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OPEN EXTENSIVE IOT RESEARCH AND MEASUREMENT INFRASTRUCTURE FOR REMOTE COLLECTION AND AUTOMATIC ANALYSIS OF ENVIRONMENTAL DATA

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Abstract: Internet of Things devices that send small amounts of data do not need high bit rates as it is the range that is more crucial for them. The use of popular, unlicensed 2.4 GHz and 5 GHz bands is fairly legally enforced (transmission power above power limits cannot be increased). In addition, waves of this length are very difficult to propagate under field conditions (*e.g.* in urban areas). The market response to these needs are the LPWAN (Low Power WAN) type networks, whose main features are far-reaching wireless coverage and low power measurement end-nodes that can be battery powered for months. One of the promising LPWAN technologies is the LoRaWAN, which uses a publicly available 868 MHz band (in Europe) and has a range of up to 20 km. This article presents how the LoRaWAN network works and describes the installation of the research and measurement infrastructure in this technology which was built in the Gdańsk area using the Academic Computer Center TASK network infrastructure. The methodology and results of the qualitative and performance studies of the constructed network with the use of unmanned aircraft equipped with measuring devices for remote collection of environmental data are also presented.

The LoRaWAN TASK has been designed to support the development of other research projects as an access infrastructure for a variety of devices. Registered users can attach their own devices that send specific metrics that are then collected in a cloud-based database, analyzed and visualized.

Keywords: Internet of Things, LoRaWAN, data gathering, data visualization, unmanned air vehicles, LPWAN Network, Long Range Data Transmission

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1. Introduction

Living in the information society, we attach more importance to all kinds of information. We want to know more and more about the world around us.

Tens years ago, the only source of information we were given was a preselected and processed content delivered by mass media or scientific publications, available in bookshops or libraries. In recent times, with the development of the Internet, access to data and information has been considerably facilitated. We need only a computer (or recently a smartphone) to instantly get information in which we are interested. For some time, with the development and significant decline of prices of various electronic components, more and more academic and scientific centers, companies and finally hobbyists, have begun to develop various proprietary projects that monitor various aspects of everyday life. In our living space smart meters (gas, electricity or water, which transmit information such as their condition or for charging fees), intelligent heating control and lighting systems are becoming increasingly popular in the building industry. This phenomenon has been defined and named by Kevin Ashton as 'Internet of Things' (IoT).

The IoT concept assumes communication with all sorts of real world objects. These may be devices, vehicles, structures, or objects of the natural environment, which have not previously transmitted information about their condition. By enabling remote monitoring, we have tools to analyze processes and influence their effectiveness and rationality. The Internet of Things is used in many different fields, such as environmental protection, farming and breeding, medicine, intelligent cities, logistics, industry, etc. One example may be monitoring of the performance parameters of an enterprise's technical infrastructure. In particular, environmental sensors (*e.g.* temperature, humidity, gas and dust concentrations), vibration sensors, acceleration, electromagnetic fields, and more can be used to monitor their correct, safe and efficient operation.

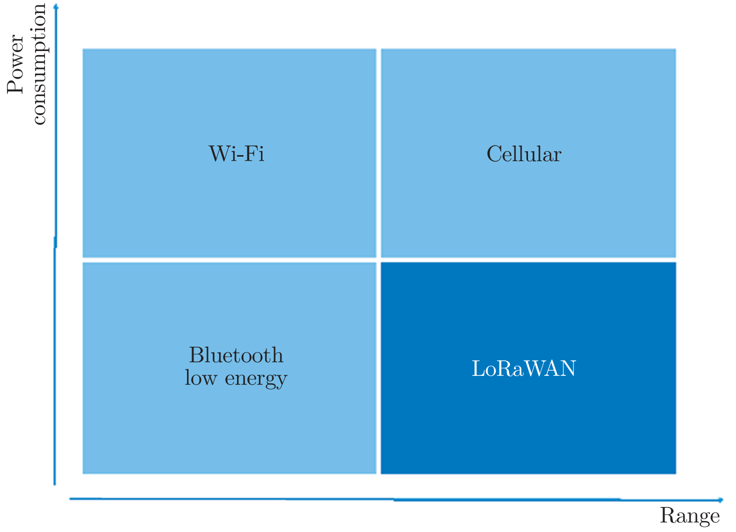

Figure 1. Various data transmission techniques and their range and power consumption [1]

Nowadays, a major problem faced by developers of Internet of Things is the problem of wireless connectivity over long distances and low power consumption at the same time. The existing transmission techniques (*e.g.* the popular IEEE 802.11b/g/n/ac commonly known as WiFi), due to their high throughput (up to 1 Gbps), are ideal for mobile computing and devices (like smartphones). However, there are also some restrictions, the most significant of these are relatively high power consumption and an extremely limited range, rarely exceeding 100 m. One common solution that would be far less energy intensive is the IEEE 802.15.1 standard (commonly called Bluetooth). In its latest version, this standard enables data transmission at very low power consumption. This solution can be used in IoT devices, but only for a very limited range (not more than a dozen meters).

2. Various data transmission techniques vs. IoT concept

The LoRaWAN (Long Range WAN) technology is an instance of the broader category of LPWAN networking the main purpose of which is to provide connectivity for Internet of Things devices. The estimated number of this kind of devices can reach even millions in the coming years. LoRaWAN is designed from the ground up to optimize the battery life, network capacity, range and low cost of endpoint devices. LoRa's physical layer is based on a combination of several modulation methods. The chirp spread spectrum technique is used with Forward Error Correction (FEC) integrated error correction [2]. This method has significantly improved sensitivity of receivers (up to 19 dB below the noise level and a power budget of 155 dB), immunity to noise and frequency shifting have been enhanced due to the inaccuracy of the cheap crystals used. LoRa has a specialized multi-mode transceiver that can simultaneously receive transmissions on different frequency channels and even decode multiple signals broadcast on a single channel. The theoretical coverage is up to 20 km in the open area, up to 3 km in the urban area. Compared to other popular wireless technologies (WiFi, cellular networks, Bluetooth Low Energy), the LoRa technology can be positioned as far-reaching and having low power requirements, which is predestined for IoT and M2M (Machine-to-Machine) telemetry applications, when no high data throughput is required. As far as the background of other parallel LPWAN technologies is considered, LoRa is attractive, although it is currently difficult to predict which solution will dominate the market in a longer run. The LoRaWAN standard is dynamically developing and promoted by the LoRa Alliance open nonprofit organization [3].

LoRaWAN is a second layer protocol (MAC) based on the LoRa physical layer. The LoRaWAN network topology is characterized as a "star of stars" where individual endpoints are not assigned to a particular gateway, and if they are within multiple gateways, they all receive a data packet and forward it to the network server.

This server is responsible for dropping duplicate packets, transferring data to the application server, selecting the gateway for feedback communication, adaptive bandwidth control. Dual-level AES-128 data encryption is provided, one

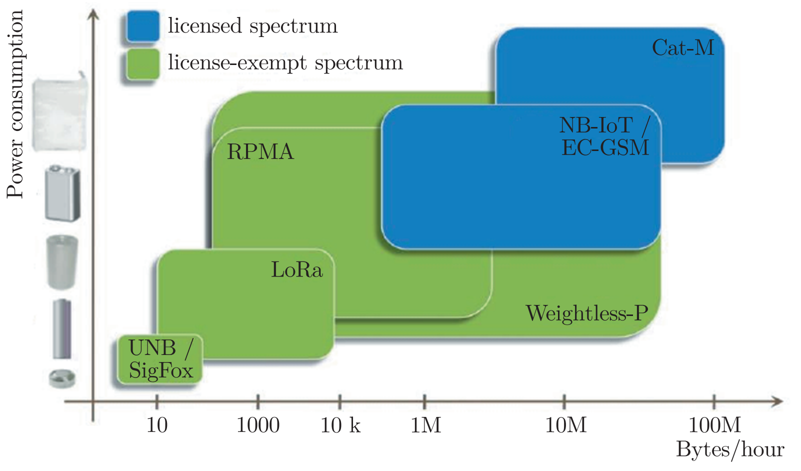

Figure 2. Various data transmission techniques and their throughput and power consumption [1]

at the wireless transmission layer level, and another at the application layer level. Before the communication starts, the terminal must activate on the network using its individual keys [4].

There are three classes of terminal equipment (A, B, C), depending on how the return transmission is performed. For class A equipment this requires the most energy-efficient operation on the battery, it is possible to send a feedback message only after the message initiated by the device. The ADR (Adaptive Data Rate) mechanism is also implemented to dynamically adapt the data bandwidth to different receivers to maximize the battery life and maximize the capacity of the entire available transmission medium. The exact protocol specification varies in detail depending on the region. In Europe, the unlicensed 868 MHz frequency band is used and there are 10 transmission channels with a throughput of 250 bps – 50 kbps. ACC TASK has launched its own LoRaWAN network, covering the Gdańsk University of Technology campus and selected other locations within the TASK network range. It has been designed to support the development of other research projects as an access infrastructure for various devices. Registered users can attach their own devices that send specific metrics that are then collected in a cloud-based database, analyzed and visualized.

3. Performance and quality assurance of LoRaWAN network

The LoRaWAN network consists of several gateways (Figure 3). The IoT network (in our research it is a yacht and an airplane, but it is possible to use broadcasting equipment in any type of 'things' of everyday use) that send data datagrams over a LoRaWAN network. This datagram can be received by one or more gateways. These devices send data to the Network Server (NS) after receiving data correctly. The whole logic of forwarding the processed package any further

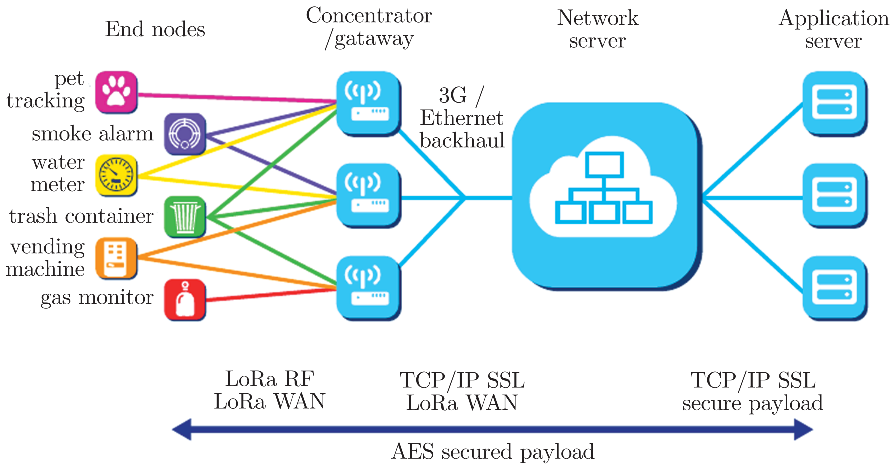

Figure 3. Schema of LoRaWAN network infrastructure

lies on its side. NS is responsible for validating the transmitted data and removing repetitions where the same data is received from different gateways and it sends data to an Application Server (AS), which allows end users to retrieve and process the collected data. For our research, an author application has been created that presents the collected data on a map, allowing it to be easily interpreted by humans (Figure 6). By qualitative research, it was realized that it was crucial to investigate the operation of devices under different wave propagation conditions, and to examine how the distance from each node influences the quality and stability of transmission. To this end, it was decided to conduct a study using two laboratories. The first was the Marine Internet Laboratory TASK yacht and the second an unmanned aerial vehicle –multiTASK airplane.

3.1. Marine Internet Laboratory – TASK

MILA is a Marine Internet Laboratory for the study of different transmission techniques in marine conditions. For tests, the laboratory has an external water temperature sensor that is installed approximately 0.5 m below the waterline. The measuring device is based on Sodaq One (Arduino compatible). The system is powered by a lithium polymer battery with a capacity of 350 mAh and a rated voltage of 3.3 V. In addition, the system is equipped with a solar cell to extend the battery life. During our research, the working time of the prototype measuring device was about 5 hours.

3.2. Unmanned Air Vehicle – multiTASK airplane

In the era of ubiquitous multirotor drones, the choice of an aircraft platform may seem unusual but it has been dictated by other requirements in which the aircraft performs much better. The biggest advantage of the aircraft in comparison with multirotor drones is its operational capacity. The airplane is able to carry a relatively large load at a distance of about tens of kilometers even in relatively difficult atmospheric conditions. In addition, the economic speed of the aircraft is higher than a multirotor drone. As a platform for the construction of an unmanned aerial vehicle, we used a model aircraft kit designed for amateur FPV (First Person View) aircraft. The model is designed for high capacity, with a push propeller system to eliminate the "Rolling shutter" [5] effect of digital cameras, which results in drawing excess horizontal lines in places of fast moving objects, such as an aircraft propeller or a helicopter rotor. This effect is unpleasant to the eye and makes it difficult to interpret the image automatically. The airplane is controlled by a multi-function control radio operating in the 2.4 GHz band, with a theoretical range of up to 4 kilometers. The video transmission is performed in an analogical way, using a 5.8 GHz band, (marked as "3" in Figure 4) with theoretical coverage of two kilometers, allowing real-time viewing of images from one of the three cameras mounted on a plane. The camera is selected by the pilot-operator from the ground using the control radio. One basic camera is stationary, in the front of the aircraft and serves piloting and orientation in the field (marked as "1" in Figure 4). The other two cameras (including one thermovision camera) are located in a rotary head mounted under the fuselage and allow observation in any direction relative to the flight of the aircraft (marked as "2" in Figure 5). Table 1 shows the basic technical characteristics of the platform used.

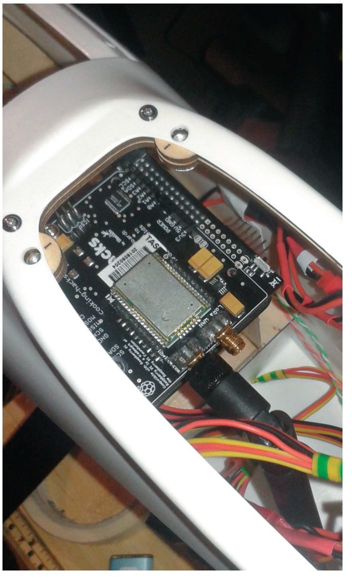

Figure 4. RaspberryPi Zero computer with LoRaWAN module

A RaspberryPi Zero miniature computer with a clock speed of 1 GHz and 512 MB of memory was installed on the airplane (Figure 5). The LoRaWAN transmission module was connected to the on-board computer. The aircraft was equipped with pressure and temperature sensors, a gyroscope, a magnetometer, an atmospheric speedometer, current sensors and a GPS receiver. Its software analyzes all the parameters read from the sensors by monitoring the flight parameters.

Figure 5. Unmanned Air Vechicle called multiTASK

In addition, data at specific time intervals, including their corresponding GPS coordinates, are transmitted through LoRaWAN to the ground where it is possible to view and analyze them further. The airplane is also equipped to install additional sensors that could measure other environmental parameters, such as air quality, humidity and transparency. The architecture of the operating system also provides the possibility of imaging the thermal imaging camera, for example, by searching for specific objects in its field of view.

Table 1. Technical parameters of multiTASK airplane

Motor	Electric 3-phase motor with power of 625 W
Battery	Lithium-polymer battery 14.7 V, 5 Ah (main) Lithium-polymer battery 11.1 V, 850 mAh (emergency)
Voltage on-board	5 V
Wingspan	1980 mm
Fuselage length	1170 mm
Maximum takeoff weight	3700 g
Flight time	2 h
Cruise speed	~50 kph
Maximum speed in horizontal flight	~100 kph

4. Research results and conclusions

Our research conducted in the MILA laboratory was mainly aimed at exploring how well LoRaWAN could work in maritime conditions and what the maximum possible range of network operations would be. For the experiment purposes, one gateway with an antenna was installed at the marina in Górki Zachodnie. Measurement campaigns were carried out on a part of the Gdansk

Figure 6. Water temperature measured in the Gdańsk Bay

Bay (towards the Vistula River estuary in Mikoszewo) (Figure 6) and on the Vistula River itself, towards the Pontoon Bridge to the Sobieszewo Island.

Values of water temperature measured in the area of interest shown in Figure 6, ranged from 21.81°C in the marina basin (point 1) to about 20.14°C in the Vistula estuary (point 2) down to 19.06°C (point 3) where communication with the gateway was eventually lost. At the same measurement points, the signal strength (RSSI) was −74 dBm (point 1), −103 dBm (point 2) and −113 dBm (point 3). The furthest recorded point was about 6.5 km from the gateway. A clearly designated range of 20 km could not have been reached. However, it should be noted that, for technical reasons, it was not possible to install a roof antenna or a high mast on a building in the marina. In fact, our makeshift antenna was installed on the first floor of the building, there was interference from the masts of the yachts in the harbor, the surrounding trees, other obstacles and probably the building itself. During the experiments, an external antenna with a gain of −6 dBi was connected to the gateway. No studies with higher gain antennas were attempted because of their size (over 3 m long) which would require an additional lightning protection system to be designed separately.

Our research during the next experiment included unmanned aircraft to test how LoRaWAN would behave at higher speeds and with more data to send. In the previous experiment, the device was sending only one value, which along with the geographic coordinates implied three values only. In the second experiment as many as 28 values plus geographical coordinates were sent. Since the LoRaWAN network does not allow the transmission of such a large datagram, the data was divided into four variable packets for one-time sending. When experimenting with the aircraft, a temporary installation was deployed on the ground with the same antenna as in previous studies with the yacht. The airplane remotely controlled from the ground, flew many times along a rectangular route. In each subsequent flight, both the side of the rectangle and the height of the flight were gradually increased. This allowed us to take measurements and attempt data transfer at various flight parameters. The biggest recorded distance was about 1 km, which in practice is a physical limit for the pilot to control the plane from the ground without loosing it from sight. The highest recorded altitude achieved during the tests was about 150 m above the ground level. The next step was to check that a higher flight speed did not cause any interruption to the network. The plane was speeded up in a flat dive and after a while reached a speed of about 58 knots (110 km/h). During the experiments, there was no sign of any loss of signal (the minimum recorded RSSI value was −97 dBm).

5. Further works

One access point is currently running which provides coverage of the Gdansk University of Technology campus. In the near future, it is planned to install another access point in another location in the Tri-City area in order to achieve greater coverage of the access network. With the advent of winter and the seasonally recurring smog issue, we plan to launch an air quality test station that will send live data through the TASK LoRaWAN network. We also plan to conduct air quality research on the outskirts of the Tri-City using our flying platform. During further development of the network, it is expected to carry out network performance tests with more devices sending data.

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