A DTMC-Based Energy Analysis for Duty-Cycled WSN with Classes

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Abstract

Wireless Sensor Networks (WSN) have experienced an important resurgence, especially through applications designed for the Internet of Things (IoT). In that sense, a WSN can be constituted of different classes of nodes, having different characteristics. On the other hand, the study of the energy consumption in WSN is of great importance due to the energy supply limitations of the sensor nodes, which commonly are battery-supplied. Furthermore, Duty Cycling (DC) is a popular technique for energy conservation in WSN, that allows nodes to wake up and sleep periodically to save energy, waking up during the packet exchange periods. In this work an analysis of the energy consumption of a WSN with a DC MAC is performed. To accomplish that, an analytical model with a two-dimensional Discrete-Time Markov Chain (2D-DTMC) is developed, and the energy consumption and energy efficiency are obtained. The analytical model exhibits excellent accuracy when compared with simulation results.

The DTMC-Based model

Introduction

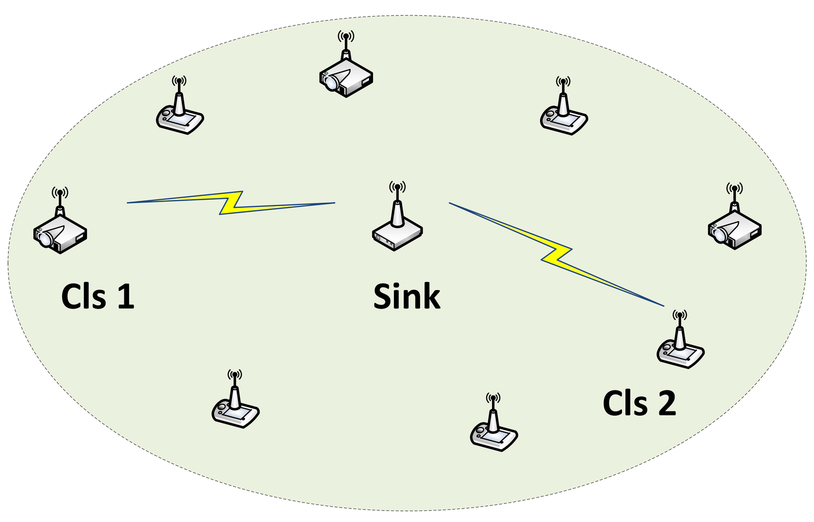

Figure 1. Heterogeneous WSN with two classes of nodes.

- A WSN may be constituted of different classes of nodes with different traffic patterns and even different priority requirements (heterogeneous scenario) [1, 2].
- The technological evolution of sensors promises to facilitate the integration of WSN with Internet of Things (IoT), enhancing applications for WSN, such as smart grid, smart water, smart transport systems and smart homes [3].

System Model

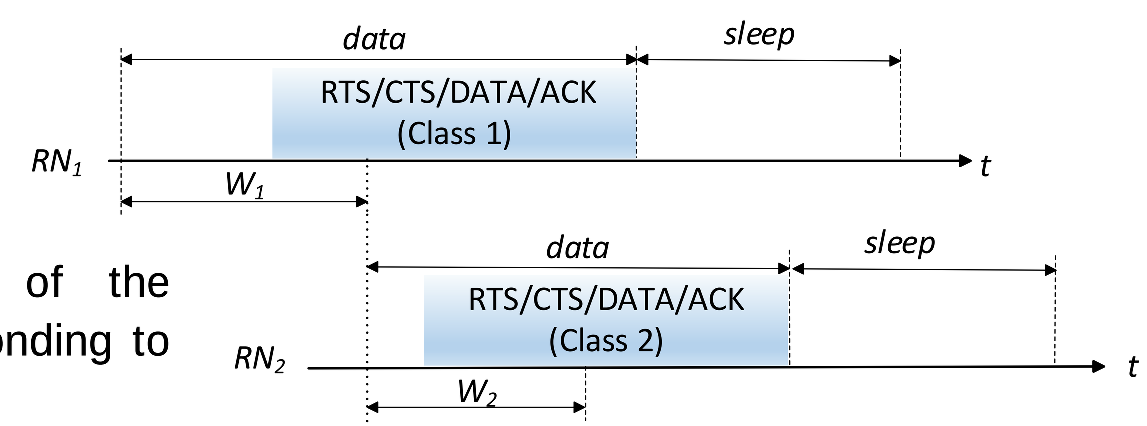

Figure 2. Operation of MAC protocol during *data* period, for both classes of nodes

- Fig. 2 shows a diagram of the transmission process corresponding to the *data* period.
- In this model, the media access priority is granted to nodes of class 1.

- The system model considers a pair of 2D-DTMC (two-Dimensional Discrete-Time Markov Chains), one chain for each class of nodes.
- The system state is represented by $\pi(i,m)$, where i is the number of packets in the queue or RN, and m is the number of active nodes other than the RN.
- Then, $\mathcal{P}_{(i,m)(j,n)}$ is the transition probability from state (i,m) to state (j,n). The state transition probabilities are given in detail in [4].
- The solution of these 2D-DTMC can be obtained by solving the set of linear equations (as in related previous works [5,6]),

$$\pi\mathcal{P} = \pi, \quad \pi e = 1.$$

Energy Efficiency (EE) and Average Energy Consumption (E_d)

Once the stationary distributions [$\pi(i,m)$, for both classes] are obtained from the solution of the 2D-DTMC, we use it to compute the average energy consumption (successful, collision, *overhearing*) and the energy efficiency.

$$E_d = E_s^{tx} + E_f^{tx} + E^{oh},$$

$$EE = E_s^{tx} / E_d,$$

$$E_s^{tx} = \sum_{i=1}^{Q}\sum_{k=0}^{K}\pi(i,k)P_{s,k}\left(P_{s,1}^{tx} + P_{s,2}^{tx} + P_s^{rx} + BT_{s,k}P_{rx}\right),$$

$$E_f^{tx} = \sum_{i=1}^{Q}\sum_{k=0}^{K}\pi(i,k)P_{f,k}\left(P_f^{tx} + BT_{f,k}P_{rx} + P_f^{rx}\right),$$

$$E^{oh} = \sum_{i=1}^{Q}\sum_{k=0}^{K}\pi(i,k)\left[kP_{s,k}\left(BT_{s,k}P_{rx}\right) + \hat{P}_{f,k}\left(BT_{f,k}P_{rx}\right)\right].$$

Energy performance analysis

Scenario configuration

The analytical and simulation results are independent each other, and are based on the scenario with the parameter configuration shown in Table I.

Table I. Parameter configuration and general scenario

Cycle time (T)	60 ms	Propagation time (D_p)	0.1 µs
t_{SYNC}, t_{RTS}, t_{CTS} y t_{ACK}	0.18 ms	Slot time (backoff)	0.1 ms
t_{DATA}	1.716 ms	Contention window W1=W2	128 slots
DATA (S)	50 bytes	Buffer (Q)	10 packets
Transmission Power (P_{tx})	52 mW	Reception Power (P_{rx})	59 mW
Number of nodes $N_1 = 5$, and $N_2 = 20$		Packet arrival rate (packets/s) $\lambda_1 = 0.5$; $\lambda_2 = [0.5,4.5]$	

Results

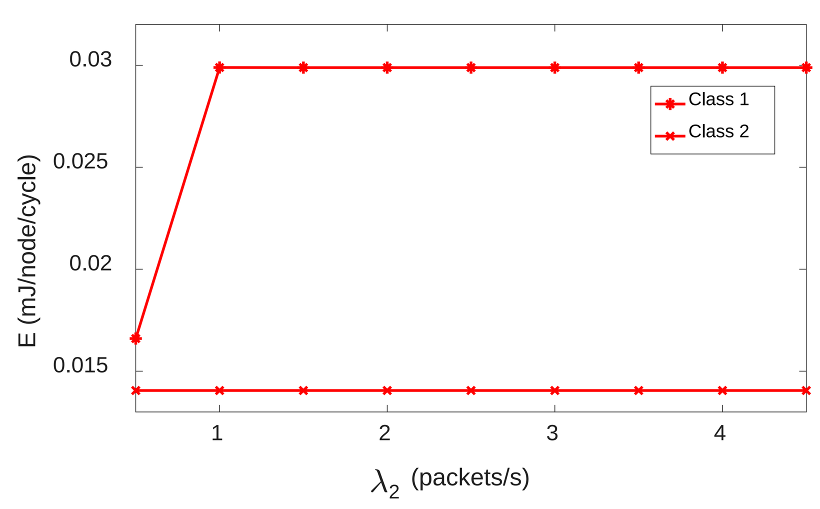

Figure 3. Average energy consumption for both classes of nodes, and λ_1=0.5.

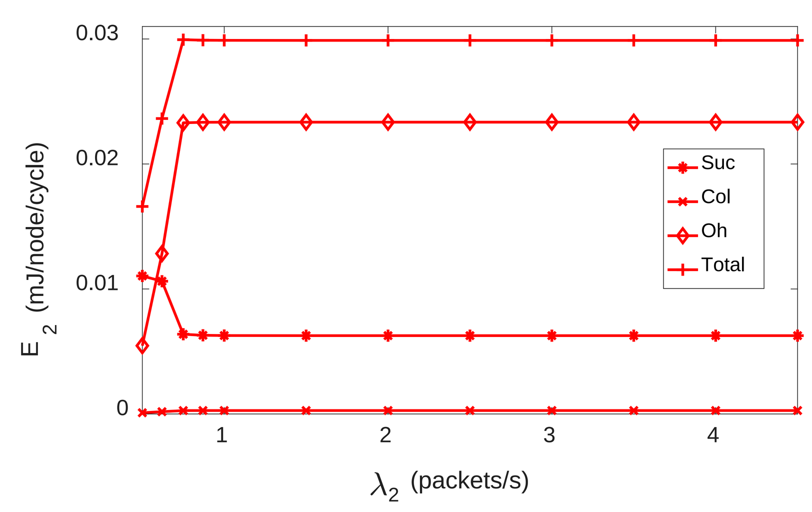

Figure 4. Successful, collision and overhearing energies for class 2 devices.

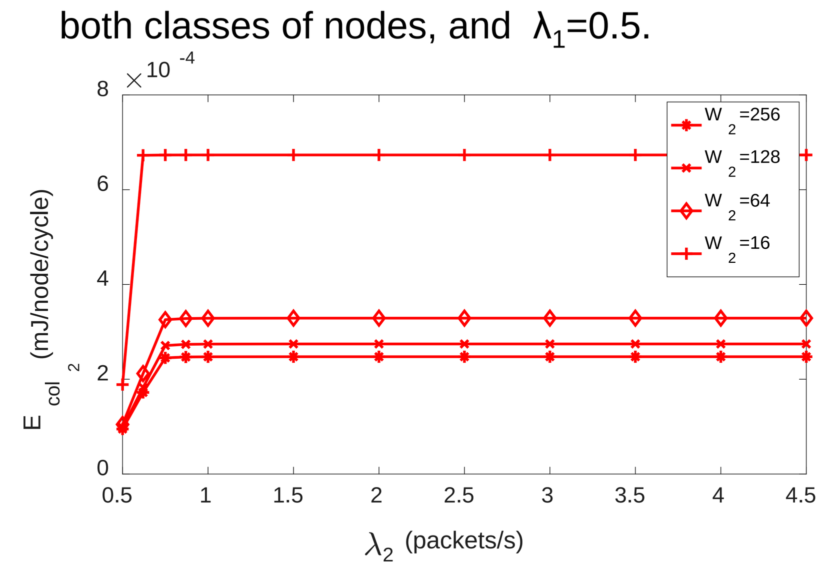

Figure 5. Energy consumption due to collisions for class 2 devices, and W_1=16.

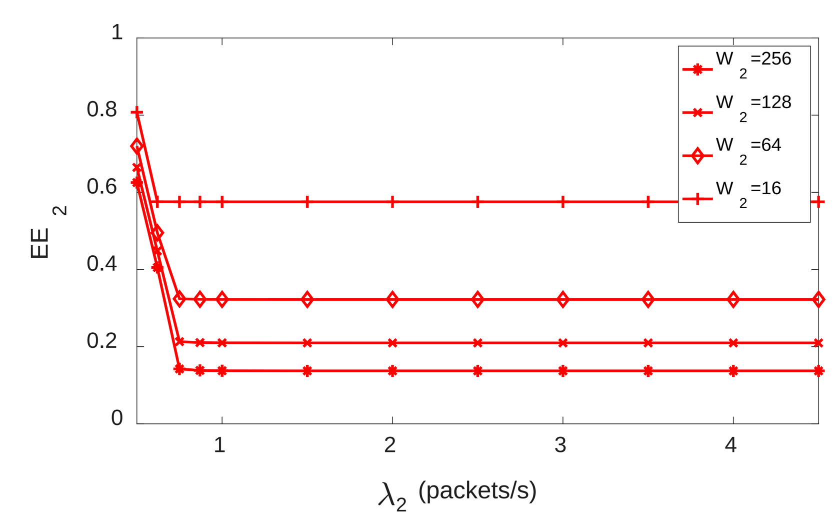

Figure 6. Energy efficiency in function of W for class 2 devices, and W_1=16.

Conclusion and future work

- The modeling and energy performance study of a WSN network has been accomplished, considering different classes of nodes and the assignment of medium access priorities.
- The analytical model, based in two 2D-DTMC, is solved for a specific scenario, obtaining values of average energy consumption and energy efficiency.
- A disaggregation of the energy is presented and the different contributions to the consumption energy are analyzed (data, *overhearing* and collisions).
- The analytical model is validated through discrete-event based simulations, showing accurate results.
- This work will be further extended to include the analysis of the *sleep* period, considering the *normal* and *awake* operating modes of sensors. Aggregated packet transmission scheme is another envisioned extension to the model.

References

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