



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

MEA. Seddik^{1,2}, V. Toldov^{2,3}, L. Clavier^{1,3}, N. Mitton²

¹IMT Lille-Douai, ²Inria, ³IRCICA USR CNRS 3380

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Outline

A complex network diagram with numerous nodes of varying sizes and colors (light blue, white, grey) connected by thin lines, creating a dense web-like structure that fills the background of the slide.

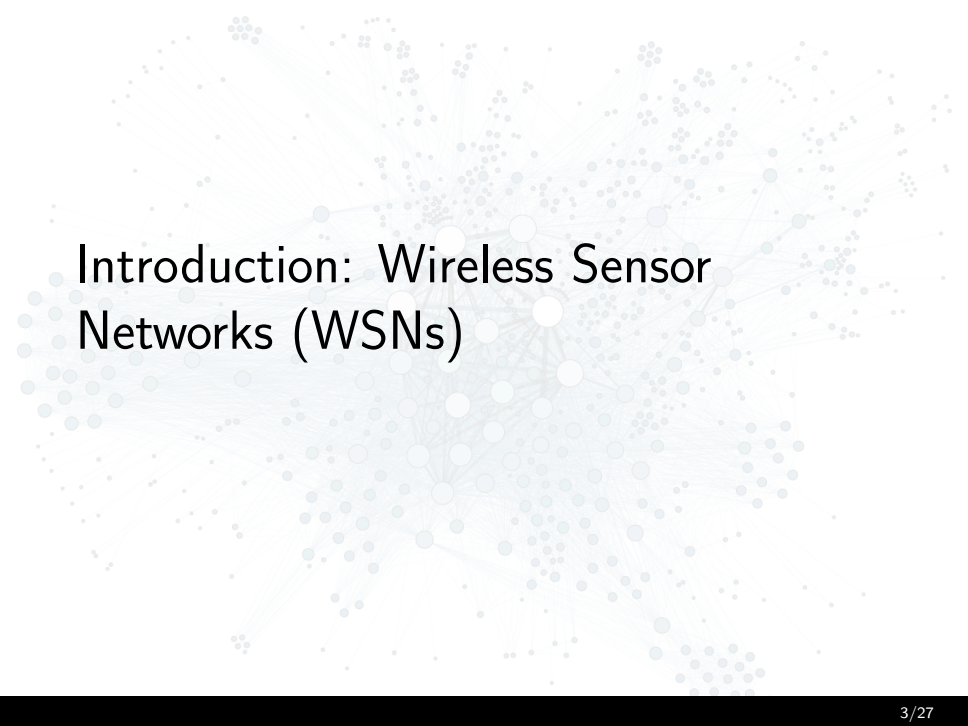
Introduction: Wireless Sensor Networks (WSNs)

Problem Statement & Outage Probability

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

Slotted-ALOHA *with* Channel Reservation and Interferences

Experimental Analysis and Main Result



Introduction: Wireless Sensor Networks (WSNs)

Nowadays, WSNs are everywhere!



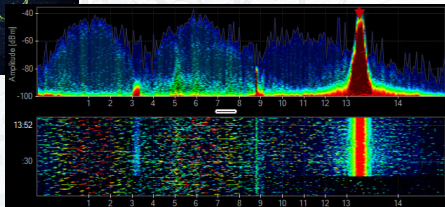
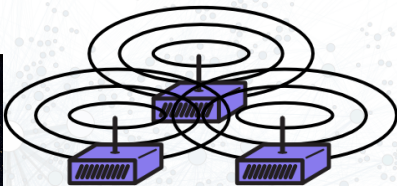
- ▶ Environmental applications.
- ▶ Home applications.
- ▶ Medical applications, etc.

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**
⇒ 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:

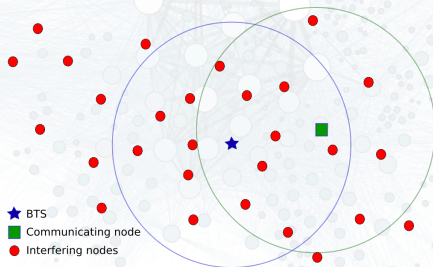
How many channels do we need to achieve high performance distributed wireless sensor network?



Problem Statement & Outage Probability

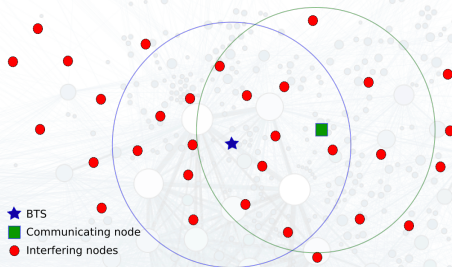
MAC Protocol: Slotted-ALOHA

- ▶ *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 $\tau > 0$,

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

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:

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

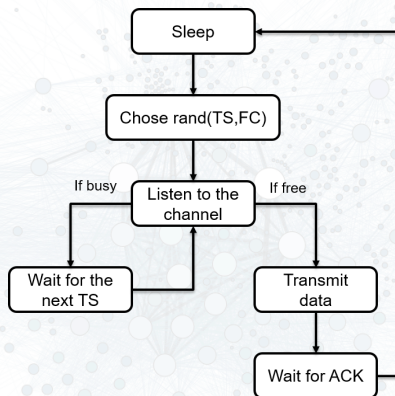
where $\mathbb{I} \langle \cdot \rangle$ is the indicator function, $\xi = \frac{r^{-\alpha}}{\tau} - \frac{N_0}{P_e}$ and

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



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

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

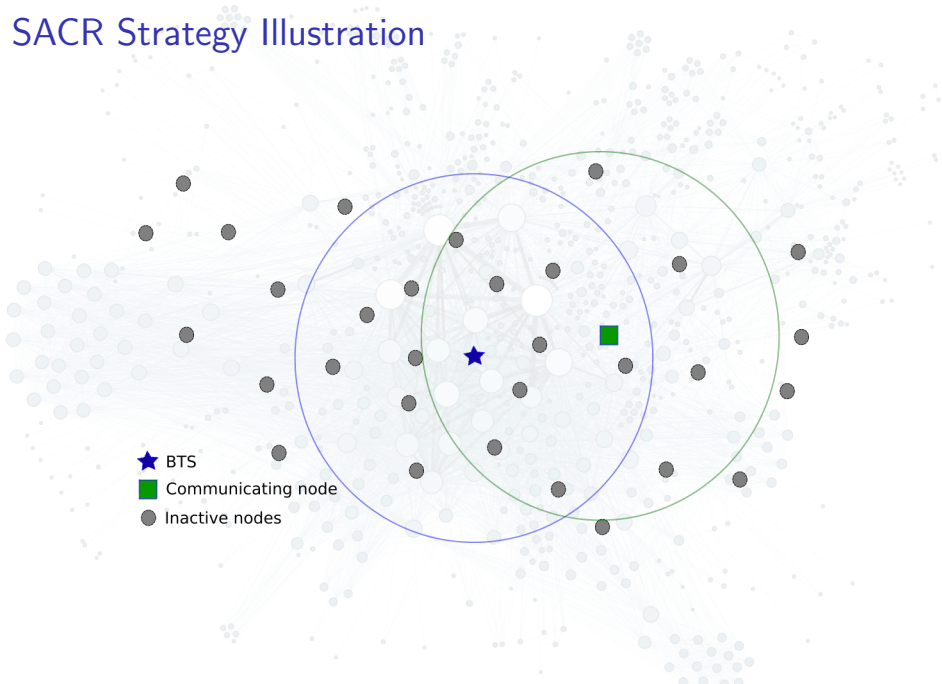


Assuming $N \sim Poiss(\mu = \frac{N_n}{N_{ts}N_{fc}})$, **the reservation probability is**

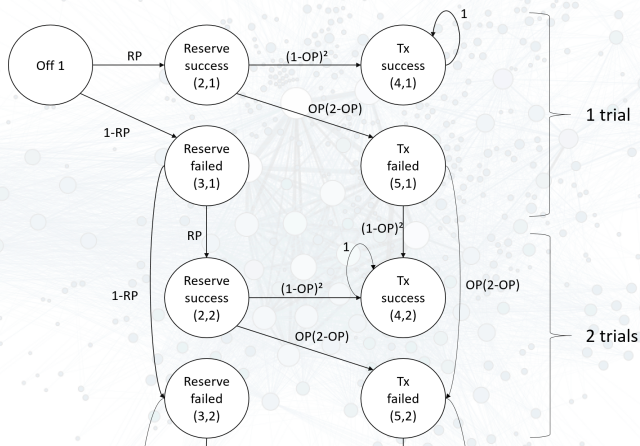
$$Rp = \mathbb{P}\{N = 0\} = e^{-\mu}$$

SACR Strategy Illustration

- ★ BTS
- Communicating node
- Inactive nodes



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 $\pi^\infty = \pi^{(0)} \lim_{k \rightarrow \infty} \Gamma^k$. In particular the **success transmission likelihood** is given by

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

Communicating Node States Modeling: Markov Chain

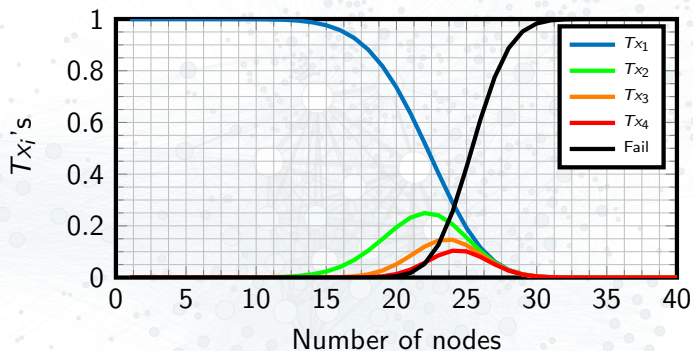
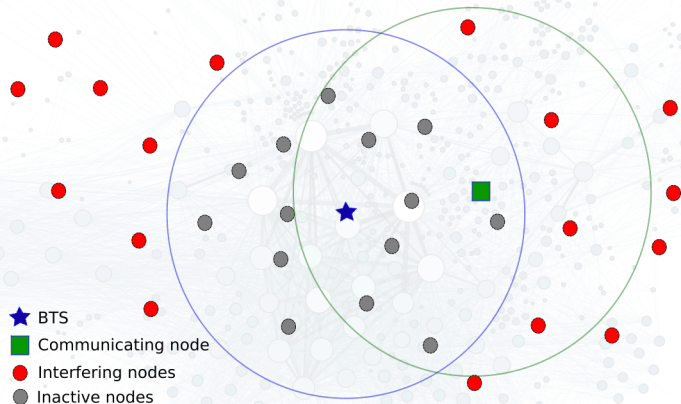


Figure 1: Curves of T_{x_i} 's.



Slotted-ALOHA *with* Channel Reservation and Interferences

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



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

where R denotes the range of the BTS.

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

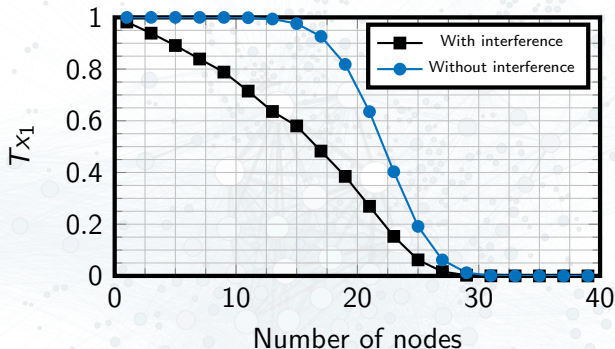
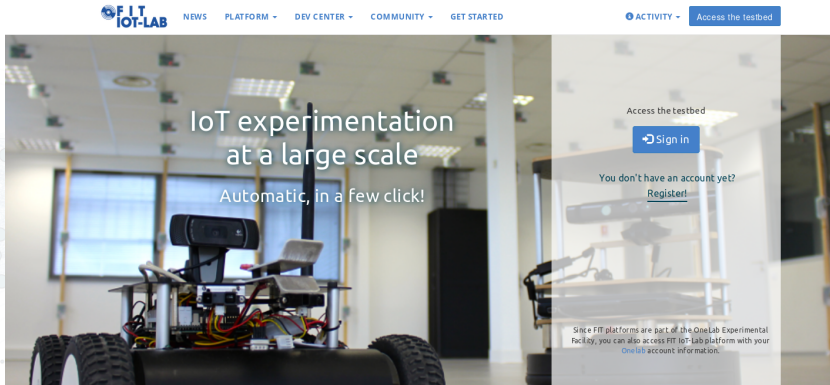


Figure 2: Comparison of the transmission success likelihood after one trial with no interfering nodes (in blue) and with interference (in black).



Experimental Analysis and Main Result

Experiment using Fit-IoT-Lab platform



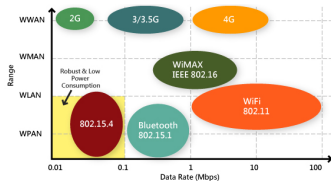
The screenshot shows the FIT IoT-LAB website interface. At the top left is the FIT IoT-LAB logo. To its right are navigation links: NEWS, PLATFORM, DEV CENTER, COMMUNITY, and GET STARTED. On the far right, there is an 'ACTIVITY' dropdown menu and a blue button labeled 'Access the testbed'. The main content area is split into two panels. The left panel features a photograph of a three-wheeled robot with a camera and sensors, with the text 'IoT experimentation at a large scale' and 'Automatic, in a few click!' overlaid. The right panel is a semi-transparent overlay containing the text 'Access the testbed', a blue 'Sign in' button, the question 'You don't have an account yet?' with a 'Register!' link, and a small disclaimer at the bottom: 'Since FIT platforms are part of the OneLab Experimental Facility, you can also access FIT IoT-Lab platform with your OneLab account information.'

IoT-LAB: a very large scale open testbed

IoT-LAB provides a very large scale infrastructure facility suitable for testing small wireless sensor devices and heterogeneous communicating objects.

Experiment details

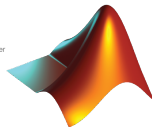
Density of nodes	$\lambda = 1.7 \cdot 10^{-6}$
Attenuation coeff.	$\alpha = 2.2$
Noise power	$N_0 = -100dBm$
Trans. power	$P_e = 25dBm$
SINR thresh.	$\tau = -10dB$
Dist. node	$r = 50m$
Numb. nodes	$N_n = 40$
Numb. channels	$N_c = 5$
Numb. time-slots	$N_{ts} = 4$



M3 Node

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

contiki



MATLAB

Theory vs Experiments

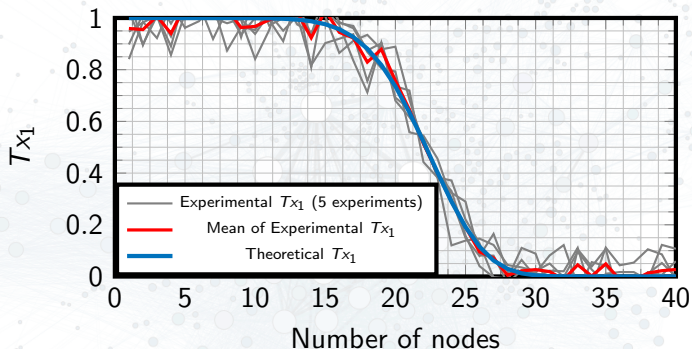


Figure 3: Comparison between the theoretical transmission likelihood and its practical estimation for 20 channels. Best view in color.

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

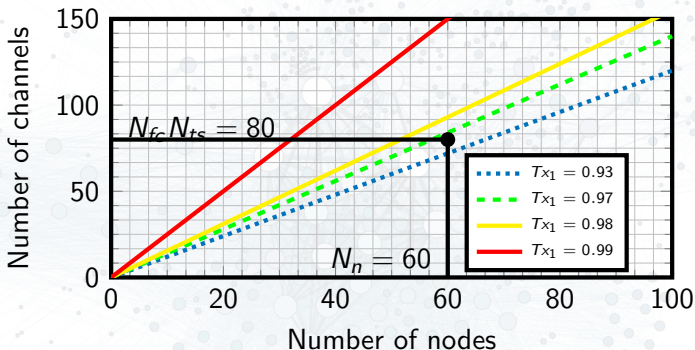


Figure 4: Transmission success likelihood in terms of number of nodes in the network and number of channels assuming the presence of interfering nodes in the out range of the BTS.



Thank you for your attention!