Design of an Rx-ZigBee for sustainable agriculture

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***Abstract*—In this work, we develop a low-power Rx-ZigBee using open-source IHP 130 nm technology. The IEEE 802.15.4–compliant circuit integrates optimized LNA, mixer, and PLL blocks. Deployed in a sensor network dedicated to sustainable agriculture, it uses a custom protocol for reliable, energy-efficient data collection. Simulations indicate that two daily measurements balance data quality and power consumption.**

***Index Terms*—ZigBee, sustainable agriculture, low-power design, RF receiver, sensor network.**

I. Introduction

"The agricultural revolution of our time must be ecological, social, and technological" [1]. Modern farming faces soil depletion, loss of biodiversity, and chemical dependency, while smallholders lack affordable tools. In this context, managing water and organic inputs is a challenge. A low-power IoT system could support sustainable practices. We present a ZigBee receiver (Rx-ZigBee) compliant with IEEE 802.15.4 [2], designed using open source tools [3]. This article details technology, protocol, receiver architecture [4], and an agricultural application to enable data-driven eco-friendly decisions.

II. Design of a ZigBee circuit

A. Open hardware

In order to design integrated circuits at no cost, we use open hardware tools with IHP 130 nm open source PDK [3]. Additionally, this low-power technology is well suited for our needs. Qucs Studio, Ngspice and Xyce are used for block design and simulations. KLayout is used for layout, enabling efficient and cost-effective work.

B. ZigBee specifications

The ZigBee protocol suits low data-rate and low-power usage such as smart homes or sensing networks. It supports mesh networking with up to 16 channels at 2.4 GHz and a typical 250 kbps rate [2]. Its simplicity and energy efficiency fit large-scale device deployments.

The project involves designing a ZigBee receiver based on the IEEE 802.15.4 standard [2]. It uses MSK modulation for energy-efficient wireless communication. The system (Figure 1) integrates key RF components: a power amplifier (PA) delivering up to 14 dBm, a low noise amplifier (LNA) with the highest gain and the lowest noise possible [4], a mixer with an image frequency (IF) of 2 MHz, and a phase-locked loop (PLL) stabilizing frequency within the 2.4-2.5 GHz range. The design ensures good sensitivity, range, and resilience to interference.

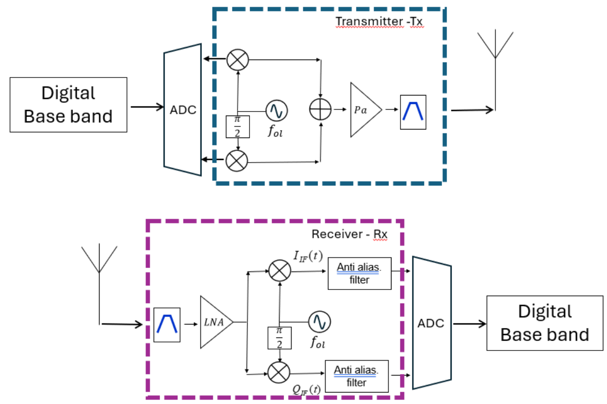

Fig. 1. System schematic

C. Receiver architecture and performance

We focus our work on the front-end receiver which includes the three key blocks: LNA, mixer and PLL. The LNA uses a common-gate architecture for broadband input matching and low noise. The mixer, a Gilbert cell, provides good linearity and isolation. The PLL, consisting of a voltage-controlled oscillator (VCO), frequency divider, and charge pump, generates the local oscillator signal for the mixer. Each block is optimized for gain, noise figure, frequency, and power consumption. For the transmitter, including the PA, we used existing designs from the literature without redimensioning. Table I summarizes the simulated receiver performance.

III. Use case

To address the challenge of soil and water management, we propose implementing ZigBee-based transceivers in low-cost, low-power sensor stations with wireless transmission that supports decision making while preserving traditional practices. On a 1 hectare plot divided into six parcels, 12 stations (two per parcel) send data to a central unit Figure 2, which analyzes input and offers recommendations, such as irrigation or crop rotation, through a simple interface. We

TABLE I
Performance Summary of the receiver Blocks

Block	Gain (dB)	NF (dB)	Frequency (GHz)	Consumption (mW)
LNA	20	3.5	2.4-2.5	1.6
Mixer	8	11.2	2.4-2.5	1.8
PLL	–	–	2.4-2.5	3.6

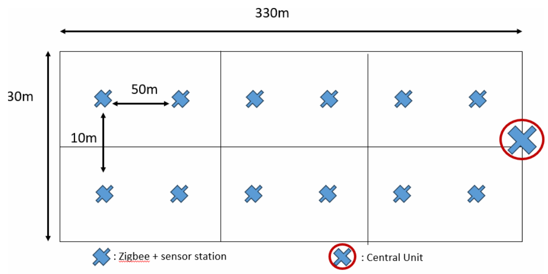

Fig. 2. AgriZigBee application schematic on 1Ha field

assume two daily measurements, timed for the warmest and coolest periods.

A. Full custom protocol

To avoid collisions, we developed a pseudosynchronous protocol leveraging the low data collection frequency. Data are gathered every 12 hours, during which the central ZigBee unit wakes up for 6 seconds. This accounts for clock drift (40ppm or 1.7s), 10ms per exchange with 12 secondary stations, and interference margins. The central unit sequentially queries each station, setting the minimum wake-up time as the product of the exchange time and the count of stations. Each exchange includes a superframe, response, and acknowledgment, with a 5-ms early wake-up. The waking times of the secondary stations vary depending on their position in the queue. Sensor to ZigBee communication uses wired links. This protocol is illustrated in Figure 3. Consumptions for each component are estimated and summarized in Table II

Based on this methodology, we model the consumption of our solution, as a function of the number of stations for a 1-Ha field. We measure the percentage of consumption for

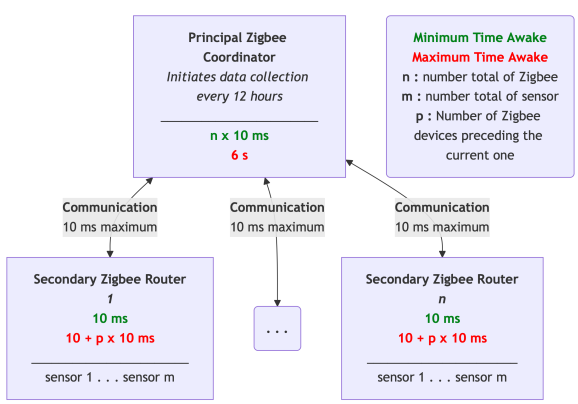

Fig. 3. Protocol Time

TABLE II
SYSTEM CONSUMPTION

Element	Consumption (W)	
	Active	Passive
ZigBee circuit	57e-3	3e-6
Primary station - Central unit (Raspberry pi)	13	3
Secondary Station - (sensors + µcontroller)	1	0.25

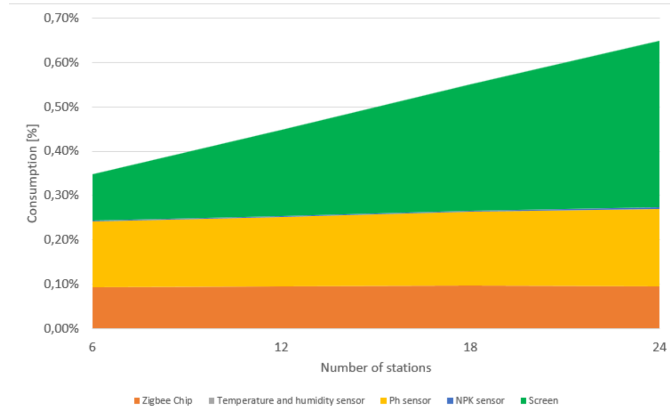

Fig. 4. Consumption model

each part of the circuit, see Figure 4. It must be noted that ZigBee and all sensors are less than 0.8% percent of the consumption (ZigBee accounts for 0.19% of the station power consumption). All the rest is due to the µ-controller and central unit. This graph reveals that even with an optimized low-power ZigBee transceiver, we need to consider the entire system for a low-consumption application.

CONCLUSION

The Rx-ZigBee project showcases how technology can work with nature to address modern agricultural challenges. Using open-source tools, we created a practical solution that empowers farmers to make informed decisions while preserving traditional practices. This project demonstrates that innovation and environmental respect can coexist.

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