One of the major sources of energy waste in a Wireless Sensor Network (WSN) is idle listening, i.e., the cost of actively listening for potential packets. This work focuses on reducing the idle-listening time via a dynamic duty cycling technique which aims at optimizing the sleep interval between consecutive wakeups. In this context, we propose an optimization framework for minimizing the energy waste of the most power hungry node of the network. To this aims, we first derive an analytic model that predicts the nodes energy consumption. Then, we use the model to derive an iterative algorithm which achieve convergence to a fixed and provably optimum point without employing any central controller. Simulation via NS-2 simulator and numerical results are included to illustrate the accuracy of the model.

**Dual LPL Mac protocol**

We consider a receiver triggered dual LPL method which presents advantages when compared to X-MAC. Moreover, the protocol gives higher scalability than TDMA-based protocols and synchronized CSMA-based protocols. In the dual LPL scheme, each receiver periodically emits a probe signal indicating availability to incoming transmissions. On the other hand, the sender node waits for the probe signal before starting its transmission. In the proposed scheme, each sender receives probe signals from several nodes, and, hence, the data are routed on multiple paths in a cluster-tree network topology. We study how to manage the probe signals’ rates in the perspective of prolonging the network lifetime as long as possible.

**Network model and design principles**

We consider a data collection scenario typical of environmental monitoring, with Poisson packet arrivals characterized by an average rate of \( \lambda \) pkt/s. The data packets must be transmitted towards an energy unconstrained sink. Each cluster has a controller node (cluster-head) that communicates, either directly or via flooding, with all the other nodes of the same cluster and that is directly connected with the controllers of the previous and the next cluster.

**Energy Model**

We derive the analytic expression of the nodes energy consumption. For the sake of mathematical tractability, we assume that the probe signals are transmitted according to a Poisson distribution. Moreover, we assume that the self-generated and the relay traffics, respectively.

The total energy consumption at generic node can be written as:

\[
E_s^{(i)} = \sum_{k \in A_i} \sum_{q \in A_i} \frac{\lambda_s^{(i)}}{q!} = \sum_{k \in A_i} \frac{b_s^{(k)}}{k!} - \lambda_s^{(i)},
\]

where \( \lambda_s^{(i)} = \sum_{k \in A_i} \sum_{q \in A_i} \frac{\lambda_s^{(i)}}{q!} = \sum_{k \in A_i} b_s^{(k)} - \lambda_s^{(i)} \), and

\[
E_{s,tx}^{(i)} = b_s^{(i)} E_{tx,pkt} + \lambda_s^{(i)} N_s^{(i)} E_{lst,pkt} + \sum_{r \in A_i} P_s^{(i)}(r) E_{lst,pkt} T_{r,1} + \sum_{r \in A_i} (1 - P_s^{(i)}(r)) E_{lst,pkt} T_{r,2} \]

where \( P_s^{(i)}(r) \) is the probability that the probe signal of user \( u_s^{(i)} \) is exploited. Hence, the total energy consumption at generic node can be written as:

\[
E_s^{(i)}(r_s, r_{s-1}) = E_{s,tx}^{(i)}(r_s) + E_{s,rx}^{(i)}(r_{s-1})
\]

**Optimization via Message Passing**

We aim at deriving a distributed strategy for evaluating the optimal signal probe generation rates \( r_s \):

\[
r_{s,op} = \arg \min_r \min_{s} \left( f_s(r_s, r_{s-1}) \right)
\]

To solve the above min max optimization problem, we consider a message passing (MP) approach.

**Simulations**

We validate the energy model by comparing it with realistic simulations. For such purpose, we develop a novel network stack for the DLPL approach in the NS-2 simulator. To validate the optimization protocol, we have run an NS-2 simulation for three different cases: fixed rates (FR), the rates are set to a common optimized value, and variable rates (VR), refers to the optimized MP approach.