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–2

The probability that the channel is sensed idle in two consecutive backoff periods is $P_{idle} = (1-p)(1-p) = 0.49$. The probability that the mote does access the channel within the first two tries is:

$$P = P_{idle} + (1 - P_{idle})P_{idle} \approx 0.4$$

The average number of attempts before the sensor nodes accesses the channel is given by $\frac{1}{P} \approx 2.04$; this means that, on average, the sensor node finds the channel busy at the first try and idle at the second try. The average number of backoff periods (slots) to access the channel can be written as:

$$E[T] \approx 1.5 + \frac{2^2 - 1}{2} + 2 = 5.$$

Note that this is an approximation since the average number of required tries is not exactly equal to 2. To correct expression of $E[T]$ would be:

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

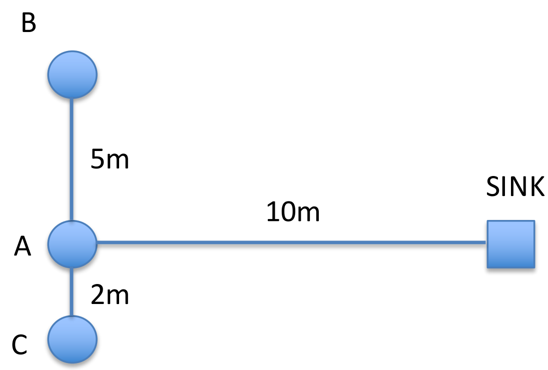

Figure 1: Reference topolgy

Exercise–3 (*July 1, 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 in a round robin fashion starting from node A (node A, then B, then C, then A, etc.) (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–3

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:

$$E_A^{tot} = 49.48[\mu J]$$

$$E_B^{tot} = 57.88[\mu J]$$

$$E_C^{tot} = 52.84[\mu J]$$

The lifetime (measured in full rounds) is: $\frac{E_b}{E_B^{tot}} \approx 2.6$

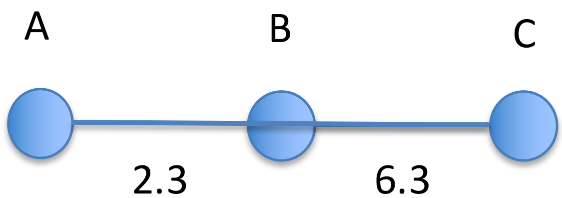

Figure 2: Reference topology for Ex. 4.

Exercise–4 (*July 1, 2016*)

Write the expression of the average energy consumed by all the sensor nodes for sending one packet from A to C through the two-hop path at the right. The numbers below each link express the ETX for the link (energy for operating the TX/RX circuitry for one packet E_c, energy for transmitting one packet E_{tx}).

Solution of Exercise–4

The total energy consumed across the two links for sending one single packet is: $E_{A-B} = E_{B-C} = E_c + E_{tx} + E_c$.

The total energy consumed is: $E_{tot} = ETX_{A-B} \times E_{A-B} + ETX_{B-C} \times E_{B-C}$.

Exercise–5 (*July 1, 2016*)

A Dynamic Frame ALOHA system is used to arbitrate 3 tags. What is the average duration of the arbitration time if the initial frame length is r_1=3 (assume that the frame size of the following frames may be optimally set to exact value of the current backlog)?

Solution of Exercise–5

The average duration of the arbitration process can be found by using the recursive formula:

$$L_3 = r_1 + \sum_{i=1}^{2} P(S = i) L_{3-i},$$

which leads to:

$$L_3 = r_1 + L_3 P(S = 0) + L_2 P(S = 1) + L_1 P(S = 2).$$

In our case, it is $P(S = 0) = 3(\frac{1}{3})^3$, $P(S = 2) = 0$, $P(S = 3) = 3!(\frac{1}{3})^3$ and $P(S = 1) = 1 - \frac{1}{9} - \frac{2}{9} = \frac{2}{3}$.

Iterating the process, we have:

$$L_2 = 2 + L_2 P(S = 0) + L_1 P(S = 1) = 2 + L_2 \frac{1}{2},$$

thus $L_2 = 4$

Substituting the value of L_2 in the expression of L_3, we obtain:

$$L_3 = 3 + L_3 \frac{1}{9} + 4\frac{2}{3},$$

which leads to $L_3 = \frac{9}{8}\frac{17}{3} = \frac{51}{8}$