WAZIUP: A Low-Cost Infrastructure for Deploying IoT in Developing Countries

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Abstract. Long-range radio are promising technologies to deploy low-cost Low Power WAN for a large variety of IoT applications. There are however many issues that must be considered before deploying IoT solutions for low-income developing countries. This article will present these issues and show how they can be addressed in the context of African rural applications. We then describe the WAZIUP low-cost and long-range IoT framework. The framework takes cost of hardware and services as the main challenge to be addressed as well as offering quick appropriation and customization possibilities by third-parties.

Keywords: LPWAN · Low-power IoT · Low-cost IoT · Rural applications

1 Introduction

There are many opportunities for IoT applications in Africa and Fig. 1 shows some typical applications where remote monitoring facilities could greatly increase quality and productivity in a large variety of rural applications.

However, Africa's countries are facing many difficulties – lack of infrastructure, high cost of hardware, complexity in deployment, lack of technological eco-system and background, etc. – when it comes to real deployment of IoT solutions [1], especially in remote and rural areas which are typical of the Sub-Saharan Africa region. In this context, IoT deployment must address four major issues: (a) Longer range for rural access, (b) Cost of hardware and services, (c) Limit dependency to proprietary infrastructures and (d) Provide local interaction models. The WAZIUP project targeting deployment of low-cost IoT in sub-saharan Africa addresses these issues that are presented below.

Longer Range for Rural Access. Traditional mobile communication infrastructure (e.g., GSM/GPRS, 3G/4G) are still very expensive to deploy IoT devices. Moreover, they are definitely not energy efficient for autonomous devices

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Fig. 1. Some ICT fields of IoT opportunities in rural environments

that must run on battery for months. Short-range technologies such as IEEE 802.15.4 can eventually be used by implementing multi-hop routing to overcome the limited transmission range but this can only be envisaged with high node density and easy access to power scenarios such as smart-cities environments. They can hardly be considered in isolated or rural environments.

Recent Low-Power Wide Area Networks (LPWAN) – Sigfox$^{\mathrm{TM}}$ or Semtech's LoRa$^{\mathrm{TM}}$ technology – provide a much more adapted connectivity answer for IoT in remote areas as a star topology with a central gateway or base station can be deployed. Most of long-range technologies can achieve 20 km or higher range in LOS condition and about 2 km in urban NLOS [2]. LoRa technology that can be privately deployed in a given area without any operator has a clear advantage in the context of developing countries over Sigfox which coverage is entirely operator-managed.

Cost of Hardware and Services. Commercial IoT devices are definitely too expensive for very low-income countries. In addition, these highly integrated devices are difficult to repair with their parts being hardly locally replaced. The availability of low-cost, open-source hardware platforms such as Arduino definitely pushes for a Do-It-Yourself (DIY) and "off-the-shelves" design approach: the Arduino Pro Mini based on an ATmega328 microcontroller has a high performance/price tradeoff and can be used to build a low-cost generic sensing IoT platform with LoRa long-range transmission capability for less than 10 euro. In addition, these boards also benefits from the support of a world-wide and active community of developers and a large variety of software libraries are available.

Commercial LPWAN gateways use advanced concentrator radio chips to listen on several channels and radio parameters simultaneously. The cost of such concentrator alone is more than a hundred euro. In the context of smaller scale rural applications, simpler "single-connection" gateways can be built using the same radio components than those for end-devices. Again, with "off-the-shelves" embedded Linux platforms such as the Raspberry PI the cost of an LPWAN gateway can be less than 45 euro.

Limit Dependency to Proprietary Infrastructures. Along with the worldwide IoT uptake a large variety of IoT clouds platforms offers an unprecedented level of diversity which contributes to limit dependency to proprietary infrastructures. Most of these dedicated IoT platforms have free account offers that, despite some limiting features, can largely satisfy the needs of most agriculture/micro and small farm/village business models. In order to take advantage of all these infrastructures, the design of an IoT versatile gateway should highly decouple the low-level gateway functionalities from the high-level data post-processing features to maximize the customization of the data management part. Furthermore, by privileging high-level scripting languages such as Python, the customization process can be done in a few minutes, using standard REST API interfaces to IoT clouds. Therefore, rather than focusing on large-scale deployment scenarios, easy integration of low-cost "off-the-shelves" components with simple, open programming libraries should be the main focus of IoT platforms in developing countries. WAZIUP provides code and example templates for quick appropriation and customization by third-parties.

Provide Local Interaction Models. With unstable and expensive accesses to the Internet, data received on the gateway should be locally stored. In addition, a versatile gateway is also an interesting feature where it should be possible to turn the gateway into an end computer by just attaching a keyboard and a display, and using visualizing data locally. With standard wireless technologies such as Wifi or Bluetooth, it is also interesting to provide local interaction with the end-user' smartphone/tablet to display captured data and notify users of important events without the need of Internet access. Figure 2 summarizes the various interaction models.

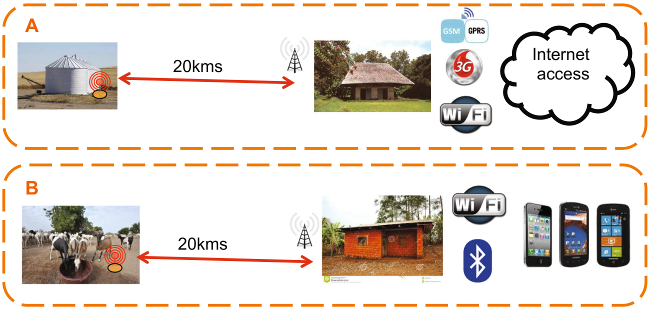


Fig. 2. Deployment scenarios in developing countries

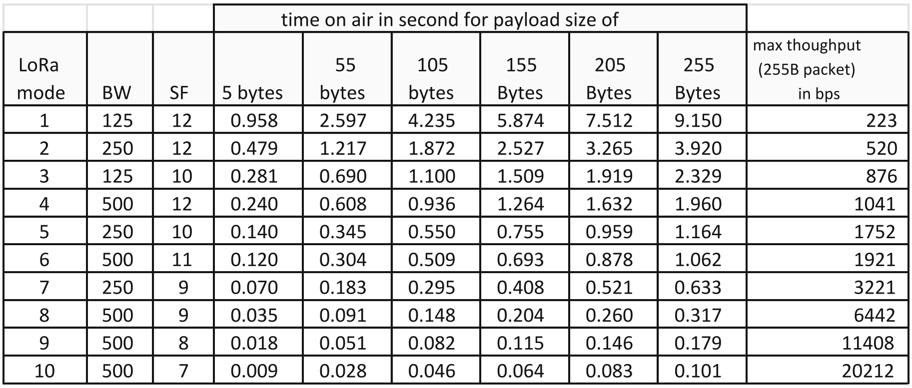
Case A depicts an Internet access based on traditional technologies such as 3G/4G or DSL+WiFi. This Internet connection can be either privately owned or can rely on some community-based access. Case B depicts a fully autonomous gateway scenario: data from remote devices are collected and stored by the gateway and smartphones/tablets using standardized technologies such as WiFi or Bluetooth can provide user-friendly access – through a web server – to the data on the gateway.

The rest of the article is organized as follows. Section 2 gives some details on the long-range Semtech's LoRa technology used in WAZIUP project. In Sect. 3, we present the WAZIUP IoT platform that has been designed specifically to address the needs and constraints of low-income developing countries, illustrating how the project addresses the 4 issues previously identified. We conclude in Sect. 4.

2 Review of Long-Range Transmission and Low-Power WAN

2.1 Semtech's LoRa Technology

Semtech's LoRa (LOng-RAnge) technology [3,4] uses a well-known spread spectrum approaches. The high receiver's sensitivity is achieved by largely "spreading" data bits in both frequencies and time, thus reducing drastically the throughput. But then, the sensitivity at the receiver can be as low as −148 dBm in the 433 MHz band (−137 dBm in 868 MHz band). Range and throughput mainly depend on 2 parameters: BW and SF. BW is the physical bandwidth for RF modulation (e.g., 125 kHz). With larger bandwidth, higher effective data rate can be achieved, but reduced sensitivity is the cost to pay. SF is the spreading factor and the lower the SF, the higher the transmission rate with a decrease of the immunity to interference. In LoRa, each bit of payload information is represented by multiple chips of information and the ratio between the nominal symbol rate and chip rate is the spreading factor. For instance, with SF = 6 (minimum value), there will be 64 chips/symbol while with SF = 12 (maximum value), this ratio will increase to 4096 chips/symbol.



			time on air in second for payload size of						
LoRa mode	BW	SF	5 bytes	55 bytes	105 bytes	155 Bytes	205 Bytes	255 Bytes	max thoughput (255B packet) in bps
1	125	12	0.958	2.597	4.235	5.874	7.512	9.150	223
2	250	12	0.479	1.217	1.872	2.527	3.265	3.920	520
3	125	10	0.281	0.690	1.100	1.509	1.919	2.329	876
4	500	12	0.240	0.608	0.936	1.264	1.632	1.960	1041
5	250	10	0.140	0.345	0.550	0.755	0.959	1.164	1752
6	500	11	0.120	0.304	0.509	0.693	0.878	1.062	1921
7	250	9	0.070	0.183	0.295	0.408	0.521	0.633	3221
8	500	9	0.035	0.091	0.148	0.204	0.260	0.317	6442
9	500	8	0.018	0.051	0.082	0.115	0.146	0.179	11408
10	500	7	0.009	0.028	0.046	0.064	0.083	0.101	20212

Fig. 3. Time on air for various LoRa modes as payload size is varied

Figure 3 shows for various combinations of BW and SF the time-on-air of a LoRa packet as a function of the payload size in bytes. The maximum throughput is shown in the last column with a 255B-payload packet. Modes 4 to 6 can provide quite interesting trade-offs for longer range, higher data rate and immunity to interferences.

Currently, LoRa uses unlicensed spectrum bands that are usually somehow regulated in many countries. In Europe, LoRa transmissions fall into the Short Range Devices (SRD) category where the ETSI EN300-220-1 document [5] applies: transmitters are constrained to 1% duty-cycle (i.e., 36 s/h) and a maximum transmission power of 14 dBm in the general case. The global duty cycle enforcement usually limits the node's total transmission time, regardless of the frequency channel. The 36 s duty-cycle is however, in most cases, quite sufficient to most of deployed IoT applications. Advanced mechanisms that implement radio activity time sharing approach can provide an elegant solution to the duty-cycle limitation as well as providing QoS levels that is definitely lacking in most of long-range technologies. In sub-saharan Africa, the regulation may differ from one country to another and our low-cost LoRa IoT platform can be adapted to follow these regulations. For instance, when deploying in Senegal, we use the 863–865MHz band with a maximum transmission power of 10 dBm.

2.2 LoRa LPWAN Network Deployment and Architecture

The deployment of a LoRa LPWAN can rely on an operator but its most interesting feature is to allow completely ad-hoc deployment scenarios. Although P2P communications between devices are possible (mesh topology), the large majority of sensing applications have mainly uplink traffic patterns that can efficiently be handled by a gateway-centric approach (star topology). In typical public large-scale LPWAN architectures data from end-devices will be pushed to Internet network servers, see Fig. 4, and dedicated application servers, that are normally managed by end-users, will later on get and decode the sensed data. While this architecture offers the highest data transparency level, it needs

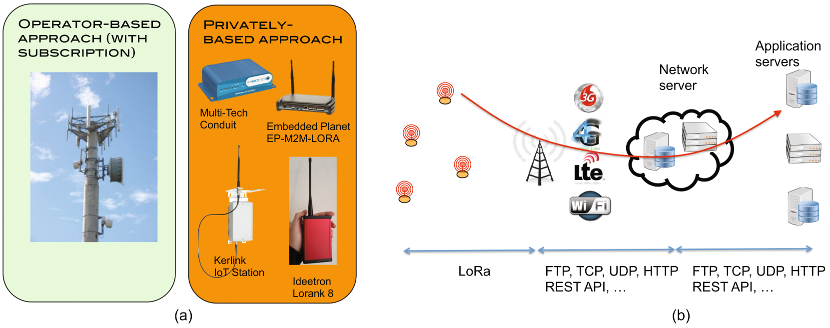


Fig. 4. (a) Gateway-centric deployment; (b) typical LPWAN architecture

various network elements and heavily relies on Internet connectivity. WAZIUP's approach is to prone a simpler approach for small, ad-hoc deployment scenarios such as those described in Fig. 2 where user's data servers or public IoT-specific cloud accounts will be accessed directly from the gateway.

3 Low-Cost LoRa IoT Platforms

3.1 Single-Connection Low-Cost LoRa Gateway

Under a full LoRaWAN specification [6], gateways must be able to simultaneously receive on several channels and LoRa settings, increasing dramatically the cost of the gateway's hardware. For developing countries, low cost and low complexity is more important to address small to medium size deployment scenarios for specific use cases instead of addressing large-scale, multi-purpose deployment scenarios. More than one gateway can deployed to serve several channel settings and this solution allows for incremental deployment as well as offering a higher level of redundancy.

Our LoRa gateway [7] is a so-called "single connection" gateway using the same simple radio module than for end-devices. Our communication library supports 7 radio models (the Libelium SX1272 LoRa, the HopeRF RFM92W/95W, the Modtronix inAir4/9/9B and the NiceRF SX1276) and most of SPI LoRa modules can actually be supported without modifications as reported by many users. The gateway is built on the well-known Raspberry PI (1B/1B+/2B/3B), see Fig. 5, and the cost of the entire gateway can be less than 45 euro.

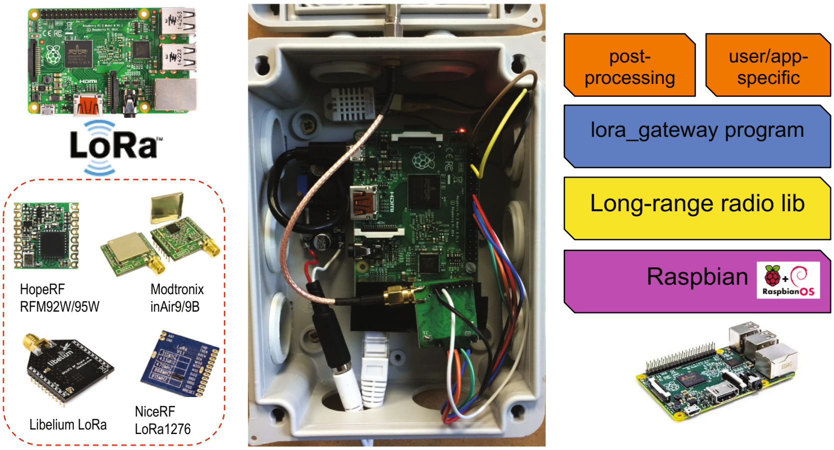


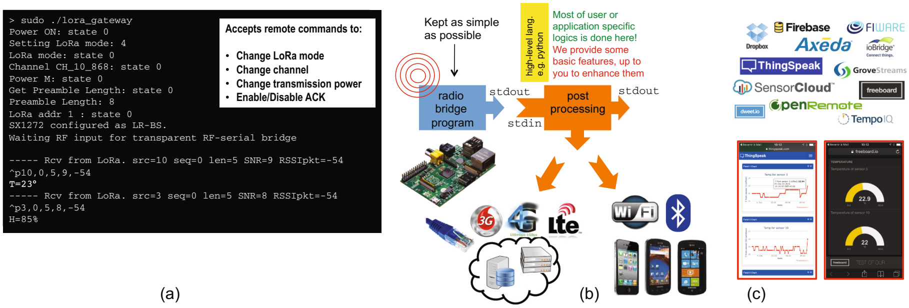
Fig. 5. Low cost gateway built from off-the-shelves components

The gateway's software is open-source running on top of a regular Raspberry Raspbian distribution. The original SX1272 communication library developed by the Libelium company has been greatly improved in many ways to provide enhanced radio channel access (CSMA-like with SIFS/DIFS) and support for both SX1272 and SX1276 chips that are used in most of radio modules available on the market.

The gateway has been tested in various conditions for several months while constantly monitoring the temperature and humidity level inside the case with a DHT22 sensor. Although the low-cost gateway is usually powered by a stable source of electricity, its consumption is low enough (about 400 mA for an RPIv3B with both WiFi and Bluetooth activated) to allow mobile applications with a high capacity battery pack offering more than 40 h of continuous operation.

3.2 Post-processing and Link with IoT Cloud Platforms

The gateway can be started in standalone mode as shown is Fig. 6a and packets received by the gateway are sent to the standard Unix-stdout stream.



```
> sudo ./lora_gateway
Power ON: state 0
Setting LoRa mode: 4
LoRa mode: state 0
Channel CH_10_868: state 0
Power M: state 0
Get Preamble Length: state 0
Preamble Length: 8
LoRa addr 1 : state 0
SX1272 configured as LR-BS.
Waiting RF input for transparent RF-serial bridge

----- Rcv from LoRa. src=10 seq=0 len=5 SNR=9 RSSIpkt=-54
^p10,0,5,9,-54
T=23°
----- Rcv from LoRa. src=3 seq=0 len=5 SNR=8 RSSIpkt=-54
^p3,0,5,8,-54
H=85%
```

Accepts remote commands to:

- Change LoRa mode
- Change channel
- Change transmission power
- Enable/Disable ACK

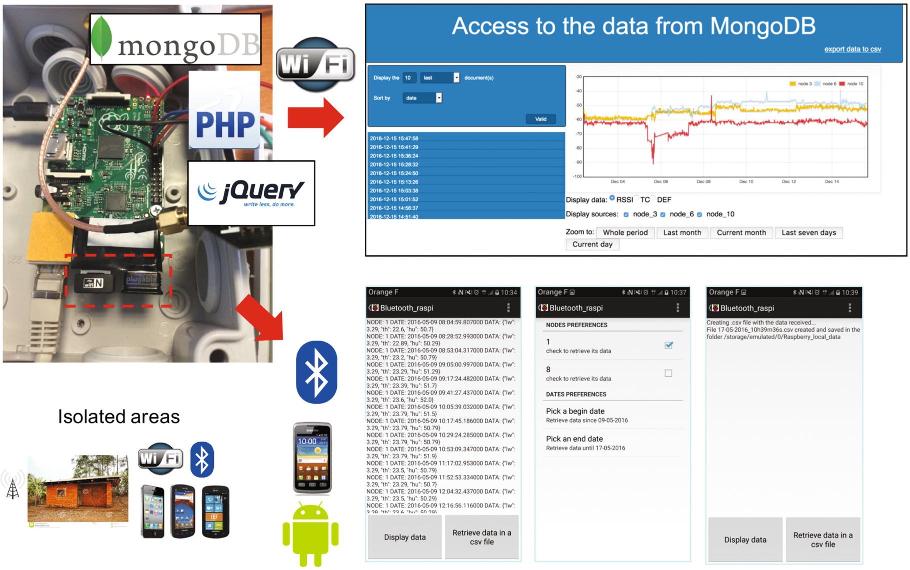
Fig. 6. Post-processing data from the gateway. (Color figure online)

All the added-value data post-processing tasks are performed after the low-level gateway stage with standard Unix redirection of low-level gateway's outputs as shown by the orange "post-processing" block in Fig. 6b. A `Python` high-level script implements all the data post-processing tasks such as access to IoT cloud platforms as well as AES encryption/decryption features. Various `Python` templates also show how to upload data on various publicly available IoT cloud platforms. Examples include `Dropbox`™, `Firebase`™, `ThingSpeak`™, `freeboard`™, `GrooveStream`™ & `FiWare`™, as illustrated in Fig. 6c.

With this architecture, WAZIUP clearly wants to decouple the low-level functionalities from the high-level features that mainly provide added-value data management facilities. With high-level languages for the data post-processing stage, the customization of data management tasks is made easier and quicker for third-parties. Therefore, the whole architecture and software stack offer either "out-of-the-box" utilization with the provided templates or quick appropriation & customization by third-parties. With the `ThingSpeak` template that WAZIUP is providing, a small farm can deploy in minutes a whole real-time remote sensing system with advanced visualization features.

3.3 Gateway Running Without Internet Access

Our low-cost gateway runs a `MongoDB`$^{\mathrm{TM}}$ noSQL database to locally store received data, and a web server with `PHP/jQuery` to offer display of received data in graphic format. With the embedded web server, the gateway can therefore interact with the end-users' smartphone/tablet through WiFi or Bluetooth as depicted previously in Fig. 6b. Notification to users of important events can therefore be realized without the need of Internet access as this situation can clearly happen in very remote areas. Figure 7 shows for instance the web interface and an Android application using Bluetooth connectivity to demonstrate these local interaction models.



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

```
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}
NODE: 1 DATE: 2016-05-09 10:17:45.186000 DATA: {"lw":
3.29, "th": 23.79, "hu": 50.79}
NODE: 1 DATE: 2016-05-09 10:29:24.285000 DATA: {"lw":
3.29, "th": 23.79, "hu": 50.79}
NODE: 1 DATE: 2016-05-09 10:53:09.347000 DATA: {"lw":
3.29, "th": 23.79, "hu": 51.9}
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":
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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":
```

NODES PREFERENCES

1
check to retrieve its data ☑

8
check to retrieve its data ☐

DATES PREFERENCES

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. 7. Fully autonomous LoRa gateway

3.4 Low-Cost LoRa End-Devices

WAZIUP fully takes the "Arduino" philosophy for low-cost, simple-to-program yet efficient hardware platforms that is ideally well-suited for developing countries. It is also worth mentioning that these Arduino boards can be purchased quite easily world-wide. Our first experiences when transferring technical competencies in developing countries show that the issue of hardware availability should not be underestimated. The Arduino ecosystem is large and proposes various board models, from large and powerful prototyping boards to smaller and less energy-consuming boards for final integration purposes as illustrated in Fig. 8. The small form factor Arduino Pro Mini board that is available in the 3.3 V & 8 MHz version for much lower power consumption, can definitely be used

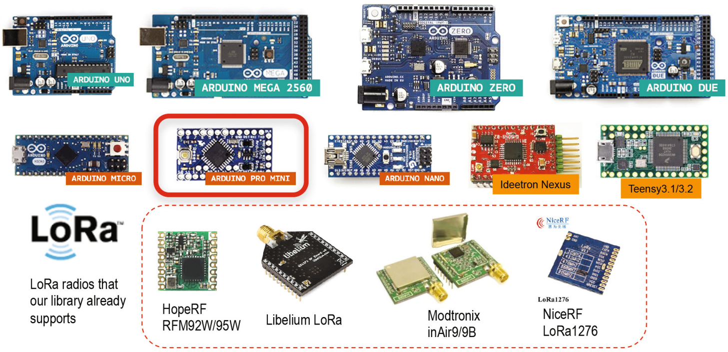

Fig. 8. Arduino low-cost ecosystem

to provide a generic IoT platform. The Pro Mini board if available for less than 2 euro from Chinese manufacturers.

WAZIUP develops and integrated building blocks for quick and easy new behaviour customization and physical sensor integration as shown in 9. Software building blocks provide security, transmission, activity & physical sensor management templates. Integration of new physical sensor can be realized without modifying the core template. Figure 9(right) also shows how the generic platform can be used to build a low-cost IoT device.

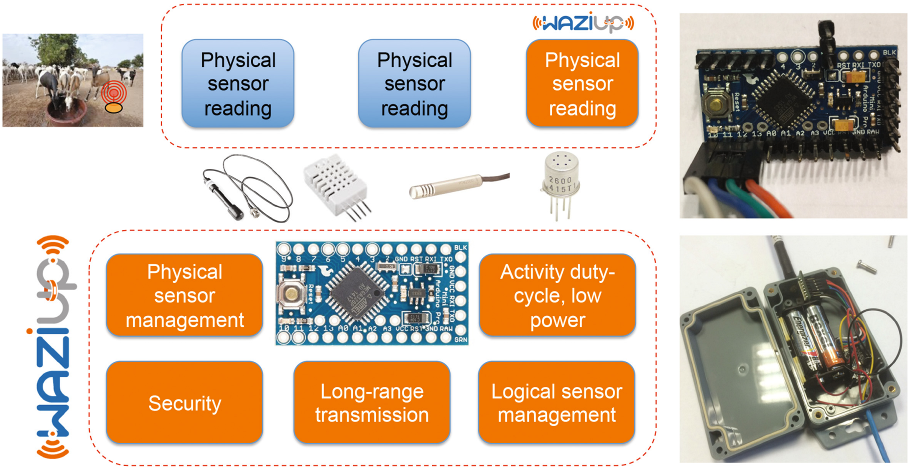

Fig. 9. Generic low-cost IoT platform and software building blocks

When deploying operational IoT application with low-power requirements, a deep-sleep mode is proposed in the example template. It is capable of running an Arduino Pro Mini for more than a year (assuming 1 measure/h) with

4 AA regular batteries without any additional hardware components. The energy consumption in this deep sleep mode is about 120 µA. Depending on the physical sensor that is needed, the activity time can be between 2 s to 8 s per hour, with an average consumption of about 50 mA. Our tests conducted continuously for the last 15 months demonstrates that Pro Mini clones are very reliable.

4 Conclusions

We presented the WAZIUP's IoT platform that addressed several important issues when deploying IoT solutions in the context of low-income developing countries. Focusing on providing low-cost, open and easy to customize IoT solutions, the WAZIUP IoT platform can provide quick and efficient answers for rural African application. The WAZIUP IoT platform framework is currently deployed in real cities, villages and farms test-beds. WAZIUP also supports a sustainable approach where the definitive target is to enable fast appropriation and new-market customized solutions. To do so, WAZIUP tightly involves end-users communities in the technical development and dissemination loop with frequent training and hackathon sessions organized in the sub-Saharan Africa region.

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