Low-cost Antenna for IoT Deployment in Developing Country

F. Ferrero[1], C. Pham[2],
[1]UCA, LEAT CNRS, Sophia Antipolis, France, fabien.ferrero@unice.fr
[2]Univ. Pau, LIUPPA Laboratory, Pau, France, Congduc.Pham@univ-pau.fr

***Abstract*—In this paper, the design of ultra-low cost antenna for gateway and end-node in rural areas is realized. The proposed structures are compared with on-the-shelf components to demonstrate an improvement on the performance combined with a more affordable integration cost.**

***Index Terms*—antenna, IoT, measurement.**

I. Introduction

Until recently, telco mobile communication infrastructure (e.g. GSM/GPRS, 3G/4G) were the only choice for long-range connectivity of remote devices. However, these technologies are expensive and definitely not energy efficient for autonomous devices that must run on battery for months as shown in Figure 1. While short-range radio, such as IEEE 802.15.4 radio, can overcome their limited transmission range with multi-hop transmission, they can actually only be realized in the context of developed countries' smart-cities infrastructures, where high node density with powering facility can be achieved. They can hardly be considered in isolated or rural environments.

Technology	2G	3G	LAN
Range (I=Indoor, O=Outdoor)	N/A	N/A	O: 300m I: 30m
Tx current consumption	200-500mA	500-1000mA	100-300mA

Fig. 1. Long-range sensing/telemetry system

Recently, Low-Power Wide Area Networks (LPWAN) based on ultra-narrow band modulation (UNB) – e.g. SigFox™ – or Chirp Spread Spectrum modulation (CSS) – e.g. LoRa™ [1] – has attracted attention with their capability to provide long range communication with a much power consumption. Most of LP-WAN technologies can achieve more than 20km in LOS condition and they definitely provide a better connectivity answer for IoT by avoiding complex and costly relay nodes to be deployed and maintained. Fig. 1 shows a typical long-range 1-hop connectivity scenario where the gateway is the single interface to Internet servers through cellular/ADSL/WiFi technologies depending on what is available locally.

We describe in this article a low-cost IoT platform, developed in the context of the H2020 WAZIUP project (http://www.waziup.eu) and enabling the deployment of smarter rural applications in developing countries. The design of the IoT platform addresses developing countries' constraints such as (a) providing longer range for rural access and (b) lowering the cost of hardware and services. The platform consists of 2 parts: a low-cost generic hardware IoT device and a low-cost flexible and customizable gateway. Targeted for small to medium size deployment scenarios, the platform also privileges quick appropriation and customization by third parties. Various IoT devices are developed in the project from the generic hardware IoT.

The do-it-yourself (DIY) approach perfectly fit the requirements and constraints of developing countries and in order to provide an affordable solution for local population, the cost of every block of the system has to be optimized, including the antenna part. Most of the existing solution are based on commercial antennas that are oftenly bulky and costly. Therefore, this study mainly focuses on the design of ultra-low cost antenna system that are both robust and easy to use. A specific integrated antenna is designed for the end-node and a printed dipole antenna is designed for the gateway.

The article is organized as follows. Section II both presents the WAZIUP IoT platform and 2 real-world deployment use cases that were at the origin of the presented work on low-cost antenna design. Sections III and IV describe 2 proposed low-cost antenna designs that can be used for gateways and end-devices depending on the deployment settings and constraints. We conclude in Section V.

II. Real use-cases of low-cost IoT deployment in developing countries

The proposed IoT platform fully takes the "Arduino" philosophy for low-cost, simple-to-program yet efficient hardware platforms that is ideally well-suited for do-it-yourself (DIY) IoT, especially in WAZIUP that addresses rural applications in developing countries. The Arduino-compatible ecosystem is large and proposes various board models, from powerful prototyping boards to smaller and less energy-consuming boards for final integration purposes. For instance, the small form factor Arduino Pro Mini board that is available in the 3.3v & 8MHz version for much lower power consumption can definitely be used to provide a generic low-cost IoT platform as it can be purchased for less than 1.5 euro from Chinese manufacturers. For more demanding IoT applications we use the Teensy family boards (LC/31/32) that offer state-of-the-art micro-controllers with more memory and advanced power management features at a very reasonnable cost (about 10 euro for the LC). In addition to the long-range communication library supporting most of SPI-based LoRa radio modules, the platform integrates software building blocks in ready-to-use templates for quick and easy customization of end-devices, see Fig. 2. One of the most important issue being the device autonomy, the proposed IoT platform succeeds in integrating very efficient low-power management for the low-cost hardware allowing more than 1 year of autonomy with regular AA batteries that can be found worldwide.

Although not presented in this paper but illustrated in Fig. 2, our platform also includes a low-cost LoRa gateway to receive, manage (including various cloud upload features) and present data from end-devices in a very flexible manner. The gateway is built on the well-known Raspberry PI (1B/1B+/2B/3B), and the cost of the entire gateway can be less than 45 euro. More details and all software can be found in [2].

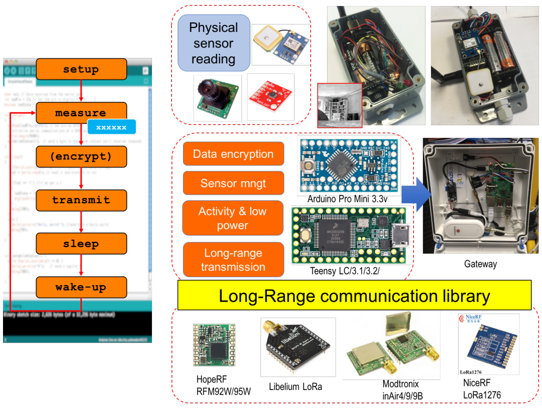

Fig. 2. Generic IoT hardware platform

The WAZIUP low-cost IoT platform has been deployed in several use cases in developing countries. Here we are describing 2 main use cases that motivated the design of the proposed low-cost antennas: (a) multi-level soil moisture monitoring for optimization of irrigation in maize crop farms – for Nestlés WaterSense project in Pakistan – and (b) real-time tracking collar for cows for preventing cattle rustling in Senegal.

A. *Multi-level soil moisture monitoring*

The deployment campaign for the WaterSense platform has been conducted in May 2017 in a number of pilot farms. Each soil moisture device has 2 physical sensors that can be placed at different depth in the soil. The device is developed from the generic hardware platform and simply uses the generic periodic sensing template (see left part of Fig. 2) with 1 measure every hour.

As can be seen in Fig. 3, maize crop plants can be rather high (easily above 2.5m) and the antenna at the device side has to be placed on top of a bamboo pole while the sensing device needs to be placed at a lower level both to be protected from the sun and to remain easily accessible. At the gateway side, which is usually located inside the farm's office to easily get power and Internet connectivity, the antenna should be placed outside and connected to the radio module with through a coaxial cable. Depending on the building structure, an antenna pole may again be needed.

Fig. 3. Deployment campaign for WaterSense

Most of antennas shipped with LoRa radio modules are simple quater-wave monopole. While these types of antennas have reasonable performance when they are directly connected to the radio module, the usage of an intermediate coaxial cable (about 3m to 5m) considerably decreases the performance level thus the link quality. During the deployment campaign, although the pilot crop fields were separated from the gateway by about 2kms, the link quality was very poor.

B. *Tracking collar*

The tracking collar application is part of the WAZIUP project as a Minimum Viable Product (MVP). The MVP's objective is to provide near real-time information about cattle to the farmers in order to prevent cattle thefts that have dramatic impacts on rural population which incomes are oftenly entirely based on their cows. The information gathered by LoRa collar devices will be sent to a gateway that will notify the farmer about critical situations. Information that will be provided to the farmer are typically the distance of the collar, and, when a GPS module is added, the exact GPS position. With the simple version (no GPS) the collar device is simply a beacon device with no particular physical sensor attached. The periodic beacon messages are received at the gateway and the packet's RSSI can be used to estimated the distance to the collar. No beacon for several period of time can raise an alarm as well as the detection of a system reset (beacon messages carry a sequence number). The collar is designed so that removal of the collar will disconnect the beacon system. The cost of the simple version can be as low as 8 per device. If a GPS module is added, an additional cost of about 8 must be added.

Fig. 4. Long-range sensing/telemetry system

As can be seen from Fig. 4, the tracking device will be placed on a cow (with a robust belt). The pilot deployment is realized in the CIMEL national breeding centre located 6km from the Gaston Berger University. However, it must be noted that the entire system can be deployed in a mobile manner as the gateway can be carried in a backpack and powered with a high capacity battery to run for several days. A smartphone can then be used to visualize received information as the gateway runs an embedded web server.

For the antenna issue, we focus here on the device part as the gateway side can be very similar to the previous use case. We show in Fig. 5 the GPS version of the tracking collar. Again, the tracking device is developed from the generic hardware platform and simply uses the generic periodic sensing template (with GPS code to get the GPS NMEA informations) sending 1 beacon with GPS coordinate every 20mins. As the GPS module is completly switched off between 2 beacons, the autonomy of the GPS version is still greater than 1 year.

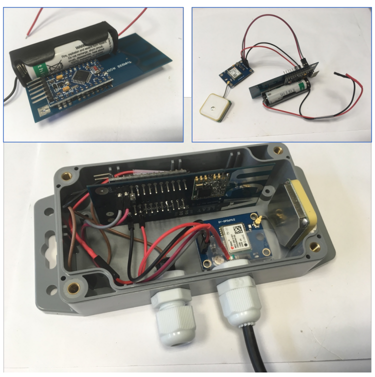

Fig. 5. Long-range sensing/telemetry system

Fig. 5 shows the usage of the proposed integrated antenna design to build the tracking device to avoid having a fragile external antenna for the collar that will be placed on the cow.

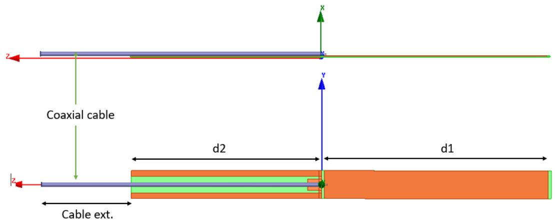

Fig. 6. Top view of the printed dipole structure

III. Gateway Antenna Design

The gateway system is based on a Raspberry Pi (although a simple version can use an Arduino platform) with a single channel LoRa module. The gateway antenna is intended to be placed in a elevated position and is connected to the electronic system by a coaxial cable. The length of the cable can vary from 30 to 300 cm. An omni-directional radiation pattern is desired and the antenna performance should be independent from the cable length. This type of performance is usually obtained with coaxial sleeve dipole available on the market. However, the price for such antenna is not negligible and a lower cost solution is investigated.

A. Antenna design

In order to reduce the fabrication cost of the gateway antenna, a printed version of the sleeve dipole is studied with the major advantage of integrating a balun inside the dipole structure itself.

In the 3D Electromagnetic simulation, the coaxial cable has to be modeled in order to obtain an accurate result. The antenna has to be simulated with a sufficient cable length in order to stabilize the input impedance around the resonance. From Fig. 6, it can be observed that a cable extension of 30mm is needed to simulate a stable S_{11}. When the correct resonance is identified in the simulation, the structure can be tuned with 2 main parameters : d1 being the top arm dipole length and d2 being the bottom arm dipole length. As it can be seen in Fig. 7 and 8, the effect of the 2 parameters on the S11 is not equivalent. d1 is slightly tuning the frequency resonance and the matching while d2 has a very large influence on the frequency resonance with a limited impact on the matching. Thanks to these 2 parameters, the antenna can be easily optimized.

B. Antenna measurement

The proposed concept is manufactured on a 0.4mm-thick substrate. In order to maintain the cable centered in the substrate, we drill 3 holes in the substrate and pass the cable through these holes as shown in Fig. 10.

The reflection coefficient of the structure is measured and compared with simulation in Fig. 11. A fair agreement is obtained between simulation and measurement, especially considering that the modeling of the cable is really ideal in the simulation. The planar antenna is matched with a -10dB criteria from 840 MHz to 910 MHz.

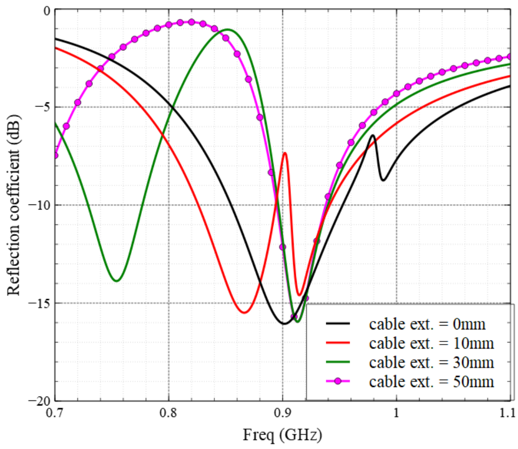

Fig. 7. S11 for different cable extension

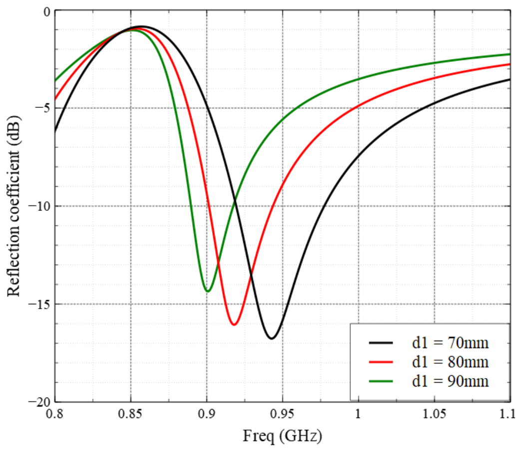

Fig. 8. S11 for different d1 length

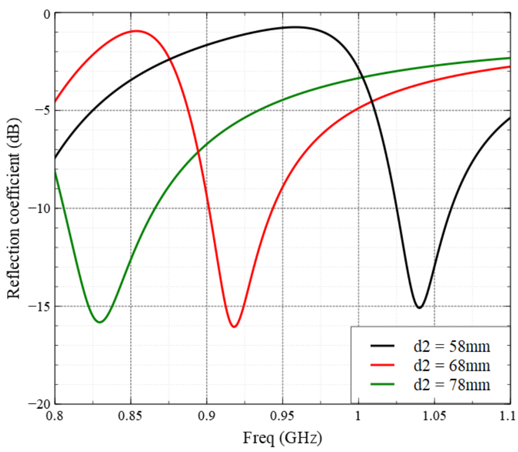

Fig. 9. S11 for different d2 length

In order to compare the performance of the proposed concept with off-the-shelf antennas, we have selected two different sleeve dipoles usually used for evaluation. The first one is provided with the Semtech evaluation kit and has a length of 140mm [3]. The second one is provided by IMST with the gateway evaluation kit and has a length of 210mm [4]. The proposed antennas are measured on a Satimo starlab station. The measured total radiation efficiency show in Fig. 12 that the printed antenna has higher total efficiency compared with the off-the-shelf antennas.

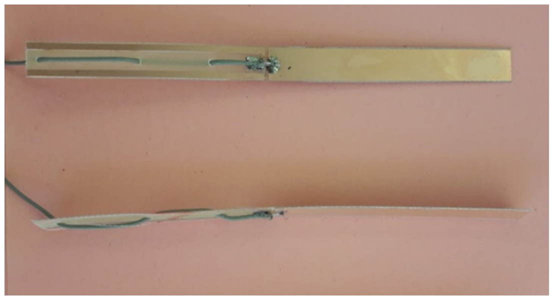

Fig. 10. Picture of the printed dipole prototype

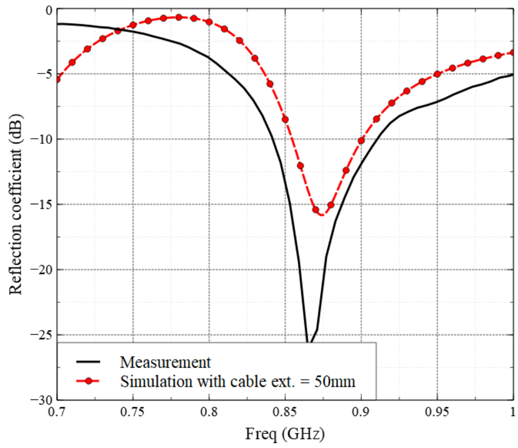

Fig. 11. Measurement and simulation reflection coefficient of the planar dipole antenna

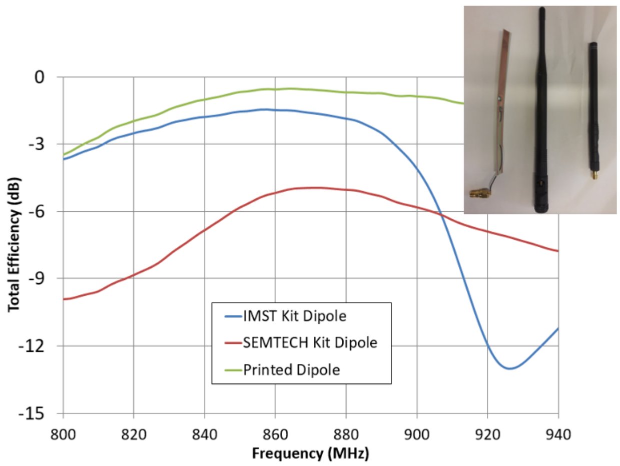

Fig. 12. Measurement comparison of different dipole total efficiency

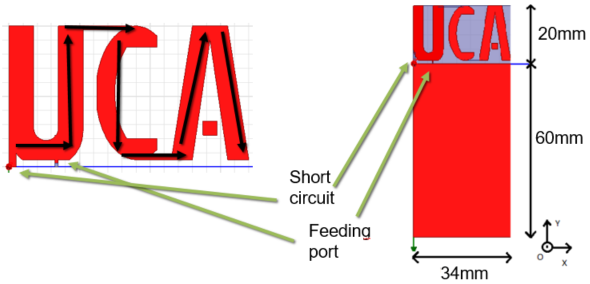

Fig. 13. Logo based IFA antenna (left) and terminal size (right)

IV. End-Node antenna design

The end-node device targets the very small form factor Arduino Pro Mini and the HopeRF RFM95W LoRa module to achieve the lowest cost. The end-node antenna has to be miniaturized as much as possible to facilitate the use of this solution in various scenarios. The node will be powered with AA batteries which imply a 60mm length for the ground plane. However, again, the price for such antenna is not negligible and a lower cost solution is investigated, especially when deployment of dozens of devices is considered. In addition, as indicated previously for the Cattle Rustling use case, being able to avoid an external antenna is a major requirement.

A. Antenna design

The geometry of the low-cost antenna is based on a Inverted F Antenna (IFA) shape. Promoting the University Cote d'Azur, the antenna structure is based on the use of the university acronym by smartly connecting the different letters together as shown in 13. The results is a meandered shape which allows the miniaturization of the antenna. The antenna is designed to provide optimal performance in terms of efficiency and impedance matching at the operating frequency of 865MHz. The optimization is carried out taking into account the presence of the antenna watertight casing.

B. Antenna Measurement

The antenna is manufactured on a 0.8mm-thick substrate and assembled together with the Arduino Pro Mini and the RF module through a simple PCB board, see Fig. 14. The battery pack can further be attached to the PCB. The radiation characteristics of the fabricated board is measured with a Satimo Starlab station in Transmitted Radiated Power (TRP) mode. The integrated transceiver on the board is set in Continuous Wave mode at 865MHz and the emitted power is measured in 3D using a spectrum analyzer. The measured 3D radiation pattern is presented in Fig. 15. The comparison with a short monopole antenna in table I show that a 76% total radiation efficiency can be obtained with a smaller structure (80mm compare with 105mm).

V. Conclusion

The paper investigated the design of ultra-low cost antennas for IoT deployment in developing countries. Comparison

Fig. 14. Top and Bottom view of the board

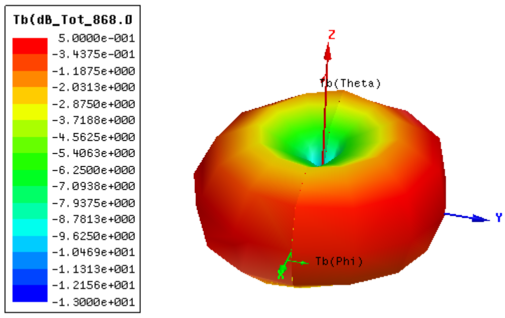

Fig. 15. 3D measured radiation pattern

with commercial components shows improvement on the antenna performances with a significant reduction of the cost. Moreover, the entire IoT solution can be built from a DIY approach that perfectly fits the developing countries needs as all antennas designs are made publicly available.

Acknowledgment

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TABLE I
Terminal TRP @865MHz with the different configurations.

	14dBm Tx mode		Dim.
	Peak EIRP Gain	Tot. Eff.	Height
	(dBm)	(%)	(mm)
Small monopole	14.7	74	105
Int. Ant.	14.8	76	80