Towards Increasing the LoRa Network Coverage: A Flying Gateway

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***Abstract*—The Internet of Things (IoT) technology has been emerging since the last two decades. It is difficult to ignore its presence as it is almost related to every aspects of our daily life, starting from smart phones to wearable medical devices and smart vehicles. A plethora of communication solutions have been developed to meet the two main features of IoT: low power consumption and long range transmissions. Unmanned Aerial Vehicles (UAVs) also are witnessing an increasing interest in a lot of different scenarios and with different roles, including the integration with IoT. Extending the coverage of IoT to rural and remote areas by using UAVs and satellite communications is envisioned as an improvement of the IoT technology towards the upcoming 5G network. This paper presents an approach integrating the aforementioned technologies to develop a flying LoRa gateway, whose aim is to extend the coverage of LoRa networks on-demand in the required locations and for the required time.**

***Index Terms*—IoT, LoRa, LoRaWAN, UAV, satellite**

I. Introduction

TODAY, the world is facing many challenges on the level of population growth, energy concerns, and increasing demands for a better quality environment. These challenges can be partially addressed through the usage of Internet of Things (IoT) technologies which can improve the way of living. Approximately 76 billion devices will be installed and connected to the Internet by 2025 [1]. This increase is due to the low cost of used sensors and the great innovation in communication technologies. Nowadays communication technologies for IoT can be grouped in categories such as short range and long range technologies. The short range ones, such as Bluetooth, WiFi, and ZigBee, are mostly used in indoor environments, while the long range ones, such as LoRa and SigFox, are mainly used in outdoor applications, e.g. surveillance, monitoring, and tracking. Low power wide area (LPWA) networks are witnessing a great attention in both academia and industry as a foreground solution to fulfill the different requirements of IoT applications. This technology is placed between short range multi-hop technologies and broadband cellular systems [2]. IoT applications are characterized by low power consumption, low data rate, and low cost, making LPWA the best solution that suits such applications. Various applications have been deployed by using LPWA into different environments, such as agriculture, healthcare, metering systems, and transportation [3]. These application require a wide area communication between low power devices. Figure 1 shows some potential use cases which can benefit from LPWA technologies.

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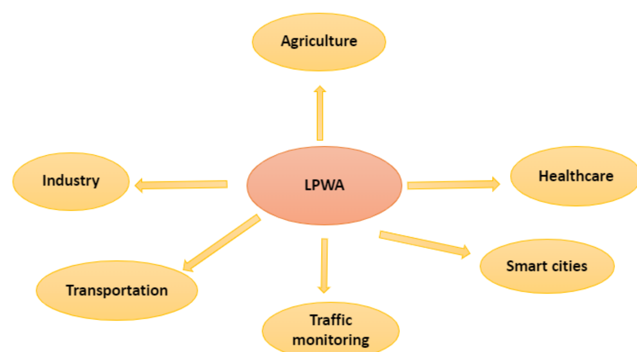


Fig. 1: Example of the different use cases that can benefit from LPWA technologies

This paper is organized as follows: Section II gives a brief description about the different IoT technologies along with a detailed description about LoRaWAN, while Section III introduces the state-of-the-art of IoT & UAVs, and of IoT & satellites integration. Our proposed approach is described in detail in Section V. Conclusions are drawn in Section VIII along with the envisioned future works.

II. IoT Communication Technologies

Figure 2 represents the IoT stack. It is composed of three layers: perception layer, network layer, and application layer. The first layer corresponds to the hardware devices deployed for a specific application such as a temperature sensor, a camera, etc. These devices are responsible for collecting useful data from the surrounding environment and transforming them into digital signals. The second layer represents the network layer which is responsible for transmitting the data from perception to application layer by wired or wireless communication. It is also the layer where data processing takes place. The third one is the application layer, whose aim is to link the users to the applications, constituting the front end of the IoT architecture [4]-[5].

Most IoT protocols have been designed for the communications between IoT devices and IoT gateways, each of them with its own characteristics and suitable for a specific application. These communication protocols are divided into two categories: Short range and Long range as said in the introduction.

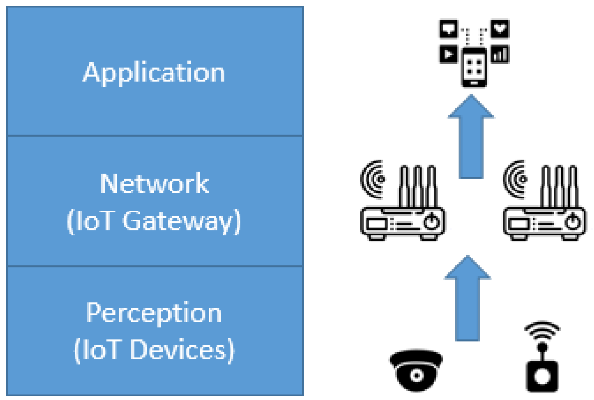


Fig. 2: IoT technology stack

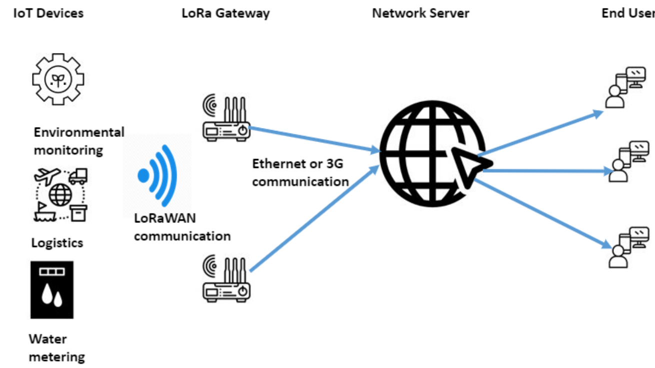


Fig. 3: LoRa network architecture

A. Short Range

Bluetooth, ZigBee, and WiFi are technologies that establish short range communications between sensors and gateways. Table I summarizes the main features of these technologies.

TABLE I: Short range protocols' features

Name	Bluetooth	ZigBee	WiFi
Modulation	GFSK/DQPSK/DPSK	BPSK/OQPSK	various schemes
MAC	FDMA/TDMA	CSMA/CA	CSMA/CA
Data rate	3 Mbps	250 kbps	7 Gbps
Coverage	up to 30m	up to 100m	up to 100m

B. Long Range

LoRaWAN, SigFox, Ingenu and NB-IoT are examples of LPWA protocols used in IoT field. A brief description is given in table II below, stating the main features of each technology. Figure 3 shows the network architecture of LoRa. LoRaWAN is considered to be the wireless radio frequency communication technology most used in the IoT field.

TABLE II: Long range protocols' features

Name	LoRaWAN	SigFox	Ingenu	NB-IoT
Modulation	Chirp Spread Spectrum (CSS)	D-BPSK(UL) GFSK(DL)	RPMA-DSSS(UL) CDMA(DL)	QPSK, 16QAM 64QAM
MAC	unslotted MAC	unslotted ALOHA	CDMA-like	SC-FDMA(UL) OFDMA(DL)
Data rate	0.3 kbps-50 kbps	100 bps(UL) 600 bps(DL)	78 kbps(UL) 19 kbps(DL)	20 kbps (UL) 200 kbps (DL)
Coverage	up to 5 Km (urban) 15 Km (rural)	10 Km(urban) 50 Km(rural)	up to 15 Km (urban)	up to 35 Km

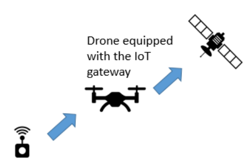
III. Related Work

A first environment to be considered is Smart Agriculture as in Figure 1. Traditional farming systems are transforming to what is known now as *"Smart Farming Systems"* by using sensing, networking technologies and Internet connections. Monitoring and controlling crop parameters would help in improving the quality and quantity of food. This can be achieved by the integration of UAVs in the IoT field. An example is given in [6] where heterogeneous IoT devices are distributed in a crop field to sense environmental parameters. On the other hand a UAV provided with a light weight energy efficient localization antenna is used to collect the data and guide the IoT devices so to form a cluster and choose the cluster head. In [7], a smart agricultural monitoring system using LoRa technology and drone is introduced. The aim of [7] is to allow the LoRa gateway to fly over the fields by using a drone and gather the data from the ground sensors, thus helping farmers to get the needed information over a large farm field, possibly remote and hard to reach locations. The used system is composed of temperature, humidity and light sensors located in a farm, and a LoRa gateway attached to a drone. Data are collected from the sensors by using LoRaWAN and transmitted through the flying gateway to a database server. Two different tests were conducted at the parking building and the tree farm respectively. In the first experiment the communication speed between the gateway and the sensor nodes isn't affected if the position of the gateway changes vertically up to 15 m, but this speed decreases while moving horizontally. The second test is carried on in the tree farm, where the drone flies over the ground sensors nodes verifying the one-to-many connection between the gateway and nodes. Smart city and crowd surveillance is another important application environment. A face recognition sensor crowd surveillance application [8] exploits a platform composed of UAVs and IoT devices. UAVs equipped with video cameras are connected to the ground station by using an LTE cellular network. When a security guard notices a suspicious behavior, he commands the UAV to take a video of the involved people and applies face recognition to verify if someone has some criminal records. An evacuation support system based on IoT and UAVs is proposed in [9]: the system consists of IoT devices and is controlled by an intelligent agent (agent-based IoT). It autonomously determines a suitable plan to support a quick evacuation guidance. More UAV and IoT use cases such as military, earthquakes and disaster management are explained in [10].

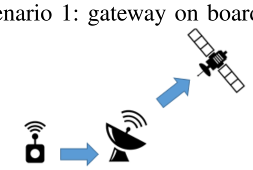
The focus on the usage of satellite communication for Internet of Things (IoT) is increasing [11] [12], such as in environmental monitoring, emergency management, and smart grids. The integration of Low Earth Orbit (LEO) satellites in some IoT applications is becoming a new trend. Instead of using Geostationary Earth Orbit (GEO) satellites, LEOs are used as they provide low propagation delay, global coverage and low loss. LEO satellites are used as a powerful supplement in the IoT field because the traditional terrestrial IoT networks may be not sufficient to cover some hard and remote areas. To solve the problems associated with remote sensing such as the increasing system cost and the information analysis complexity, a LEO constellation-based IoT system may be the solution. It allows the direct access to the information monitored by different types of sensors, ensures more frequent data gathering than the case of a single sensing satellite and enhances the accuracy of predictions. An example is a water monitoring system where the satellite is used to replace the traditional terrestrial network in unreachable locations such as wetlands and oceans [13].

IV. Possible Scenarios

The use of UAVs (or drones) and satellite communication becomes of paramount importance if sensors are deployed and distributed over a wide area which is hard to reach and monitor as in the use cases presented in [10]. The use of satellite communication depends on the available communication means for example if a mobile network is available or not. UAVs help extend the coverage of the IoT networks when they are equipped with gateways on board. Figure 4 shows two possible scenarios. In 4a UAV is considered as an intermediate node bridging the connection between the IoT nodes and satellite allowing data transmission and communication in and out of the service areas. There is no need of UAVs in the scenario of 4b because in the area a satellite base station can be installed.



(a) Scenario 1: gateway on board of UAV.



(b) Scenario 2: gateway implemented in the satellite base station.

Fig. 4: Possible Scenarios

V. Approach

Extending the coverage of LoRa networks to reach uncovered areas is the main objective of our study. Figure 5 shows our proposed approach. IoT devices are installed in harsh areas hard to reach and out of IoT gateway/base station coverage. In practice the reference is 4a even if the satellite connection may be used only in case of need. Figure 5 shows the alternatives. A flying gateway on-board of a drone is considered. This gateway is able to fly over such areas, collect data generated by the IoT sensors, and transmits them by using wireless communication to the IoT server on the Internet to be processed and stored. Satellite communication can be useful when other wireless technologies, such as cellular networks, are not available, thus allowing real-time data exchange and guaranteeing a connection between the edge and the core of the network.
From the implementation view point, the testbed we planned to build consists of a drone equipped with a RAK2245 Pi-Hat based on Raspberry Pi gateway providing LoRa connectivity, which will fly over IoT sensors based on Arduino boards. Using mobile connectivity, the drone will be able to send the collected data to the LoRa cloud platform called The Things Network (TTN). In case there is no mobile connectivity coverage, a satellite communication link will be emulated by using proper tools (e.g. OpenSAND) in order to allow the drone to transmit data to the server.

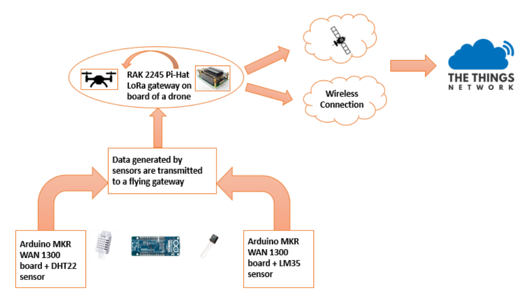


Fig. 5: Proposed approach architecture.

Figure 6 shows the overall design of the connectivity model between IoT devices and drone as well as the connectivity model between drone and satellite. The same setup can be integrated in the 5G terrestrial network where the drone acts as 5G User Equipment (UE) and the satellite is a Relay Node (RN) presented with a terrestrial 5G-gNB [10].

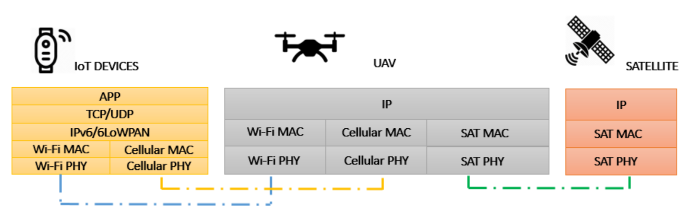


Fig. 6: Protocol stack for the proposed approach.

VI. Implementation Details

Each IoT node is based on an Arduino MKR WAN 1300. This Arduino board offers LoRa connectivity and is ideal for low power applications. It offers practical and cost effective solution for LoRa based IoT applications. DHT22 and LM35 temperature and humidity sensors , are used for sensing and generating data only. They are connected to separate Arduino boards and registered on the TTN. After connecting these sensors to the IoT server, they are configured through the Arduino IDE. A 868 MHz antenna is used to transmit data from the sensor to the gateway. The gateway is based on Rak2245 Pi-Hat board equipped with Raspberry Pi. This board represents the smallest LoRaWAN gateway concentrator.Such board is powered by Semtech SX1301 which is capable of packet management from remotely dispersed end points. The RAK2245 board is configured and registered on the TTN as an IoT gateway. After the registration process, the gateway is able to forward the received data from the IoT nodes to the IoT server (TTN).

VII. Preliminary Results

The system composed of the sensors and the gateway was tested first using WiFi connection. The gateway was configured in our lab's network. The graph in Figure 7 shows the RSSI (Received Signal Strength Indicator) values which correspond to the strength of the received signal and indicates how well the gateway can receive the signal from the IoT node. The small values of RSSI measured are because the packets were transmitted by IoT nodes near the gateway. As clear in the graph in Figure 8, the positive values of the SNR (Signal to Noise Ratio) show that both the gateway and the IoT node are placed near to each other or more precisely in the same room as it was tested through WiFi.

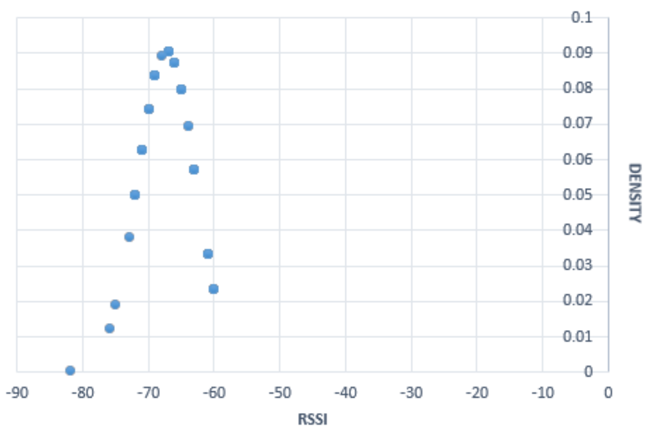


Fig. 7: Probability density function of the of RSSI values for the received packets by the gateway.

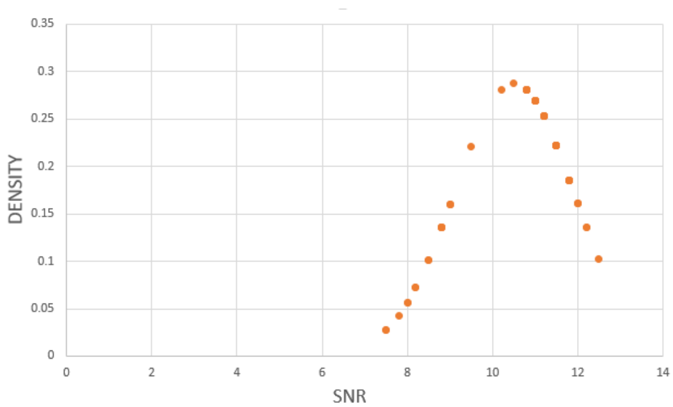


Fig. 8: Probability density function of the SNR values for the received packets by the gateway.

VIII. Conclusions and Future Work

This paper presents a new approach integrating UAVs and IoT based on the deployment of IoT gateways on-board UAVs. The main aim is to propose a solution able to extend the current coverage of commercial IoT solutions network to rural and remote areas. LoRaWAN is the protocol considered in this work. UAVs are able to achieve the planned coverage extension acting as deployable on-demand intermediate nodes between the IoT sensors and network core. Mobile and satellite communications can help UAVs achieve this goal when they are flying in or out areas covered by the mobile network, respectively. Our future work will focus on the full development and testing of the proposed system by using RAK2245 Pi-Hat and Raspberry Pi boards for the IoT LoRaWAN gateway and Arduino-based IoT LoRaWAN sensors. A Long Term Evolution (LTE) module for Raspberry Pi will be employed to test the system by using mobile connectivity while a satellite link will be emulated through proper available tools such as OpenSAND and employing this gateway on-board of a drone.

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