Low-cost Antenna Technology for LPWAN IoT in Rural Applications

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***Abstract*—The article describes a low-cost and open IoT platform for rural applications in developing countries. Using the latest low-power, long-range radio technologies and off-the-shelves components, the platform can be quickly deployed and customized for a large variery of rural applications. We present in the article how a low-cost IoT collar device especially addressing the cattle rustling issues can be built from the platform. The article then focuses on the antenna part by presenting how a low-cost integrated antenna design can increase the robustness of the IoT collar by avoiding external fragile parts while preserving a high transmission quality.**

***Index Terms*—LPWAN, Low-cost IoT, Antenna design, rural applications**

I. INTRODUCTION

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, (b) lowering the cost of hardware and services and (c) limit dependency to proprietary infrastructures and provide local interaction models. 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 and the article focuses on the design of an IoT collar addressing the cattle rustling issues that are main concerns of farmers in developing countries. The IoT collar communicates with a gateway using long-range radio technologies and we propose a low-cost antenna design to avoid having a fragile external antenna attached to the IoT collar.

The rest of the article is organized as follows. Section II presents our low-cost IoT platform taking into account developing countries needs and constraints. Section III presents the Cattle Rustling rural application and the developed low-cost IoT collar with cattle localization. In Section IV we will present the low-cost antenna design to reduce the cost of the wireless communication parts and increase both hardware integration level and robustness of the casing without an external antenna. We conclude in Section V.

II. LONG-RANGE, LOW-COST IOT FOR RURAL APPLICATIONS

A. LPWAN IoT

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. 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.

Recent so-called Low-Power Wide Area Networks (LPWAN) such as those based on Sigfox™ or Semtech's LoRa™ technology [1] definitely provide a better connectivity answer for IoT as several kilometers can be achieved without relay nodes to reach a central gateway or base station. Fig. 1A 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. Most of long-range technologies can achieve 20km or higher range in LOS condition and about 2km in urban NLOS [2].

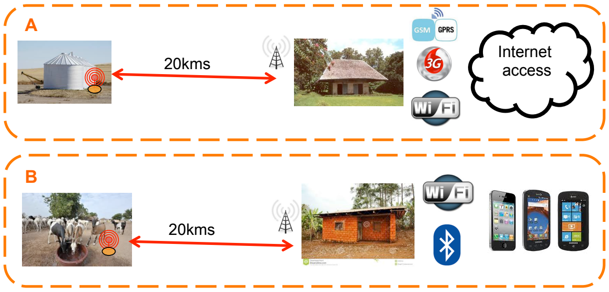

Fig. 1. Deployment scenarios in developing countries.

B. Low-cost IoT hardware platform

The availability of low-cost, open-source hardware platforms such as Arduino-like boards is clearly an opportunity for building low-cost IoT devices from consumer market components. For instance, boards like Arduino Pro Mini based on an ATmega328 microcontroller offers an excellent price/performance/energy tradeoff and can provide a low-cost platform for generic sensing IoT with LoRa long-range transmission capability for a total of less than 10 euro. In addition to the cost argument such mass-market board greatly benefits from the support of a world-wide and active community of developers.

With the gateway-centric mode of LPWAN, commercial gateways with LoRaWAN specifications [3] for instance are usually able to listen on several channels and radio parameters simultaneously. They use advanced concentrator radio chips that alone cost more than a hundred euro. Here, the approach can be different in the context of agriculture/micro and small farm business: simpler "single-connection" gateways can be built based on a simpler radio module, much like an end-device would be. Then, by using an embedded Linux platforms such as the Raspberry PI with high price/quality/reliability tradeoff, the cost of such gateway can be less than 45 euro.

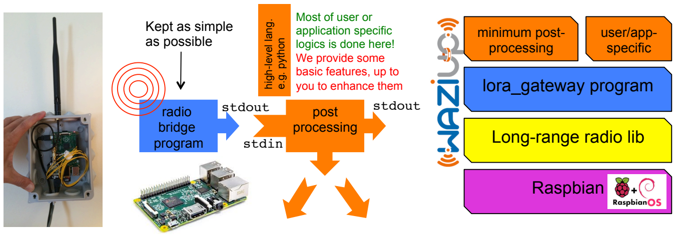

Fig. 2. Flexible gateway software architecture.

Therefore, rather than providing large-scale deployment support, IoT platforms in developing countries need to focus on easy integration of low-cost "off-the-shelves" components with simple, open programming libraries and templates for easy appropriation and customization of the post-processing stage by third-parties, as illustrated in Fig. 2.

C. Data management and local access

Data received on the gateway are usually pushed/uploaded to some Internet/cloud servers. It is important in the context of developing countries to be able to use a wide range of infrastructures and, if possible, at the lowest cost. Fortunately, along with the global IoT uptake, there is also a tremendous availability of sophisticated and public IoT clouds platforms and tools, offering an unprecedented level of diversity which contributes to limit dependency to proprietary infrastructures. Many of these platforms offer free accounts with limited features but that can already satisfy the needs of most agriculture/micro and small farm/village business models. It is therefore desirable to highly decouple the low-level gateway functionalities from the high-level data post-processing features, privileging high-level languages for the latter stage (e.g. Python) so that customizing data management tasks can be done in a few minutes, using standard tools, simple REST API interfaces and available public clouds.

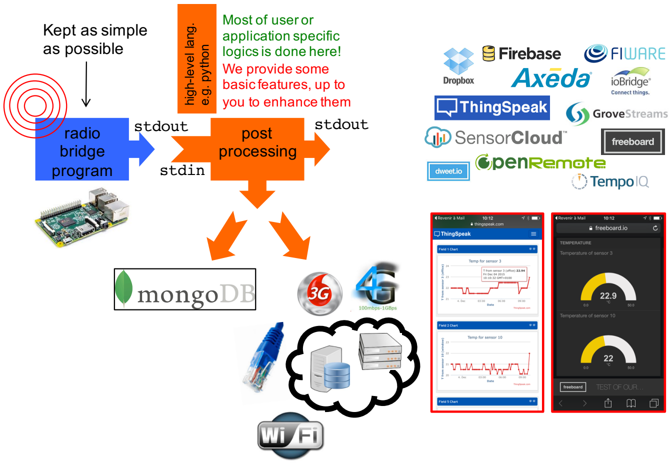

Fig. 3. Post-processing data from the gateway.

We provide a template that already supports a number of publicly available IoT clouds such as `Dropbox`™, `Firebase`™, `ThingSpeak`™, `freeboard`™, `GroveStream`™ & `FiWare`™, as illustrated in Fig. 3(right). With public IoT clouds "out-of-the-box" surveillance applications can be deployed in minutes as most of these platforms propose free accounts. For instance, a small farm can deploy the sensors and the gateway using a free account with `ThingSpeak` platform to visualize captured data in real-time.

As can also be seen in Fig. 3, our gateway can also handle cases where Internet connectivity is not available as data can be locally stored on the gateway in a NoSQL MongoDB database. The gateway can either be used as an end-computer by just attaching a keyboard and a display, or it can also interact with the end-users' computing device (smartphone, tablet) through WiFi (through a web server) or Bluetooth (with an Android app on a smartphone) as depicted in Fig. 4.

Display the 10 last document(s)
Sort by date

```
2016-12-15 15:47:58
2016-12-15 15:41:29
2016-12-15 15:36:24
2016-12-15 15:28:32
2016-12-15 15:24:50
2016-12-15 15:13:26
2016-12-15 15:03:38
2016-12-15 15:01:52
2016-12-15 14:56:37
2016-12-15 14:51:40
```

Display data: ● RSSI ○ TC ○ DEF
Display sources: ☑ node_3 ☑ node_6 ☑ node_10
Zoom to:

```
NODE: 1 DATE: 2016-05-09 08:04:59.807000 DATA: {"lw": 3.29, "th": 22.6, "hu": 50.7}
NODE: 1 DATE: 2016-05-09 08:28:52.993000 DATA: {"lw": 3.29, "th": 22.89, "hu": 50.29}
NODE: 1 DATE: 2016-05-09 08:53:04.317000 DATA: {"lw": 3.29, "th": 23.2, "hu": 50.79}
NODE: 1 DATE: 2016-05-09 09:05:00.997000 DATA: {"lw": 3.29, "th": 23.29, "hu": 51.29}
NODE: 1 DATE: 2016-05-09 09:17:24.482000 DATA: {"lw": 3.29, "th": 23.39, "hu": 51.7}
NODE: 1 DATE: 2016-05-09 09:41:27.437000 DATA: {"lw": 3.29, "th": 23.6, "hu": 52.0}
NODE: 1 DATE: 2016-05-09 10:05:39.032000 DATA: {"lw": 3.29, "th": 23.79, "hu": 51.5}
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NODE: 1 DATE: 2016-05-09 11:17:02.953000 DATA: {"lw": 3.29, "th": 23.5, "hu": 50.79}
NODE: 1 DATE: 2016-05-09 11:52:53.334000 DATA: {"lw": 3.29, "th": 23.29, "hu": 50.7}
NODE: 1 DATE: 2016-05-09 12:04:32.437000 DATA: {"lw": 3.29, "th": 23.5, "hu": 50.29}
NODE: 1 DATE: 2016-05-09 12:16:56.116000 DATA: {"lw":
```

1 check to retrieve its data ☑
8 check to retrieve its data ☐
Pick a begin date — Retrieve data since 09-05-2016
Pick an end date — Retrieve data until 17-05-2016

```
Creating .csv file with the data received...
File 17-05-2016_10h39m36s.csv created and saved in the folder /storage/emulated/0/Raspberry_local_data
```

Fig. 4. Fully autonomous LoRa gateway.

III. LOW-COST IOT DEVICE FOR CATTLE RUSTLING APPLICATIONS.

A. *Cattle rustling in developing countries*

Cattle theft is a recurrent phenomenon that is observed in many African countries. In recent years, it is increasingly the main concern of farmers and is one of the major constraints to livestock development. For farmers, the practice of animal husbandry has always been and will remain their main source of income and economic losses due to this problem is quite significant with many dramatic consequences. Confronted with this problem, farmers generally remain without solutions. To prevent theft of livestock, farmers find solutions to mark each animal, counting the herd before and after grazing, to put fence to the grazing area. These solutions are clearly far from being enough efficient to combat this phenomenon in large scale.

The use of new technologies including those related to IoT could be a good solution in the prevention and fight against cattle rustling. The choice of technologies to prevent and combat cattle theft in the African context should be made taking into account specific criteria to the rural areas and also the social conditions of farmers in this environment. In this context, the major criteria include cost and internet access. Indeed, the rural farmers are mostly poor and so they will most likely accept and adopt a solution if it has low costs. In addition, they live in areas where Internet access is difficult (and expensive) and they are not generally covered by mobile (e.g. 3G) operators.

In this context, the low-cost LPWAN IoT framework described previously is particularly well-suited for deployment as a completely autonomous system consisting of IoT collar devices and a gateway with local storage and embedded data management features can be deployed even in a mobile, on-the-go, scenario as illustrated in Fig. 5.

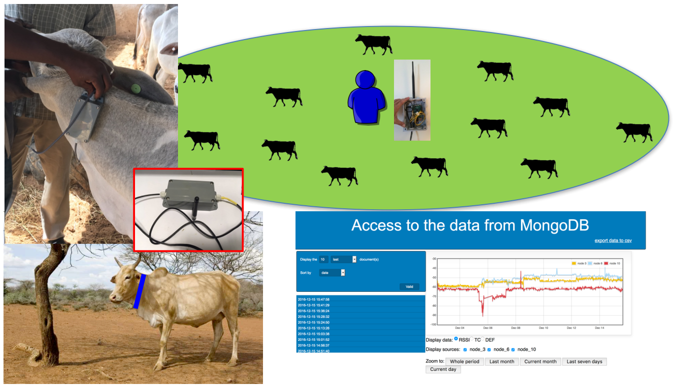


Fig. 5. On-the-go mobile cattle surveillance system.

A high-capacity battery pack can be used to power the gateway for more that 40 hours and the battery pack can itself be recharged with portable solar panel if needed.

B. *Low-cost LoRa IoT collar*

The proposed prototype is based on Semtech's long-range LoRa transmission from collar devices to a central gateway. LoRa belongs to the spread spectrum approaches where data can be "spreaded" in both frequencies and time to increase robustness and range by increasing the receiver's sensitivity, which can be as low as -137dBm in 868MHz band or -148dBm in the 433MHz band. Throughput and range depend on the 3 main LoRa parameters: BW, CR and SF. BW is the physical bandwidth for RF modulation (i.e. 125kHz, 250kHz or 500kHz). Larger signal bandwidth allows for higher effective data rate, thus reducing transmission time at the expense of reduced sensitivity. CR, the coding rate for forward error detection and correction. Finally SF, the spreading factor, which can be set from 6 to 12. The lower the SF, the higher the data rate transmission but the lower the immunity to interference thus the smaller is the range.

The designed collar is fixed to the cow around the neck and will periodically send beacon messages to the gateway when powered on. The operational range of the collar can be fixed by setting both BW and SF: the longest range can be obtained with BW=125kHz and SF=12. Most of designed collars or tags for cattle management is not suitable in the context of cattle rustling because they are easily removable and thieves can cut the collar without farmers' awareness. To overcome this problem we design the collar so that cutting or removing the collar can be detected by the absence of beacon messages (unplugging and replugging the collar can also be detected). This is illustrated in Fig. 6.

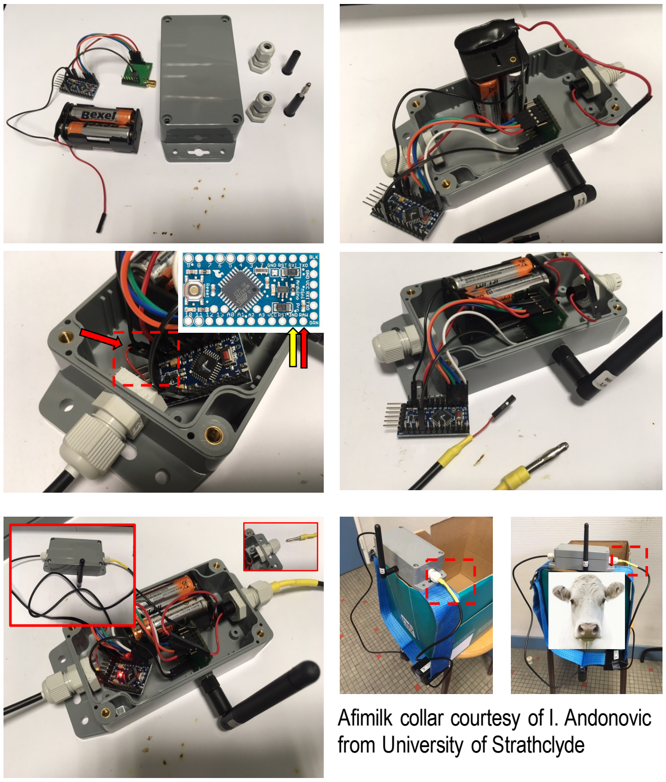

Afimilk collar courtesy of I. Andonovic from University of Strathclyde

Fig. 6. The active beacon collar IoT device.

The LoRa gateway stores the received beacon messages and their associated RSSI (Received Signal Strength Indicator) and process them in order to detect whether an alarm should be raised or not. The processing result can be sent to the cloud if internet connectivity is available or directly to the farmer's smartphone or tablet (via Bluetooth or WiFi) if not. The reception of a beacon message means that the collar which send it is in the range of the gateway (RSSI analysis can further be done to have a range estimation). If cows are out of range or collar are disconnected or damaged an alarm can be raised. The beacon message can further carry GPS coordinates for more accurate position information if a GPS module is added to the collar but this would add about 10 euro for the GPS module, thus doubling the cost of the collar device.

The beacon collar can simply be built with the software building blocks developed by the WAZIUP project as shown in Fig. 7. The duty-cycle building block can be configured to trigger sensor reading every M minutes. All sensors connected to the board will be polled and the returned values concatenated into a message string for transmission. For the simple collar, the message contains the beacon indication and sequence number, `SN/0`. With GPS, the message includes the GPS coordinates, `SN/0/LAT/16.027/LGT/-16.484` for instance.

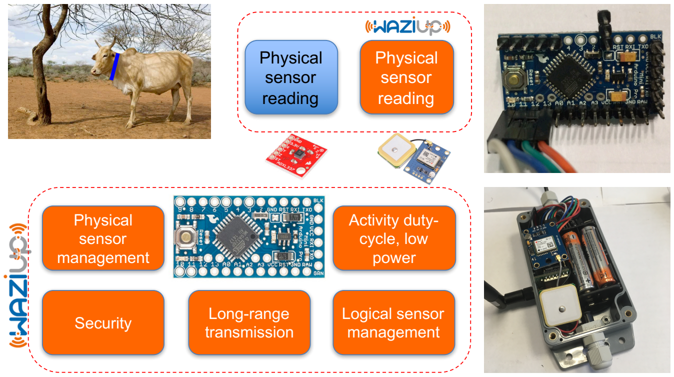


Fig. 7. The generic IoT platform with software building blocks.

Then, the low-power building block provides a deep-sleep mode to run an Arduino Pro Mini with 4AA regular batteries. With a duty-cycle of 1 sample every hour, the board can run for more than a year, consuming about $120\mu A$ in deep sleep mode and 40mA when active and sending, which represents about 2s of activity/hour. With the radio module connected to the Pro Mini board, there are still plenty of analog and digital pins for various sensors. For out-door usage, the board is powered by 4-AA batteries and is put into a water-proof case. With the basic version of the beacon collar, no additional sensor is used as only the radio module is needed for sensing the beacons. Additional sensors such as GPS or accelerometer can be added by integrating dedicated sensor reading building blocks as depicted in Fig. 7.

C. *Increasing robustness by removing the external antenna*

One crucial issue when dealing with cow collar is the robust casing for such animals. This robustness can be greatly increased by avoiding any external parts such as the antenna as it induces reliability issues due to corrosion and high fragility. Moreover, the use of plastic-coated external antennas implies additional costs, which are non-negligible in developing countries. For instance, the price of off-the-shelf antennas with the RF connectors (e.g., SMA-type connectors) can represent 1/3 of the total device's cost. An integrated antenna that can be directly placed on the main PCB can have a much lower cost as, from a fabrication perspective, it only requires to partially extend the PCB. For this purpose, a simple PCB with integrated antenna has been designed to simply connect the Arduino Pro Mini board and the radio module as illustrated in Fig. 8.

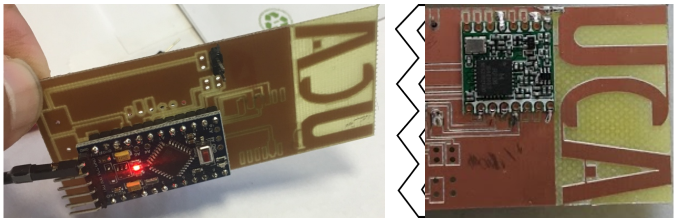


Fig. 8. Simple PCB with integrated antenna.

Fig. 9 shows the integrated antenna targeting ultra-low fabrication costs when compared to traditional helical and straight antennas. It also shows how the PCB with the integrated antenna can be nicely placed in the case, avoiding fragile external parts.

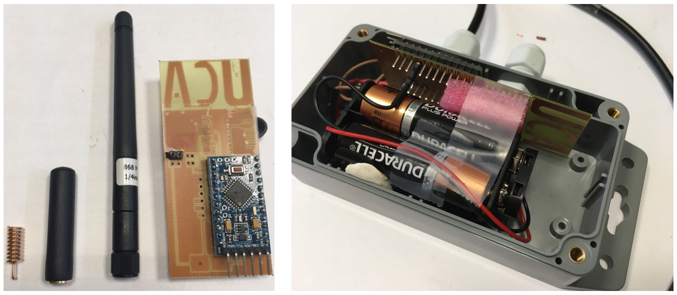


Fig. 9. Various antennas comparison.

IV. PERFORMANCE OF THE LOW-COST ANTENNA FOR LPWAN IOT

A. *Integrated antenna design*

Some preliminary results [4], [5] have demonstrated that miniature printed antennas can be used to design efficient and reliable communication system working in UHF bands. The geometry of the low-cost antenna presented in this paper is based on a Inverted F Antenna (IFA) shape. Promoting the University Côte d'Azur, the antenna structure is based on the use of the university acronym by smartly connecting the different letters together. 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. Prototype measurement and comparison

In order to assess the performance of the proposed antenna compared to off-the-shelf solutions, a generic PCB equipped with an SMA connector was fabricated. Three different 868MHz antennas have been considered for the comparison: a short monopole, a quarter-wave monopole and a half-wave monopole, see Fig. 10. The measured radiation characteristics as well as the main dimension of each configurations are provided in Table I. A Satimo station was used to measure the Total Radiated Power (TRP) of the various antennas when the transceiver was set into a continuous transmitting mode with output power set to 14dBm.

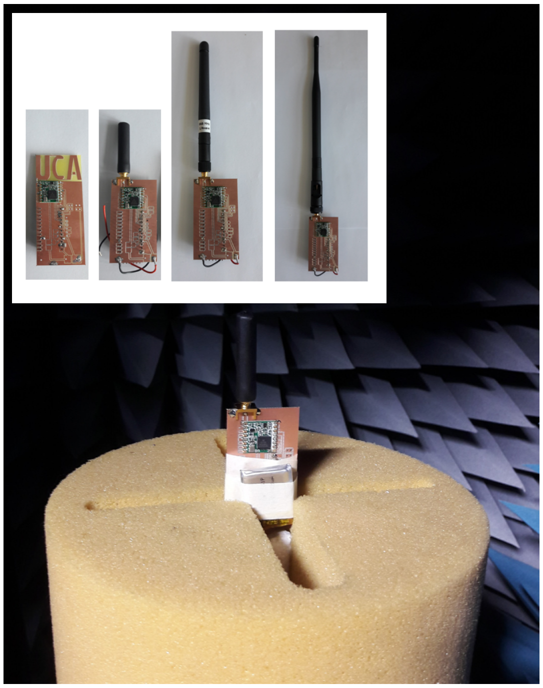


Fig. 10. Measurement set-up for communicating module and set of measured configurations

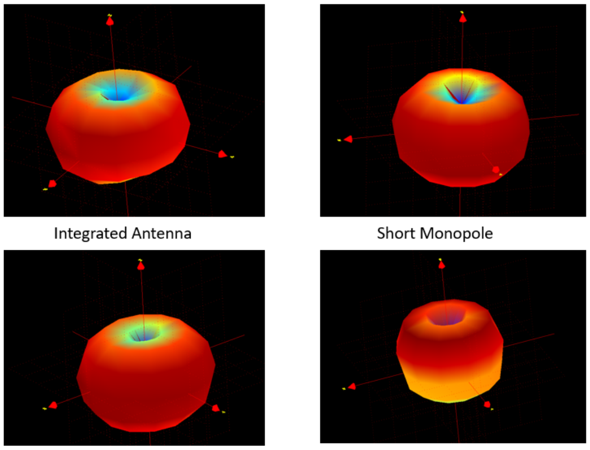
TABLE I
Terminal TRP @865MHz with the different configurations.

	14dBm Tx mode		Dim.
	Peak EIRP Gain	Tot. Eff.	Height
	(dBm)	(%)	(mm)
Small monopole	14.7	74	105
Quarter-wave monopole	15.7	94	170
Half-wave dipole	14.7	61	280
Int. Ant. wo casing	13.8	60	80
Int. Ant. with cas.	14.8	76	80
SLot Ant. from [6]	14	60	120
3D Ant. from [7]	15	79	100

As it can be seen in Table I, the best performance in terms of total antenna efficiency are achieved by the quarter wave antenna (94%). The proposed integrated antenna exhibits slightly lower values (76%), but with the advantage of reduced size (80 mm vs. 170 mm height), which is fundamental to increase the robustness of the device. It is worth noting that, as the antenna is integrated in the PCB, the presence of the casing has a major impact on the antenna performance. As expected, the efficiency of the proposed antenna when measured without the casing, decreases to 60%. This confirms the importance of taking into account the device casing during the antenna optimization process.

In order to highlight the radiation performance of this printed antenna, state-of-the art results are integrated in Table I. A printed monopole slot antenna is integrate into a 120*60mm terminal in [6], and a 60% efficiency is obtained at 868MHz. In [7], a 3D multi-band inverted antenna (more expensive to fabricate) mounted on a 100*50mm terminal provide a 1 dB gain at 868MHz.

The 3D radiation patterns for the various configurations have also been extracted from the measurement and are presented in Fig. 11. The 4 configurations provide an equivalent omni-directional radiation behavior, as required by the targeted application.



Integrated Antenna

Short Monopole

Quarter-wave Monopole

Half-wave Dipole

Fig. 11. Radiation pattern measurement for the different antenna configurations

C. Field tests

We also performed field tests to assess the performance of the integrated antenna in real deployment conditions. The transmission power for all tests has been set to 14dBm.

Fig. 12. Field test setting

The distance between the gateway (with a DIY ground plane antenna) and the devices is about 800m with a lot of vegetation as it can be seen in Fig. 12(left). One beacon device is equipped with the quarter-wave monopole antenna, Fig. 12(middle) while the other has the integrated antenna, Fig. 12(right). Also, to reproduce the attenuation introduced by the cow's body (because the beacon collar will be placed as shown previously in Fig. 5), the beacon device will be placed against the chest of the experimenter. We will show the SNR and the RSSI of 5 beacon transmissions. The quarter-wave monopole antenna will simply be denoted as ”monopole” and the integrated PCB antenna as ”integrated”. In addition, each device will be tested when (a) facing the gateway, denoted as ”face” and (b) back to the gateway where the signal has to go through the experimenter's body, denoted as ”back”.

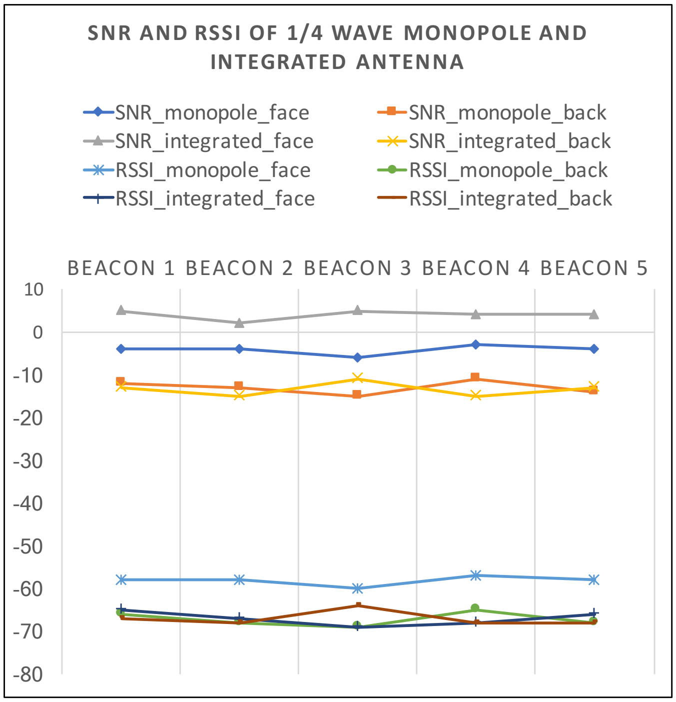


Fig. 13. Field test setting

As can be seen from Fig. 13, the RSSI is quite stable in all cases. The SNR with the integrated antenna, when facing the gateway, is actually much better then the SNR with the quarter-wave monopole in the same position. When tested in the ”back” position, both antennas shows comparable SNR. This preliminary field tests show that the real-world performance of the integrated antenna is quite comparable to the quarter-wave antenne, while simplifying the hardware integration and increasing the robustness of the whole device.

V. CONCLUSIONS

In this article we described our low-cost, long-range and open IoT platforms for rural application. Focusing on Cattle Rustling applications, we describe a low-cost IoT collar that actively and periodically sends beacon messages to the gateway. In order to increase the robustness of the IoT collar, a dedicated compact antenna directly printed on the device PCB has been designed and its performances measured. The obtained results demonstrated the effectiveness of the proposed antenna with respect to classical off-the-shelf solutions. Preliminary field tests also confirmed the performance of the integrated antenna for real-world deployment of cattle rustling devices while offering an significant reduced cost compared to the other solutions.

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