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Duty-cycle MAC protocols - Energy conservation

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1. Introduction

Duty cycle mac protocol are such protocols which apply sleep/awake cycles to save energy by setting nodes to sleep in idle listening periods. Turning node's radio off while nodes are off duty can reduce the unnecessary power consumption by up to 50%. The duty cycle mac protocols trade off latency for energy efficient operation.

The objective of the project is to optimize a energy consumption in duty-cycle mac protocol, to do so, we have chosen X-MAC protocol.

We considered an unsaturated network with low traffic also we assumed a ring topology to make it simply and easy, and a spanning tree is constructed with static nodes that maintains a unique path to sink and use the shortest path routing with a maximum length of D hops, which is the depth of the tree. We also assume N number of nodes which defines the size of our network. The N nodes are layer into levels according to their distance to the sink, found at level d=0. Every source node generates traffic with frequency F_s, used for computing input traffic F_{in}^d output traffic F_{out}^d and background traffic F_B^d. In the table below you can see all the variables that are used in this project and in our simulation.

(a)

CC2420 Radio	Parameter Description	Values
R	Rate [kbyte/s]	31.25
T_{cs}	Time [ms] to turn the radio on and probe the channel (carrier sense)	2.60
T_{up}	Time [ms] to turn the radio on into RX or TX	2.40
L_{pbl}	Packet preamble length [byte]	4
Traffic & Network	**Parameter Description**	**Values**
P	data payload [byte]	32
F_s	Sampling rate [pkt/node/min]	F_s^*
F_I^d	Node's Input Traffic Frequency at level d	$F_{out}^d - F_s = F_s \frac{D^2-d^2}{2d-1}$
F_{out}^d	Node's Output Traffic Frequency at level d	$F_s \frac{D^2-d^2+2d-1}{2d-1}$
F_B^d	Background Node's Traffic Frequency at level d	$\|B^d\| F_{out}^d = C - \|I_d\| F_{out}^d$
N	Network Size (number of nodes) [#nodes]	200-512
D	Network Depth [#levels]	5-8
C	Network Density (Connectivity) [#neighbors]	4-8

(b)

MAC	Parameter & Description	Values
X-MAC	T_w X-MAC wake-up period [ms]	T_w^*
	T_{al} Acknowledgement listen period [ms]	0.95
	T_{ps} Strobe preamble duration [ms]	$\frac{5+L_{pbl}}{R}$
	T_{cw} Contention window size [ms]	15 * 0.62
	T_{hdr}, T_{ack} pkt header & Ack duration [ms]	$\frac{9+L_{pbl}}{R}$

Table 1: (a) CC2420 Radio Constants [1], Network and Traffic Model with Typical Parameter Values. (b) X-MAC, DMAC, and LMAC Symbols used in Energy & Delay Equations

Table 2: Eenrgy consumption and e2e delay formulas for XMAC.

Network Energy consumption	**End-to-End Delay**
$E^{\text{XMAC}} = \max_{n \in N}(\frac{\alpha_1}{T_w} + \alpha_2 T_w + \alpha_3)$	$L^{\text{XMAC}} = \max_{n \in N}(\beta_1 T_w + \beta_2)$
$\alpha_1 = T_{cs} + T_{al} + \frac{3}{2} T_{ps}(\frac{T_{ps} + T_{al}}{2} + T_{ack} + T_{data}) F_B^{d^n}$	$\beta_1 = \sum_{i=1}^{d^n} 1/2$
$\alpha_2 = \frac{F_{out}^{d^n}}{2}$	
$\alpha_3 = (\frac{T_{ps}+T_{al}}{2} + T_{cs} + T_{al} + T_{ack} + T_{data}) F_{out}^{d^n} + (\frac{3}{2} T_{ps} + T_{ack} + T_{data}) F_I^{d^n} + \frac{3}{4} T_{ps} F_B^{d^n}$	$\beta_2 = \sum_{i=1}^{d^n} (\frac{T_{cw}}{2} + T_{data})$

Above tables describes all the variables and the equation that we have used in this project.

2. Energy consumption and delay for worst case condition

Firstly we have calculated Energy consumption (En) and End-To-End delay (Ln) with fixed number of Tw between 100 and 400, with the fixed value for Fs = 1/(60*30*1000). The obtained values are demonstrated in table 1.

Tw	En	Ln
100	0.036526	452.048
150	0.025123	652.048
200	0.019637	852.048
225	0.01788	952.048
250	0.016517	1052.048
300	0.014581	1252.048
350	0.013321	1452.048
400	0.012484	1652.048

Table 1: energy consumption (En) and end-to-end delay (Ln) with fixed value of Tw.

Secondly, we plot the E-L curve, in Figure 1, because we wanted to see how increasing in energy will affects the delay, so that we can make our decisions depending on our resources and our requirements. Either is it beneficial to have a very small delay, spending the more energy or with normal delay spending less energy. This helps to make a decision when there are limited resources. The graph shows when we have a limited resource the bigger delays are expected as usual. We obtained the graph by calculating pairs of (En,Ln) with different values of Tw and fixed value of Fs.

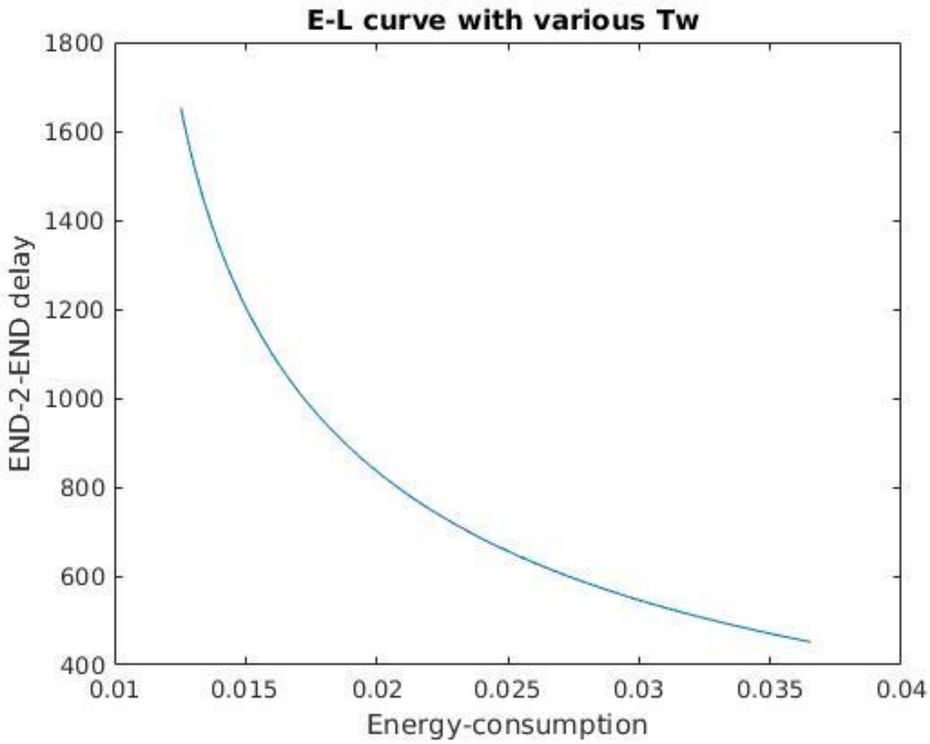

Figure 1: E-L curve for fixed Fs value and different Tw values (100-400)

As a next step we have calculated again the Energy consumption En and Delay Ln with many values of Fs between[0.005, 5] pckts/ms, with fixed value of Tw=200. Table 2 shows the obtained values.

Fs	En	Ln
0.005	17.264575	852.048000
0.01	34.511399	852.048000
0.1	344.954241	852.048000
0.5	1724.700204	852.048000
1	3449.382657	852.048000
1.5	2257.605268	852.048000
2	4515.192786	852.048000
3	6772.780305	852.048000
4	9030.367823	852.048000
5	11287.95534	852.048000

Table 2: different value for En and Ln for fixed value for Tw and different values for FS [0.005,5].

We again plotted the E-L curve, in Figure 2, this time the En and Ln are calculated using different values for Fs and a fixed value for Tw. In this case we can see changing the value of Fs doesn't affect the Ln. by seeing this graph and a table we can conclude that we can spend as little energy we can, because the delay will be the same. ie: Reducing the energy capacity doesn't gives a lower delay.

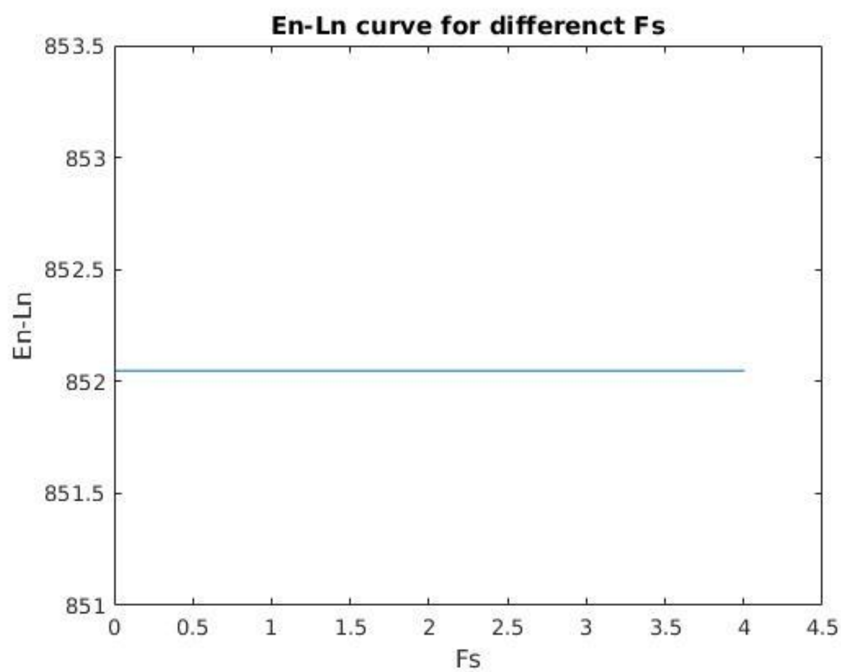

Figure 2 : En – Ln curve for different Fs.

3. Optimization problem

In this section, we have optimized two problems energy consumption and end to end delay by the help of cvx. In previous section we saw some interaction between energy consumption and delay, now we will show how could we obtain the best values for both of them, knowing our requirements and our resources.

A. Minimization energy consumption

Here in this part our objective function is to minimize our energy consumption. we have calculated the energy consumption for several values of L_{max} [0.01, 5] seconds. We expect that least energy spent will lead us to higher delay.

B. Minimization Delay

In the second problem, we want to minimize the end to end delay (L_{xmac}) for several values of E_{budget} between [0.5, 5] joules. We also want to plot the values of L_{xmac} in correlation with the E_{xmac}. In this case we assume that however increasing in the delay shouldn't affect the energy consumption.

Nash bargaining schema