From Outage Probability to ALOHA MAC Layer Performance Analysis in Distributed Wireless Sensor Networks

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Outline

Introduction: Wireless Sensor Networks (WSNs)

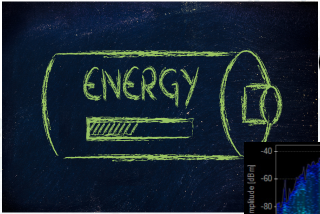
Nowadays, WSNs are everywhere!

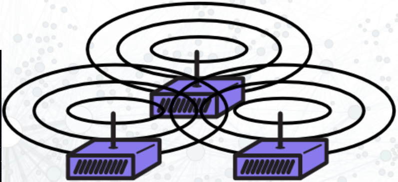
- Environmental applications.
- Home applications.
- Medical applications, etc.

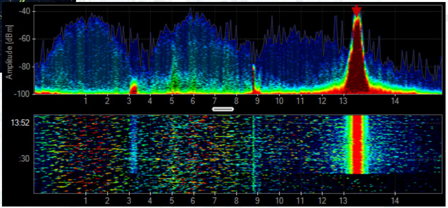
LIRIMA PREDNET Project

- Even Rhinos need smartphones!

Challenges behind WSNs







- Keep the network up for several years (5-10 years).
- Generally the deployed architectures are **distributed**
  $\Rightarrow$ Interferences! (partially responsible for the loss of energy).

To face these challenges

Two directions are natural:

- Use different sources of energy (solar for example).
- Optimizing the hardware and the **software**.

The **software** concerns essentially:

- The physical layers.
- The *Medium Access Control* (MAC) Layer.

In this work, we study:

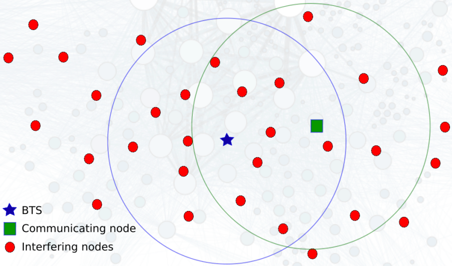
- The influence of the MAC layer on the network performance.
- In particular, we address the following question:

How many channels do we need to achieve high performance distributed wireless sensor network?

Problem Statement & Outage Probability

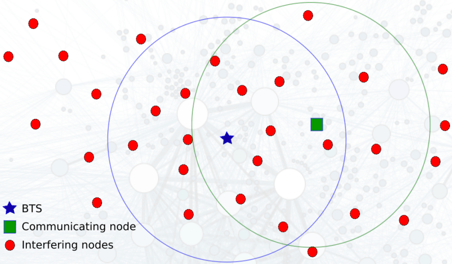
MAC Protocol: Slotted-ALOHA

- *Multiple* nodes and a *unique* BTS.
- **Distributed** access policy $\Rightarrow$ the nodes make the decision (randomly) to transmit on their *own* (e.g. Slotted-ALOHA MAC protocol).



Multiple nodes could choose **the same channel** $\Rightarrow$ Interferences!

Interferences quantification: *Outage Probability*



The probability that the signal-to-interference-plus-noise-ratio (SINR) is less than a given threshold $\tau > 0$*,*

$$Op = \mathbb{P}\{SINR < \tau\},$$

where, $SINR(o, r) = S(o, r)/(I(o) + N_0)$.

Assumptions

- $\Pi_\lambda \subset \mathbb{R}^2$ Homogeneous Poisson Point Process (HPPP) spacial distribution of the nodes with density λ.
- The wireless channel consists of **path loss attenuation** with no fading:

$$\forall X_i \in \Pi_\lambda, P_i = P_e \|X_i\|^{-\alpha},$$

  where $\alpha, P_e > 0$.
- The Medium Access Control strategy is **a Slotted-ALOHA**, the communicating nodes have a density λ^* s.t.

$$\lambda^* = \frac{2T_s}{T}\frac{1}{N_c}\lambda.$$

Expression of Op

Proposition

The Outage probability for Slotted-ALOHA MAC protocol is given by the following expression:

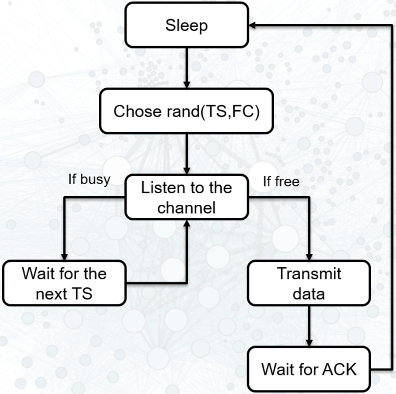
$$Op^{SA} \equiv \lim_{N \to +\infty} \frac{1}{N} \sum_{j=1}^{N} \mathbb{I}\langle \Sigma_\alpha^j > \frac{\xi}{(\lambda^* \pi)^{\alpha/2}} \rangle \qquad (1)$$

where $\mathbb{I}\langle . \rangle$ *is the indicator function,* $\xi = \frac{r^{-\alpha}}{\tau} - \frac{N_0}{P_e}$ *and*

$$\Sigma_\alpha^j = \log\left(\frac{1}{1 - U_0^j}\right)^{-\alpha/2} + \sum_{k=1}^{+\infty} \left(-kW_0\left[-\frac{1}{k}\exp\left(\frac{\log\left[(1-U_k^j)k!\right]}{k}\right)\right]\right)^{-\alpha/2}.$$

Slotted-ALOHA *with* Channel Reservation and *Without* Interferences

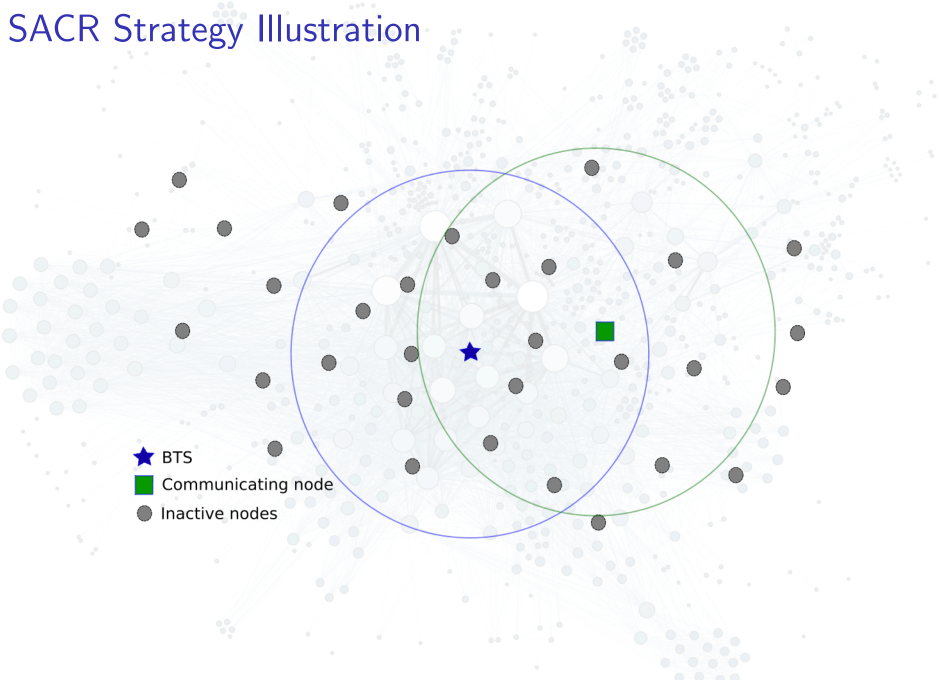
MAC Protocol Description: Slotted-ALOHA with Channel Reservation (SACR)



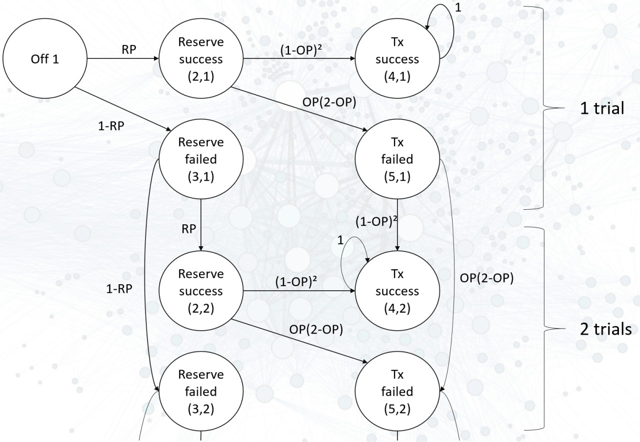
Assuming $N \sim Poiss(\mu = \frac{N_n}{N_{ts} N_{fc}})$, **the reservation probability** is

$$Rp = \mathbb{P}\{N = 0\} = e^{-\mu}$$

SACR Strategy Illustration



Communicating Node States Modeling: Markov Chain



Communicating Node States Modeling: Markov Chain

Given its transition matrix Γ, the distribution over states is given by a stochastic row vector π s.t. $\pi^{(k+1)} = \pi^{(k)}\Gamma$ and so $\pi^{(k)} = \pi^{(0)}\Gamma^k$, thus $\pi^{\infty} = \pi^{(0)} \lim_{k\to\infty} \Gamma^k$. In particular the **success transmission likelihood** is given by

$$Tx_i = \left[\lim_{k\to\infty} \Gamma^k\right]_{(1,4i)}$$

Communicating Node States Modeling: Markov Chain

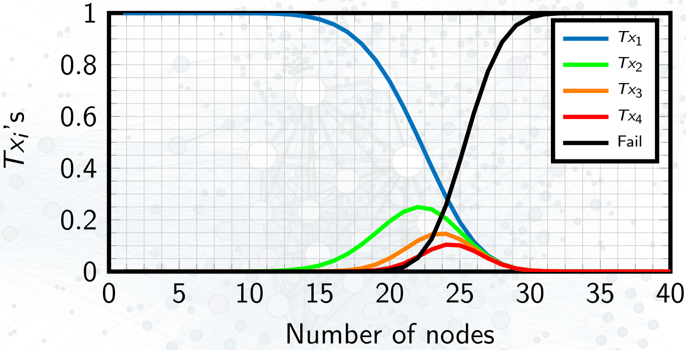
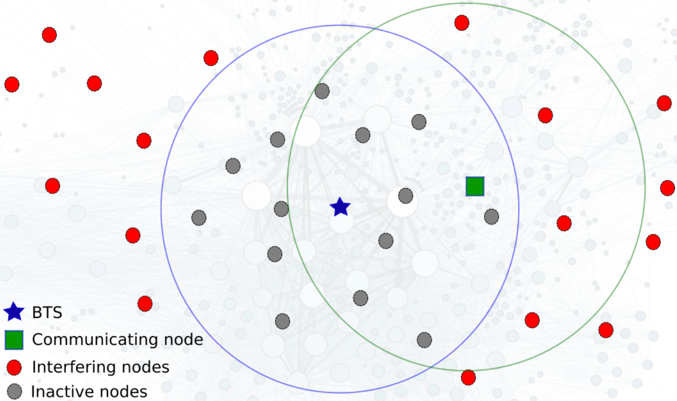


Figure 1: Curves of Tx_i's.

Slotted-ALOHA *with* Channel Reservation and Interferences

When interfering nodes in the *out range* of the BTS



$$Op^{\|X_0\|>R} = \mathbb{P}\left\{\Sigma_\alpha > \frac{\xi}{(\lambda^*\pi)^{\alpha/2}} \middle| \|X_0\| > R\right\},$$

where R denotes the range of the BTS.

When interfering nodes in the *out range* of the BTS

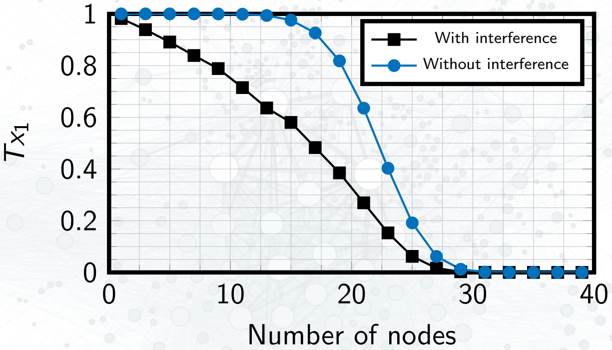
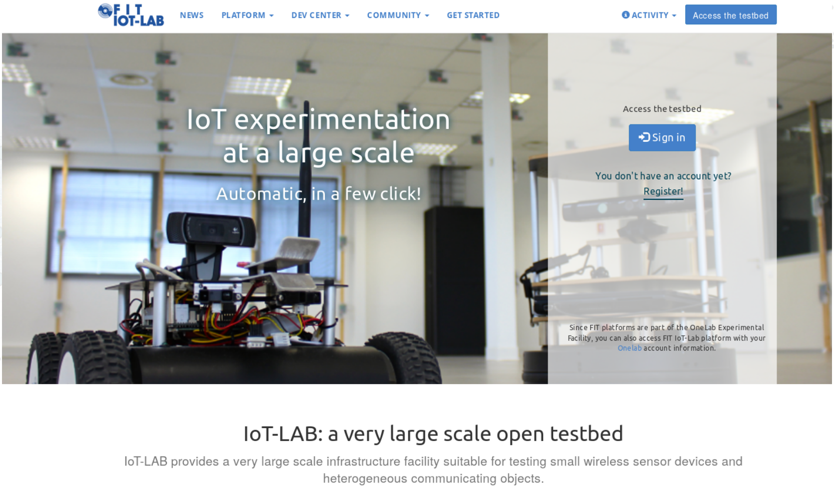


Figure 2: Comparison of the transmission success likelihood after one trial with no interfering nodes (in blue) and with interference (in black).

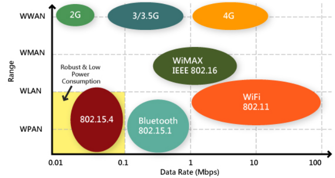
Experimental Analysis and Main Result

Experiment using Fit-IoT-Lab platform



Experiment details

Density of nodes	$\lambda = 1.7 \cdot 10^{-6}$
Attenuation coeff.	$\alpha = 2.2$
Noise power	$N_0 = -100dBm$
Trans. power	$P_e = 25dBm$
SINR thresh.	$\tau = -10dB$
Dist. node	$r = 50m$
Numb. nodes	$N_n = 40$
Numb. channels	$N_c = 5$
Numb. time-slots	$N_{ts} = 4$



M3 Node

based on STM32F103REY MCU and communication with a 802.15.4 PHY Layer (2.4 GHz)

contiki

MATLAB

Theory vs Experiments

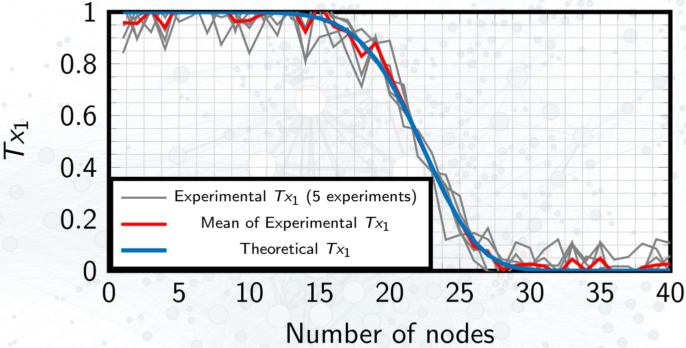


Figure 3: Comparison between the theoretical transmission likelihood and its practical estimation for 20 channels. Best view in color.

Main result: How many channels do we need to a achieve high performance distributed wireless sensor network?

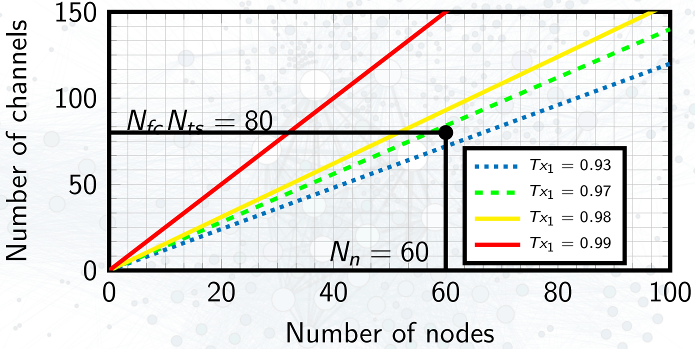


Figure 4: Transmission success likelihood in terms of number of nodes in the network and number of channels assuming the presence of interfering nodes in the out range of the BTS.

Thank you for your attention!