TLTN – The local things network: on the design of a LoRaWAN gateway with autonomous servers for disconnected communities

1st Pape Abdoulaye Barro
dept. of Information and Communications Technology
IMSP
Porto-Novo, Benin
pape.barro@imsp-uac.org

2nd Marco Zennaro
T/ICT4D Laboratory
ICTP
Trieste, Italy
mzennaro@ictp.it

3rd Ermanno Pietrosemoli
T/ICT4D Laboratory
ICTP
Trieste, Italy
epietros@ictp.it

***Abstract*—IoT devices should be easy to deploy and able to endure long periods of activity in the field without further intervention. LoRaWAN is geared to attain these objectives. European developers can easily leverage the public gateways of The Things Networks (TTN) already installed to obtain connectivity for LoRaWAN end-devices. In many developing countries Internet access cannot be taken for granted thus precluding the use of TTN. In this paper, we present a solution that allows connecting local IoT end-nodes to a LoRaWAN gateway without the need of internet access, at low cost and with low power consumption. We implement the three building blocks of the LoRaWAN architecture (Gateway, Network Server and Application Server) in a single box based on a Raspberry Pi and a LoRaWAN module. Local access to the application data is offered via a WiFi Access Point, allowing community members to access their community data even when there is no Internet access. In addition to real time IoT data, bulletin board like services can be implemented in the local repository to provide educational, health and other content that addresses the most pressing needs of isolated communities. The complete box with mentioned capabilities constitutes then the Base Station (BS).**

***Index Terms*—LoRaWAN, Edge computing, Gateway, Community Networks, Wireless network, IoT for development**

I. INTRODUCTION

While IoT devices are popular in industrialized countries, their deployment in developing countries faces additional hurdles, like the prohibitive cost of Internet access or its unavailability. Connecting in a stable way to a cloud service such as the one offered by The Things Network (TTN) [2] is not feasible in rural areas of many developing countries. Nearly 9 out of 10 young individuals not using the Internet live in Africa, Asia or the Pacific according to the latest ITU statistics [5]. Furthermore, Charith [6], says that ”in reality sensing all possible data items captured by a smart object and then sending the complete captured data to the cloud is less useful. Further, such an approach would also lead to resource wastage (e.g. network, storage, etc.)”. He also stated that ”The Fog (Edge) computing paradigm has been proposed to address this weakness by pushing to the edges processes of knowledge discovery using data analytics. However, edge devices have limited computational capabilities.”.

In the global south, the applications that are more useful are the ones that provide information about the environment: water and air quality monitoring, landslide detection, water levels in rivers, meteorological data and so on. In many countries there is little information about the environment, creating a knowledge divide that adds to the digital divide. These data can nevertheless be available if a local infrastructure to generate and share the relevant information is in place. Many IoT applications, especially in rural developing countries, need to span considerable range while consuming as little power as possible. LoRa modulation can achieve these goals by spreading the transmission spectrum (typically 125 kHz) but limiting the data rate to a few kilobits per second at most. The relationship between these two variables is called the spreading factor (SF) and it can be varied to suit different needs. A low SF allows higher throughput while a high SF allows decoding signals even below the receiver’s noise floor, thus permitting ranges of dozens of kilometres in unencumbered environments and a few kilometres even in urban areas. LoRaWAN is an open media access control (MAC) layer protocol for wide area networks that provides all the functionalities for a complete solution, based on multiple end-nodes that communicate to one or more LoRaWAN Gateways. Gateways, in turn, connect to a Network Server (NS) using any kind of IP protocol based links. The NS connects to the Application Servers (APs) also using the IP protocol as shown in Fig. 1. Gateways are transparent bridges relaying messages between end-devices and one or more network servers. The payload is encrypted by the end-node using the 128-bit Advanced Encryption Standard (AES), so each application is isolated from the others. Traffic is bidirectional, but mostly up, from the end-node to the Gateways with very little in the downlink direction. A significant advantage of LoRaWAN is the fact that it uses unlicensed bands and open protocols so it can be implemented by any organization independently of any commercial service providers.

Smartphones and tablets are often owned even by people who live outside the coverage of cellular service, and even people who are inside the coverage area sometimes cannot afford the extra cost of data services charged by some operators. So we propose a sort of *”Intranet of Things”* in which data are locally generated and locally consumed even in the absence of internet connectivity, or when internet connectivity is either intermittent or painfully slow. Environmental data collected in the region by low cost and low power end-devices will be transmitted to one or more ”Base Stations” using LoRaWAN [1] and made accessible through a WiFi access point or ”Hot Spot” included in the Base Station (BS). Users can then obtain real-time environmental and other pertinent data by means of their standard devices, as well as access stored static content regarding health, education, legislation, environment protection and any sort of content deemed of interest, including folklore and traditional knowledge shared by the community members. Optionally, if there is Internet connectivity at the Base Stations, Selected time-sensitive content can also be accessed by the whole community at a lower cost since a single Base Station can provide services to many users, thus performing also the ”proxy” service. So, the Base Station will act as a LoRaWAN Gateway, a LoRaWAN Network Server, a LoRaWAN Applications Server, a local data and content repository, a Bulletin Board and a WiFi Access Point that can be accessed by any WiFi client device. Since the Base Station cannot be sleeping at any time, its power consumption is considerably greater than that of the end-nodes, but it is nevertheless modest and easily accommodated by means of a photovoltaic panel and battery. Despite its many functions, it is also cheap since it is based on a Raspberry Pi with a LoRaWAN hat and Open Source software. Optionally, it can be connected to the Internet by means of an appropriate router, in which case the connection costs are shared among the several users of the Base Station.

This document is divided into 5 sections: Section II presents the related work and Section III proposes requirements and architecture of the proposed solution. Section IV presents the performance tests and at the end, Section V concludes and defines the next step.

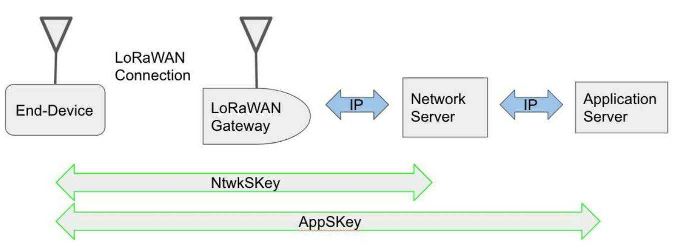

Fig. 1. LoRaWAN Secure Architecture

II. RELATED WORK

The original scope was to offer citizens of developing countries an opportunity to learn about the quality of the air around them as well as to allow their governments to take appropriate preventive measures to ensure a healthy and sustainable environment. Inspecting existing relevant publications [7] [8] [9] [10] [11] [12] [13] revealed that all take for granted internet connectivity. In developing countries, Internet costs are a huge burden for people who are struggling to make ends meet [3]. The challenge is thus to make the Internet of Things accessible to the underprivileged [4] by leveraging the LoRaWAN protocol. An open-source LoRaWAN Gateway described in [15], collects the LoRa packets from the end-nodes and transports them to the network server over IP by making use of the MQTT protocol.

We propose a Multi-option and multi-services edge gateway for communities with three variants: a standard box always connected to the Internet, a box connected intermittently over a delay tolerant network or a standalone box catering to the essential needs of isolated networks. In all three cases the data and also additional content are made accessible to the community members over a WiFi AP accessed by means of their smartphones or tablets

III. PROPOSED SOLUTION

A. *design requirements*

Our solution is based on the following design requirements:

1) low cost: As computing platform we selected the Raspberry Pi single board linux device which is inexpensive and widely available worldwide. The LoRa capabilities are provided by two hardware additions: An eight channel module from ISMT that costs 200 euro or a single channel module from Uputronics that is only 26 euro. The WiFi radio is built-in, and the Ethernet port can be used for Internet access or for connection to a local network.
2) low power: The Gateway must be always on to receive messages from any end-node, so it must be power frugal. The end-nodes will be sleeping most of the time, so their battery will last very long, the exact duartion depending on the consumption of the attached sensors and the frequency of transmission.
3) expandable storage: Swapping the SD card for a higher capacity one allows the storage of extra data and content.
4) open source: Only open source software is used, so other researchers/organizations can replicate and expand it. All relevant scripts can be found on GitHub [17].
5) Unlicensed bands: Radio communications is done on ISM bands, freely usable worldwide.

B. *Architecture*

The architecture of the Base Station is divided in four parts, as shown in Fig. 2: LoRaWAN Gateway (GW), Network and Application servers, TIG, and WiFi Access Point and content server.

LoRaWAN is used to collect data from the end nodes (shown on the right of Fig. 3) and WiFi to communicate final users to the web server through the Access Point (shown on the left of Fig. 4). The TIG component uses MQTT.

1) LoRaWAN gateway

   The LoRaWAN gateway acts as packet forwarder between the end nodes and the Network server, based on

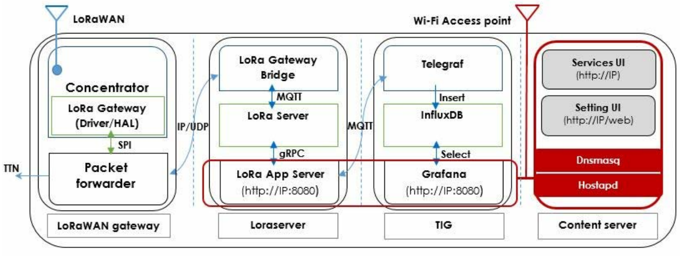

Fig. 2. Four main parts of the Base Station.

the open implementation proposed by Semtech, and built with a Raspberry Pi and additional hats. For the-eight channel version, the concentrator hat is based on the Semtech SX1301 chip which allows the simultaneously listening in eight different frequencies or spreading factors. The single channel gateway uses a cheaper hat based on the RFM96W RF module.

2) Network and Application server
The role of the network server is to authenticate nodes to make sure that only data from registered nodes will be forwarded. It is also responsible for the deduplication and processing of uplink frames, MAC layer processing and downlink transmission planning. The application server provides payload processing and decryption. It offers to the end user the requested data, like weather, air quality index, alarms and so on. Data are locally processed, stored, and made available through the WiFi Access Point.

3) TIG
The Telegraf tool is used to subscribe to the MQTT Mosquitto broker, to collect the messages (in JSON format) transmitted by the LoRa App Server and to inject it into the InfluxDB times series database. Thanks to Grafana (The open platform for beautiful analytics and monitoring), measurements can be retrieved on influx DB for analysis and monitoring.

4) Content Server
The Content Server provides access to both static content like educational material, health information, farming best practices, etc., as well as Community Bulletin Board services. The WiFi Access Point makes this material available to the community through a web interface.

The output of the eight channels concentrator is sent to the Packet forwarder (PF) via a Serial Peripheral Interface (SPI). The PF transfers it to the LoRa Gateway Bridge by IP/UDP (see Fig. 2 and 4). We wrote the edge-gateway.service that starts a start.sh script that installs and executes the dependencies specified in the Mainfile and then launches the packet forwarder if all executions are successful. It also allows to upgrade the firmware as needed. For the single channel GW, everything is included in the packet forwarder, including the HAL library.

Tools such as hostapd (WiFi Captive Portal) and dnsmasq (DHCP and DNS server) allow access to the graphical interface of the LoRa App Server (http://IP:8080), grafana (http://IP:3000) to register a node, add parameters or see the evolution of the measurements. Community content and Bulletin Board services are accessed through (http://IP).

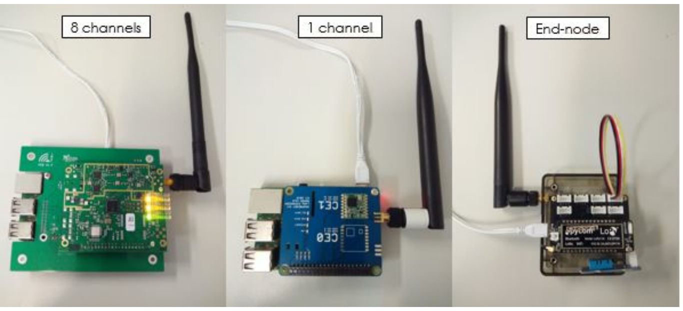

Fig. 3. BS with eight channels gateway (left), BS with single channel GW (middle) and end-node (right)

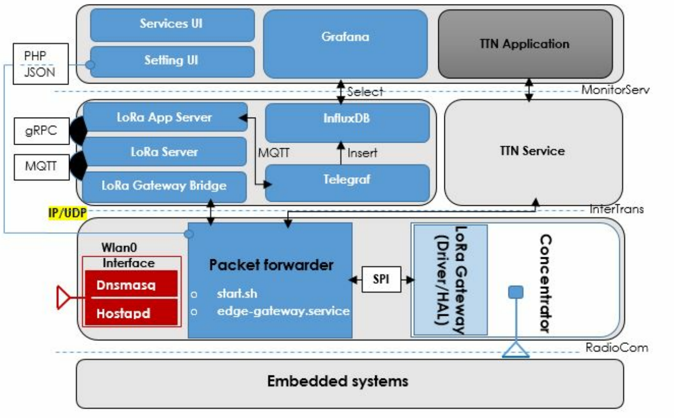

Fig. 4. Edge gateway architecture.

References [16] and [17] give more details as well as the proof of concept. The Raspberry Pi has a built in WiFi interface that has been configured as a WiFi Access Point and its SD card is the local storage for data and content. The mentioned hats provide the LoRa functionalities for the complete Base Station.

IV. PERFORMANCE TESTS

For the tests, we used a LoPy LoRaWAN transceiver fitted with a DTH11 temperature and humidity sensor as the end-node and a Raspberry Py embedded computer as the Base Station (BS), communicating on the 868 MHz unlicensed band with a bandwidth of 125 kHz. We measured power consumption and CPU load of the BS at a constant 5.0 voltage. The 8 channels BS had a peak power consumption of 5.2 W, and an average of 4.5 W, while the single channel one had the same peak of 5.2 W but an average of 1.8 W. This amount of power can be provided by an inexpensive photovoltaic panel connected to a battery for continuous operation. A 324 Wh or 64.8 Ah battery will allow 3 days of operation of the 8 channels gateway without recharging, while for the single channel gateway a 129.6 Wh battery will suffice.

Fig. 5 shows CPU usage by different processes like CPU.user, CPU.system (indicating the amount of time used by the kernel, which is responsible for low-level tasks, such as hardware interaction, memory allocation, communication between operating system, running device drivers and managing the file system), CPU.nice, CPU.idle (which shows the unused CPU time), CPU.iowait (which marks the wait time for input or output operations), the CPU.softirq (which indicates the time that the processor spends processing interrupts).

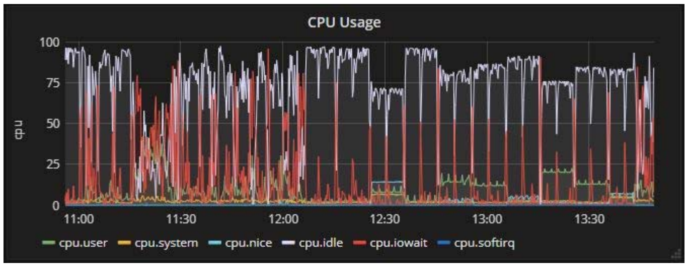

Fig. 5. cpu usage by different processes.

V. CONCLUSIONS AND FUTURE WORK

This work is aimed at extending the benefits of IoT to people that live in areas with limited or no Internet connectivity, by collapsing the LoRaWAN servers normally spread in the cloud into a single box that provides all the required functionalities. It can use TTN wherever it is available, even on an intermittent basis, or be a complete stand-alone system serving a community. Users interact with the proposed BS by means of their own devices using WiFi connectivity.

The end devices are very cheap and battery powered, while the modest power required by the always on BS can be supplied by an affordable photovoltaic system. For small communities, the single channel gateway is very inexpensive and power miser, while the eight channels offer more capabilities with a modest increase in power and consumption. The storage used for the prototype is a 16 GB SD card that can be expanded to add content of interest to the community. The inexpensive and widely available Raspberry Py is the core of the BS and proved adequate for the required communication tasks. Two types of BSs where tested, a very inexpensive single channel device, that can handle moderate traffic, and a more expensive eight channels one that can be deployed when the amount of traffic grows.

Future work will focus on the Bulletin Board and content management systems that are very useful features for isolated communities, as well as on an extension of this model to accommodate the database synchronization of several Base Stations deployed in the same community, interconnected among themselves but independent from an Internet connection.

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