Master-MIRI
Topics on Optimization and Machine Learning (TOML)

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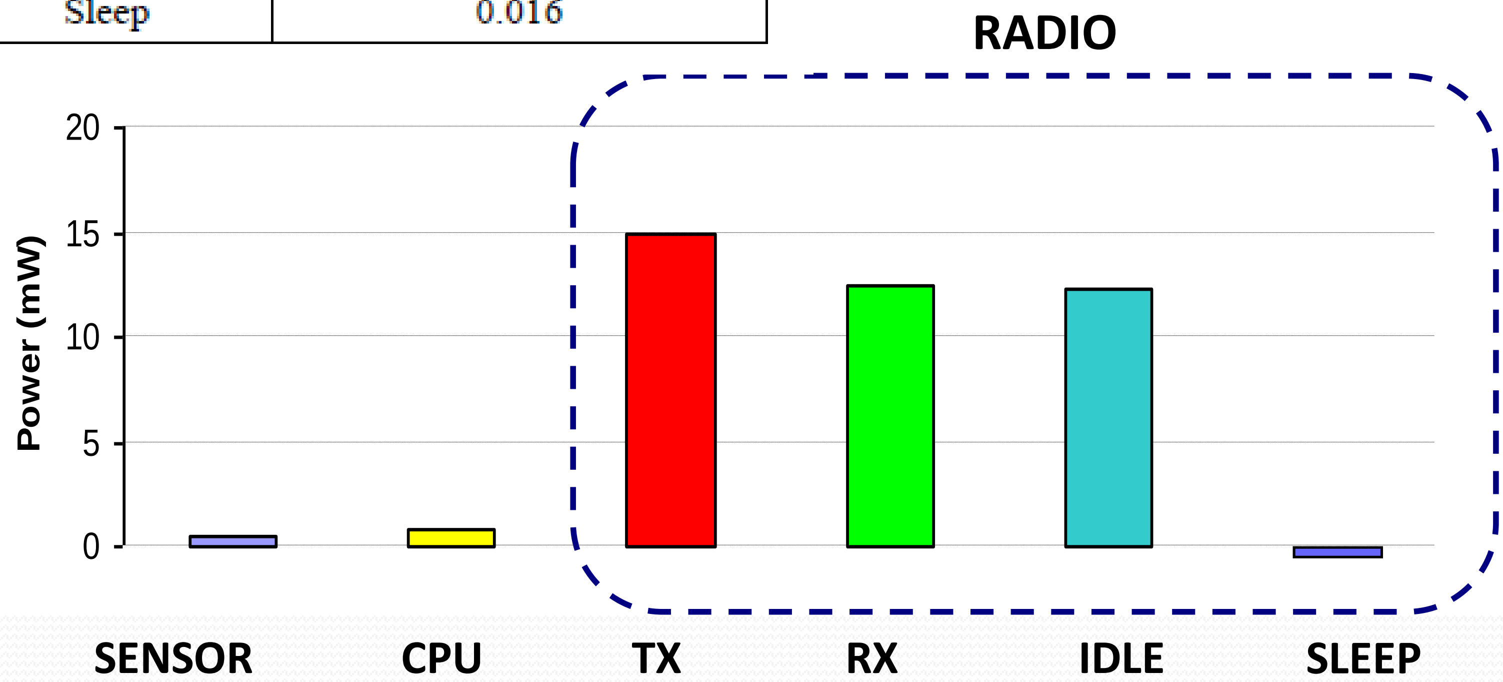
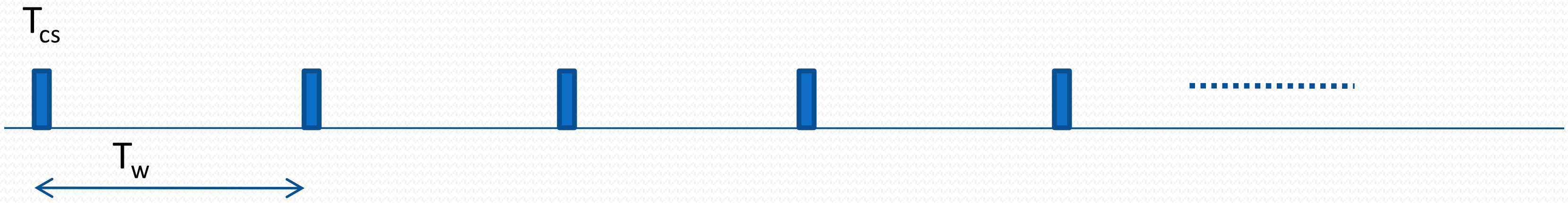
- **Power consumption in a sensor**

Table 1. Radio power characterization

Radio mode	Power consumption (mW)
Transmit (T_x)	14.88
Receive (R_x)	12.50
Idle	12.36
Sleep	0.016



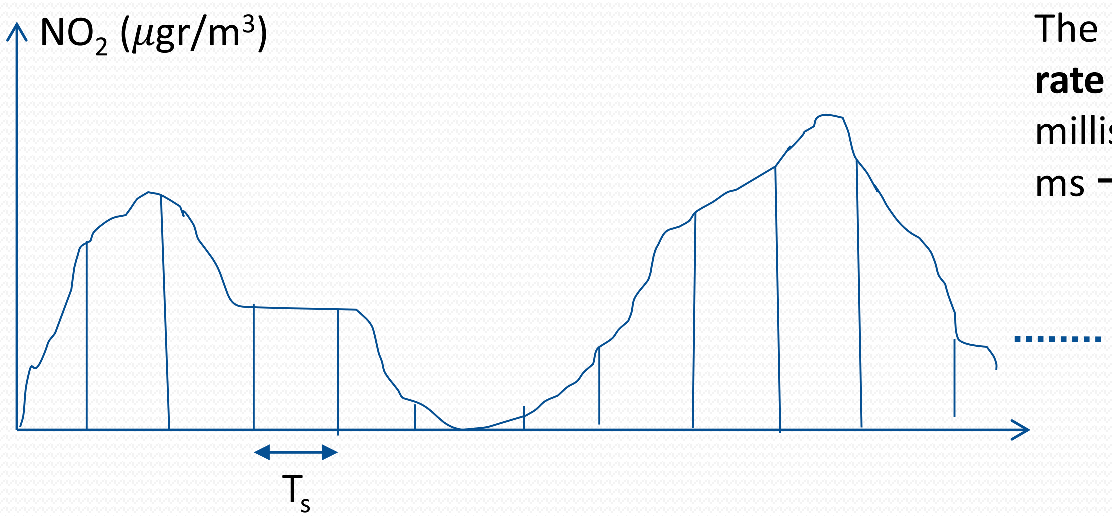
- **Duty Cycle (DC) MAC protocols in Wireless Sensor Networks**



In general MAC, contention-based, the duty cycle is defined as the quotient between the carrier sense (**T_{cs}**) period over the **$T_w = (T_{cs} + T_{sleep})$** period, i.e., **$DC=T_{cs}/T_w = T_{cs}/(T_{cs}+T_{sleep})$**,

DC ~ 1 if $T_{cs} \sim T_w$, the extreme case is that the radio is always ON and DC=1

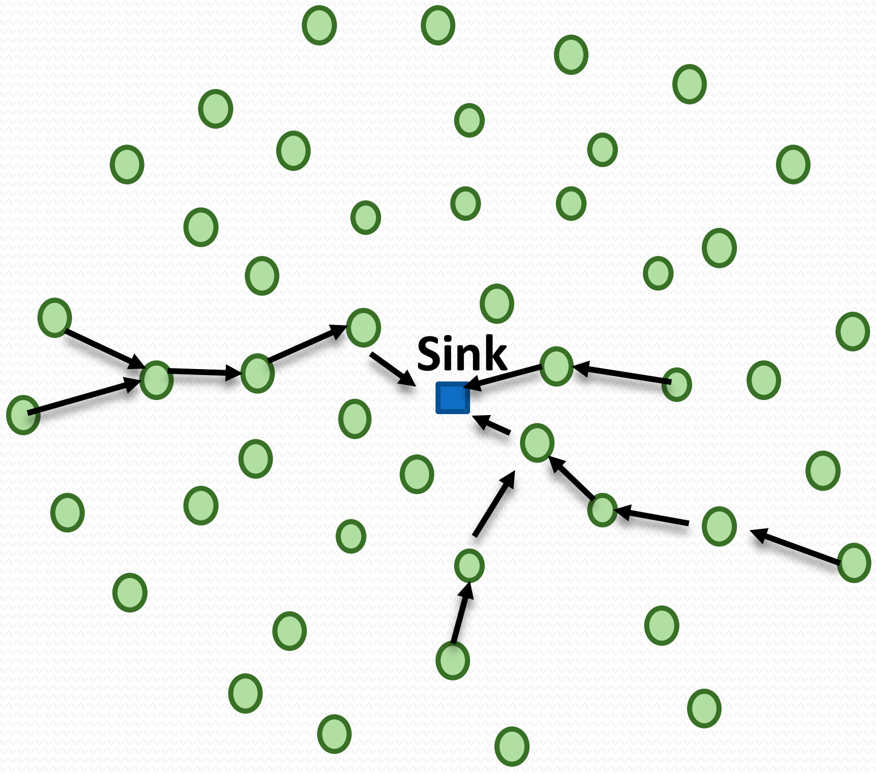
DC ~ 0 if $T_{cs} \ll T_w$, where we can make T_w as large as we want and then the radio is OFF, of course, not transmitting any packet,



The amount of traffic (packets) or **sampling rate $F_s = 1/T_s$** = 1/(10*60*1000) packets per millisecond if T_s =10 minutes = 10*60*1000 ms → **low data rate traffic model**

- **Duty Cycle MAC protocols in Wireless Sensor Networks**

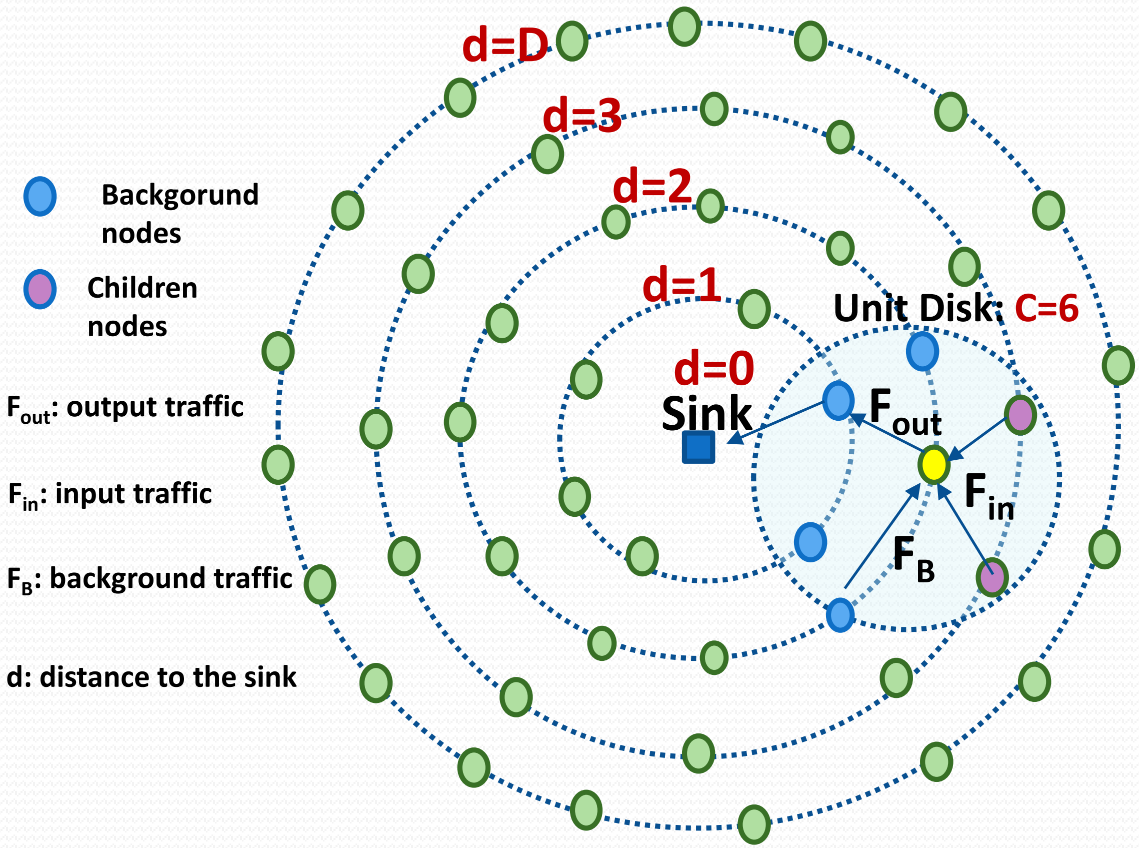
Random Topology: deploy N sensors randomly in an area



Nodes transmit using a multi-hop routing transmission protocol.

Nodes form a tree with multiple branches, where <u>the root of the tree is the sink</u>

- **Duty Cycle MAC protocols in Wireless Sensor Networks**



Random Topology: deploy N sensors randomly in an area

D rings, where in ring d=0 is placed the gateway (or sink) and in ring d=D are the outer nodes

I_d: average number of input links per node at ring d=1,…,D,

C: average number of neighbors

B: background nodes, **B= C-I_d,**

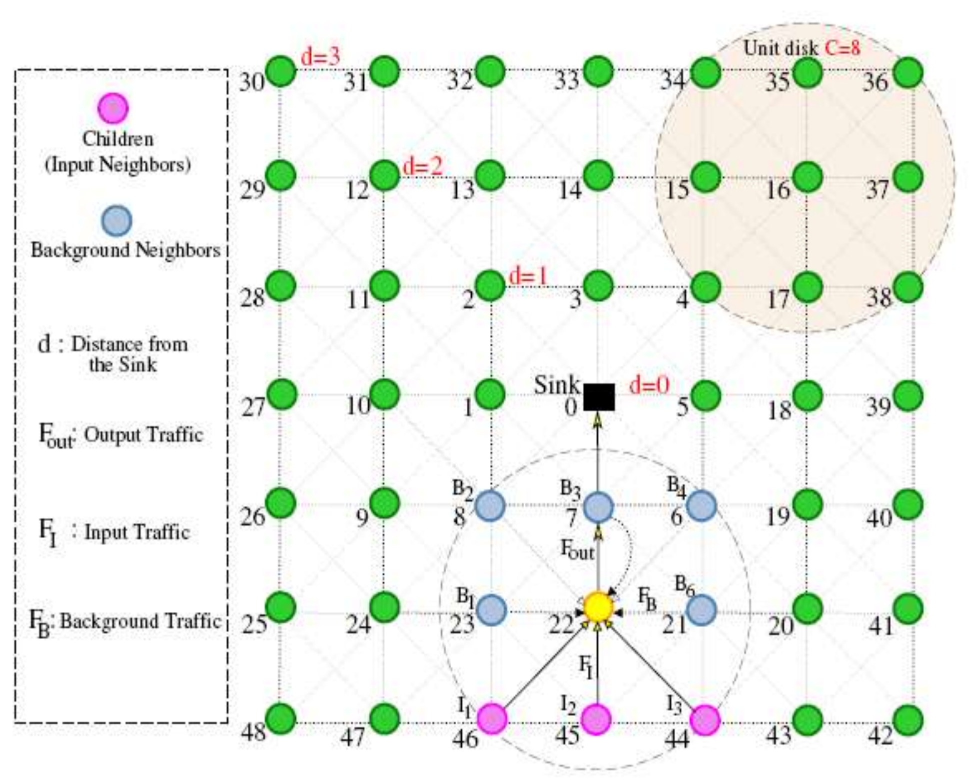
N_d: average number of nodes at ring d:

$$N_d = 1 \qquad \text{if } d = 0$$

$$N_d = Cd^2 - C(d-1)^2 = C(2d-1) \qquad \text{otherwise}$$

- **Duty Cycle MAC protocols in Wireless Sensor Networks**

Grid Topology: nodes are deployed in squares, with C neighbors



D rings, where in ring d=0 is placed the gateway (or sink) and in ring d=D are the outer nodes

I_d: average number of input links per node at ring d=1,…,D,

C: average number of neighbors per node,

B: background nodes, **$B= C-I_d$**,

N_d: average number of nodes at ring d:

$N_d=1$	**if d=0**
$N_d=C*d$	**otherwise**

Duty Cycle MAC protocols in Wireless Sensor Networks

I_d: average number of input links per node at ring d=1,…,D,

C: average number of neighbors,

N_d: average number of nodes at ring d,

F_s: average generated traffic: sampling rate (one packet every sample),

F^d_I: average input traffic freq at ring d, → **$F^d_I = I_d F^{d+1}_{out}$**

F^d_{out}: average output traffic freq at ring d, → **$F^d_{out} = F^d_I + F_s = I_d F^{d+1}_{out} + F_s$**

F^d_B: average background traffic freq at ring d, → **$F^d_B = B\, F^d_{out} = (C-I_d)\, F^d_{out}$**

We can find the average number of input links, average input traffic, and average output traffic, either for grid or for random topology. For example, for grid topology:

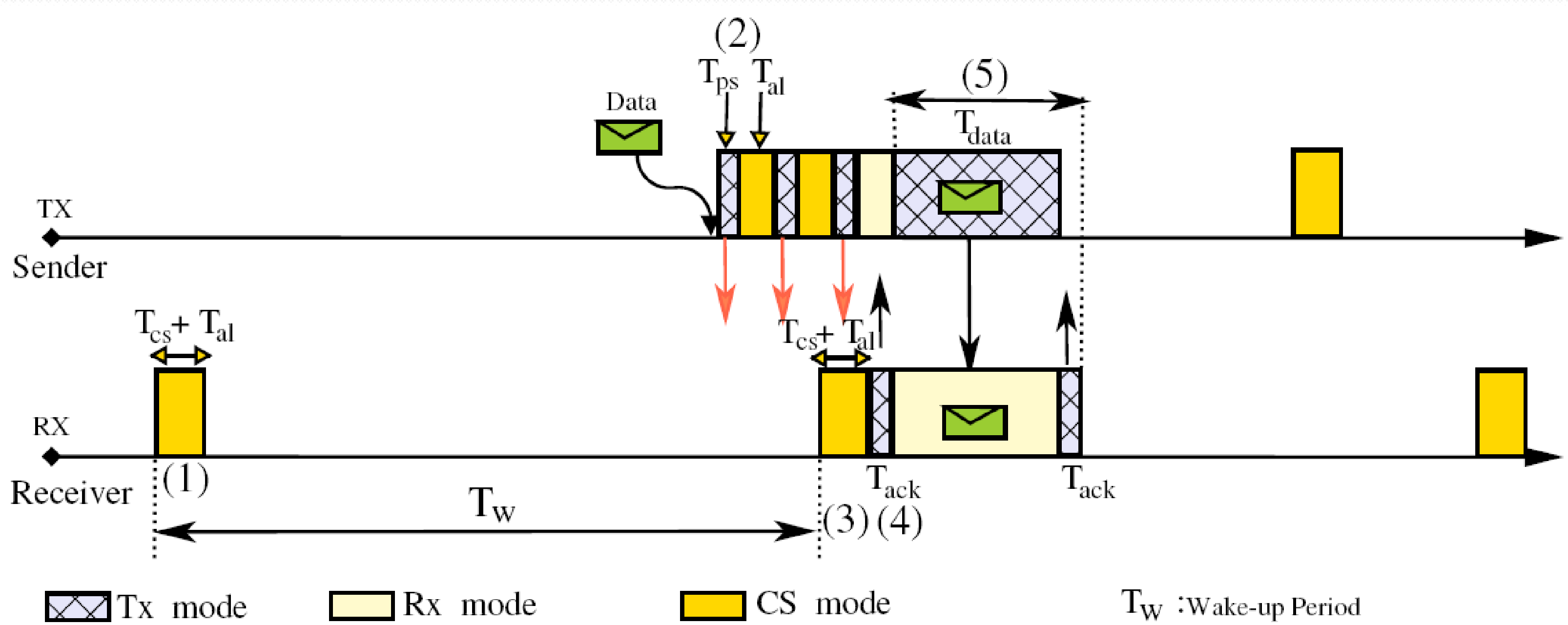
$$I_d = \begin{cases} 0, & if\ d = D, \\ C, & if\ d = 0, \\ \frac{N_{d+1}}{N_d} = \frac{d+1}{d}, & if\ 0 < d < D. \end{cases}$$

$$F^d_{out} = \begin{cases} F_s & if\ d = D, \\ 0 & if\ d = 0, \\ \frac{D^2-d^2+D-d}{2d} F_s & if\ 0 < d < D. \end{cases}$$

$$F^d_I = \begin{cases} 0 & if\ d = D, \\ C(\frac{D^2+D}{2} - 1)F_s & if\ d = 0, \\ \frac{D^2-d^2+D-3d}{2d} F_s & if\ 0 < d < D. \end{cases}$$

Duty Cycle MAC protocols in Wireless Sensor Networks

XMAC: is an asynchronous preamble sampling based protocol where nodes wake up periodically every T_w seconds to perform carrier sensing for $T_{cs} + T_{al}$ (1) as depicted in the figure. To send a packet, a node transmits a sequence of strobe preambles of duration T_{ps}, short packets containing the identifier of the receiver and listen to an acknowledgment for T_{al} (2). Strobes continue for a period sufficient to make at least one strobe overlap with a receiver wake-up (3). The receiver replies with an acknowledgment of duration T_{ack} (4) and keeps the radio on. After that, the sender transmits the data packet, T_{data}, which spans for the transmission of the header, the payload, and the data acknowledgment (5).



Duty Cycle MAC protocols in Wireless Sensor Networks

a) The Energy of node n:

$$E^n = E^n_{cs} + E^n_{tx} + E^n_{rx} + E^n_{ovr}$$

$$E^n_{cs} = \frac{(T_{cs} + T_{al})}{T_w}$$

$$T_{tx} = \lceil \frac{T_w}{T_{ps} + T_{al}} \rceil \frac{T_{ps} + T_{al}}{2} + T_{ack} + T_{data}$$

$$E^n_{tx} = (T_{cs} + T_{al} + T_{tx})\, F^n_{out}$$

$$E^n_{rx} = (\frac{3}{2} T_{ps} + T_{ack} + T_{data})\, F^n_I$$

$$E^n_{ovr} = (\frac{T_{tx}}{T_w} \times \frac{3}{2} T_{ps})\, F^n_B$$

$$E^n_{stx} = E^n_{srx} = 0$$

b) The delay of node n at level d^n:

$$L^n_{d^n} = \sum_{i=1}^{d^n} \left(\frac{T_w}{2} + \frac{T_{cw}}{2} + T_{data} \right)$$

where $T_{data} = T_{hdr} + P/R + T_{ack}$.

c) The bottleneck constraint:

$$|I^0|\, E^1_{tx} < 1/4$$

M. Buettner, G. V. Yee, E. Anderson, and R. Han, "X-MAC: a short preamble MAC protocol for duty-cycled wireless sensor networks", ACM SenSys, pages 307--320, 2006.

Duty Cycle MAC protocols in Wireless Sensor Networks

Note that:

- Nodes in the inner rings spend more energy than nodes in the outer rings. Then, the energy consumed at node *n* is **$E(T_w)$=** $\max_n (\alpha_1 T^{-1}_w + \alpha_2 T_w + \alpha_3)$ = **$(\alpha_1 T^{-1}_w + \alpha_2 T_w + \alpha_3)_{n\in\{d=1\}}$**
- Nodes in the outer rings have more delay than nodes in the inner rings. Then, the delay at node *n* is **$L(T_w)$=** $\max_n (\beta_1 T_w + \beta_2)$ = **$(\beta_1 T_w + \beta_2)_{n\in\{d=D\}}$**

$E^{XMAC} = \max_{n\in N}(\frac{\alpha_1}{T_w} + \alpha_2 T_w + \alpha_3)$ $\alpha_1 = T_{cs} + T_{al} + \frac{3}{2}T_{ps}(\frac{T_{ps}+T_{al}}{2} + T_{ack} + T_{data})F^n_B$ $\alpha_2 = (\frac{T_{ps}+T_{al}}{2} + T_{cs} + T_{al} + T_{ack} + T_{data})F^n_{out} + (\frac{3}{2}T_{ps} + T_{ack} + T_{data})F^n_I + \frac{3}{2}T_{ps}F^n_B$ $\alpha_3 = \frac{F^n_{out}}{2}$	$L^{XMAC} = \max_{n\in N}(\beta_1 T_w + \beta_2)$ $\beta_1 = \sum_{i=1}^{d^n} 1/2$ $\beta_2 = \sum_{i=1}^{d^n}(\frac{T_{cw}}{2} + T_{data})$

Duty Cycle MAC protocols in Wireless Sensor Networks

XMAC Energy optimization model:

Minimize $E(T_w) = \max_n (\alpha_1 T^{-1}_w + \alpha_2 T_w + \alpha_3) = (\alpha_1 T^{-1}_w + \alpha_2 T_w + \alpha_3)_{n\in\{d=1\}}$

subject to $L(T_w) = \max_n (\beta_1 T_w + \beta_2) = (\beta_1 T_w + \beta_2)_{n\in\{d=D\}} \leq L_{max}$

$T_w \geq T^{min}_w$

$|I^0|\, E^1_{etx} \geq 1/4$

Var T_w

XMAC Latency optimization model:

Minimize $L(T_w) = \max_n (\beta_1 T_w + \beta_2) = (\beta_1 T_w + \beta_2)_{n\in\{d=D\}}$

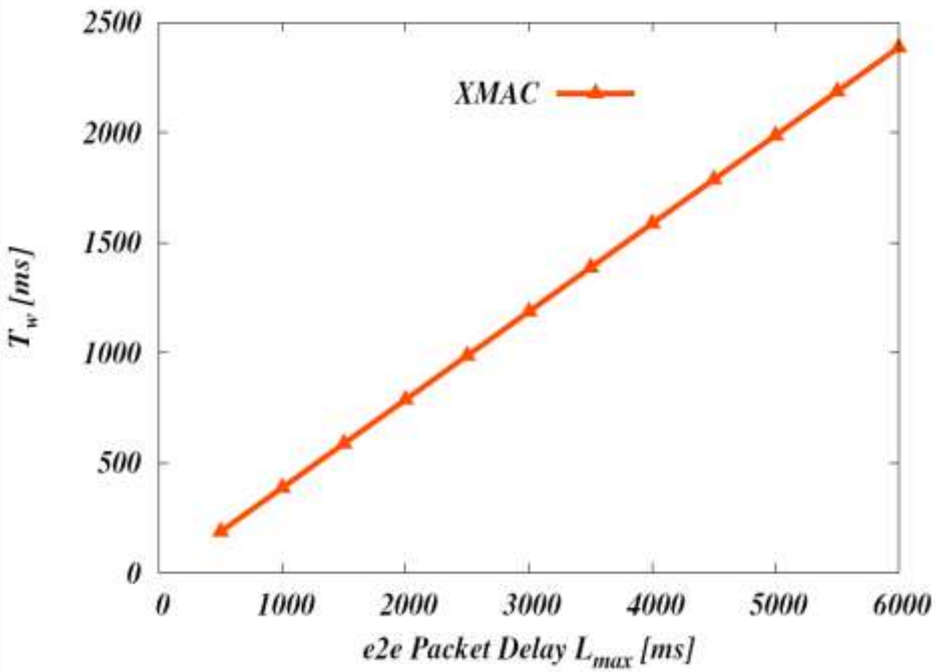
subject to $E(T_w) = \max_n (\alpha_1 T^{-1}_w + \alpha_2 T_w + \alpha_3) = (\alpha_1 T^{-1}_w + \alpha_2 T_w + \alpha_3)_{n\in\{d=1\}} \leq E_{budget}$

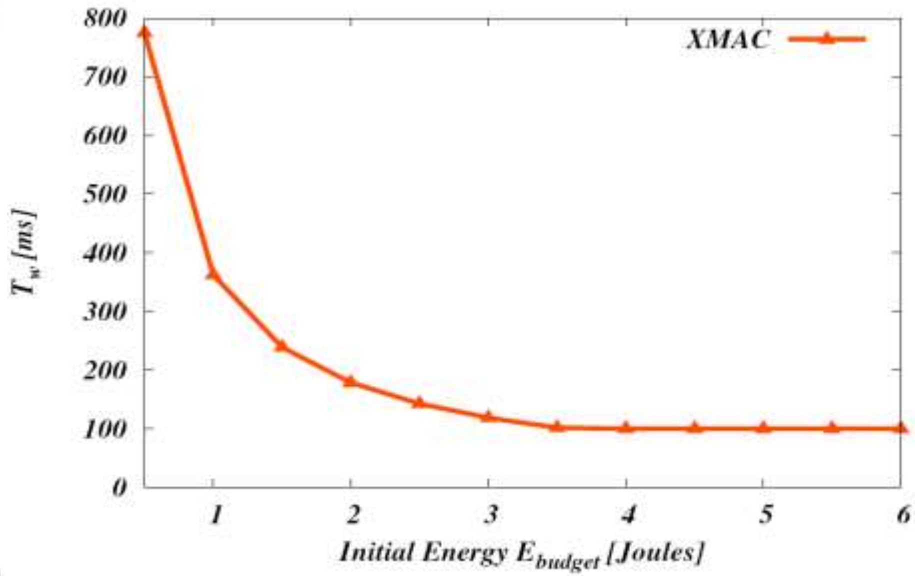
$T_w \geq T^{min}_w$

$|I^0|\, E^1_{etx} \leq 1/4$

Var T_w

- **XMAC optimal values**





- **XMAC optimal values**