Setting up an IoT lecture for Centrale Lille:

A LoRa(WAN)™-based labwork, from data transmission to data visualization

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ABSTRACT: As part of the education reform of the École Centrale de Lille, a new lecture for the "*Internet of Things*" has been created. Entitled "*Mobile networks, IoT and UHS (Ultra High Speed) communications*" and taught in English it takes place in the "*Advanced communication networks*" teaching unit (UE) for the third year students of the École Centrale de Lille engineering curriculum as well as for master students enrolled in Centrale Lille. In this lecture, students acquire knowledge about cellular networks, new LPWAN (Low Power Wide Area Network) technologies such as LoRa™ or Sigfox™ and UHS communications. The labwork focuses on the LoRa(WAN) protocol, where students create their first and complete IoT application, from data transmission to data visualization using popular applications/software. The labwork is based on a "*problem analysis/problem resolution*" (PAPR) approach where students first need to analyze what they observe and finally need to propose solutions to avoid encountered problems based on knowledge acquired during the lecture.

Key words: Internet of Things, LoRa™ modulation, Arduino, Dragino, RTL-SDR, The Things Network (TTN), Cayenne my Devices.

1 INTRODUCTION

First coined by Kevin Asthon (co-founder of the Auto-ID research center in the MIT) in 1999, the expression "*Internet of Things*" (IoT) has nowadays become a topic of interest. Vast theme gathering together several wireless technologies (Fig. 1) such as Bluetooth, ZigBee, RFID, etc. chosen according to the targeted application, we present here a new module which is part of the reform of the third year of the École Centrale de Lille curriculum. This lecture focuses on LPWAN (Low Power Wide Area Network) networks recently introduced in the IoT domain. Specifically, LPWAN technologies such as LoRa™ and Sigfox™ introduced around 2010 are presented.

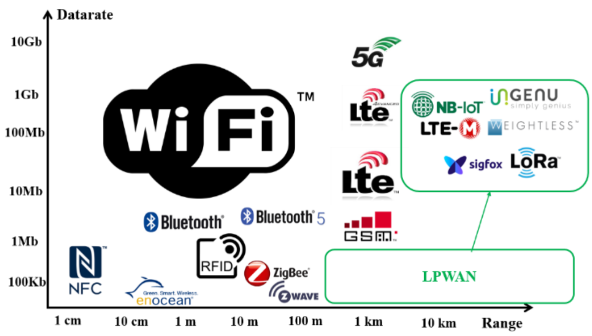


Fig 1: Simplified wireless technologies jungle

2 CENTRALE LILLE PRESENTATION

2.1 The school

Centrale Lille is an EPSCP (Établissement public à caractère scientifique, culturel et professionnel) whose main activity consists in the training of engineers taught in four internal schools:

- École Centrale de Lille for multidisciplinary engineers,
- École Nationale Supérieure de Chimie de Lille (ENSCL) for chemical engineers,
- IG2I (Institut de génie informatique et industriel) for engineers in Computer and Industrial Engineering,
- ITEEM (Institut technologique européen d'entrepreneuriat et de management) in partnership with SKEMA Business School, for entrepreneurial manager engineers.

Centrale Lille graduates around 400 engineers each year and is a member of the groupe des Écoles Centrales that includes Centrale-Supélec, École Centrale de Lyon, École Centrale de Nantes, École Centrale de Marseille as well as the International Écoles Centrales: Centrale Pékin and Centrale Casablanca. In addition to engineering degrees, the establishment delivers national master's degrees, including four international masters as well as Ph.D. diplomas through two doctoral schools.

2.2 The students

Different groups of students can follow the IoT lecture including:

- Third year (G3) students from École Centrale de Lille
- Students on mobility within the Groupe des Écoles Centrales (GEC)
- Second year of Master's degree students, enrolled at Centrale Lille registered in the "*Master Networks and Telecommunications*"

For the first year (19/20), 13 students were registered in the IoT lecture including 6 from the multidisciplinary

Article publié par EDP Sciences et disponible sur le site https://www.j3ea.org ou https://doi.org/10.1051/j3ea/20222024

branch and 7 from the Master's degree in Networks and Telecommunications.

2.2.1 Multidisciplinary branch

The third year of training at the École Centrale de Lille (G3) allows in particular to choose and go in depth into a disciplinary thematic. The IoT lecture is included into one of them entitled "*Smart systems and smart environments*", where the objective of this thematic is to train engineers capable of mastering the entire global system approach dedicated to the deployment of intelligent environments, with combined hardware and software skills that have become essentials in these areas starting from the design stage. Always keeping this system and combined Hard-Soft approach deployed in the common core of the thematic, students have the possibility to go in depth whether with aspects related to the physical world and technological aspects (Intelligent Systems and Advanced Communication Networks), or to aspects related to the virtual world (Networks of the Future and Ambient Intelligence).

2.2.2 Master's degree branch

The Master's degree Networks and Telecommunications co-accredited with the University of Lille trains versatile engineers in the telecommunication sectors including 3G, 4G and 5G networks, communicating objects, the Internet of Things, RFID and the technologies used in these applications (micro-technologies, Nanotechnologies). This qualifying training also uses an active pedagogy based on projects, internships and seminars.

3 LECTURE PRESENTATION

The lectures take place in the teaching unit entitled: "*Advanced communication networks*" for a total of 30 hours. Among these 30 hours, 8 are intended for the labwork and the rest for the courses/exercises. The latter are divided into three main points that are:

1) Cellular networks
2) LPWAN for the IoT networks
3) UHS (Ultra High Speed) communications

In the first part, the fourth generations (1G to 4G) of cellular networks are presented focusing on the physical layer aspect and an introduction to the 5G future technology is given. The second part describes mainly what are the LPWAN networks and presents two French and well-known protocols that are LoRa™ [1] and Sigfox™ [2]. Finally, the last part concerns the UHS communications including fiber and THz communications.
For these lectures, we made the choice to evaluate the students based on labwork as well as group presentation. Indeed, since many applications and technologies may be related to the "*Internet of Things*", we asked the students to work by group of 3 to 4 on a specific technology and related use case and to make a PPT presentation (about 20 min, followed by 10-15min of questions). The goal is to raise students' awareness of the importance as an engineer, to be keep updated on technological changes.
The following malleable guide was given to the students to facilitate their works:

- ➢ Summary (1 slide)
- ➢ Introduction about the technology (2~3 slides)
- ➢ Emphasize on the physical layer (6~7 slides) as well as the energy consumption part (1~3 slides)
- ➢ Pros (regarding other technologies/rivals 1~2 slides)
- ➢ Cons (regarding other technologies/rivals 1~2 slides)
- ➢ Use cases (at least one concrete IoT example analyzed! ~5 slides) Why the studied technology is suitable for this specific use case (in terms of bandwidth needed, range, etc.)
- ➢ Conclusion (1 slide)
- ➢ Used references (1 slide)

For this first year, Bluetooth (BLE), Z-Wave, LTE-M and NB-IoT were selected as topics. Student feedbacks are available in Section 5.
At the end of the lecture, students should have acquired the following objectives:

- ➢ Understand differences between wireless technology families
- ➢ Assimilate basics knowledge of actual and future cellular networks as well as new LPWAN technologies for the IoT
- ➢ Be able to identify a wireless technology for a specific use-case
- ➢ Be able to set up a simple yet complete IoT application

The message we also want to deliver is that there is actually no wireless technology that fits all IoT use cases, a wireless technology should be chosen according the technical specifications of the intended applications.

4 LABWORK PRESENTATION

4.1 LPWAN and LoRa(WAN) Introduction

Before discussing the labwork procedure, we give some necessary theoretical elements about LPWAN technologies as well as LoRa™ and LoRaWAN® protocols to facilitate the understanding of this paper.
LPWAN as the acronym indicates are new kinds of networks recently introduced for the IoT that are characterized by the following key elements:

- Low power ⇔ long battery life ⇔ minimum human intervention
- Low cost
- Long range 2⇔15-30km
- Small device
- Easy to deploy
- Small data rate

- High density nodes

They are optimized for connected objects with limited resources for which several years of battery life are required. These networks are particularly suitable for applications that do not require high speed communications.
Among, all the existing LPWAN technologies, we choose to focus on the LoRa™ technology for the labwork. The main reason is that it is easy to use and allows to quickly set up a simple IoT applications. Furthermore, unlike Sigfox™ it does not require any subscription, therefore it is appreciated from the electronic hobbyist community.
LoRa™ represents one of the first LPWA Networks with Sigfox™, both technologies are (or were) developed by French start-up. LoRa keyword refers to the physical radio layer enabling the Long-Range (LoRa) communication link. It uses the ISM (Industrial, Scientific and Medical) band (868MHz) and is based on Chirp Spread Spectrum technology (CSS) where a chirp or a sweep is a signal in which the frequency continuously increases (up-chirp) or decreases (down-chirp) with time as seen in Fig. 2 from [3]. The frequency center is actually chosen to be around 868MHz for the Europe. The BW acronym represents the bandwidth used for transmission, a higher bandwidth means a higher available data rate. All these skills are transferred to the students by using and working on the LoRa™ chip (SX1272) datasheet [4] during lectures. Among all the important parameters that can be adjusted with LoRa, the SF (Spreading Factor) allows to control the available data rate and the maximum range that can be obtained for transmission. The higher the SF, the longer the Symbol time (T_{symb}) and the range (up to 15km), however the lower the available data rate. We insist on the trade-off between range and available data rate for LoRa™ during lecture as well as labwork.

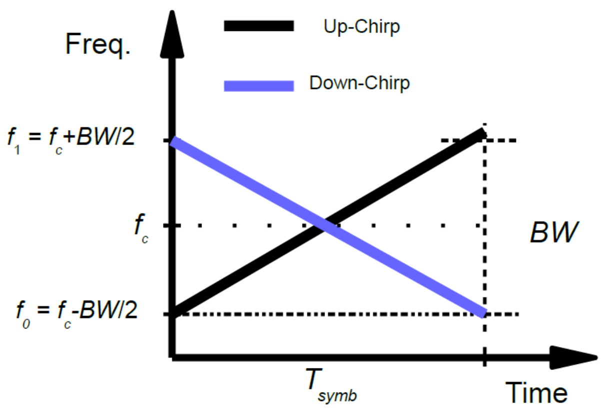


Fig 2: Spectrogram of the up chirp and down chirp from [3]

LoRa transmitted frames obey a typical form that can be seen in Fig. 3 where, at the beginning up chirps are used and represent the preamble of the frame. This preamble is followed by two down chirps that indicates the beginning of the payload. Finally, data information or payload are transmitted by cyclically shifting up chirps.

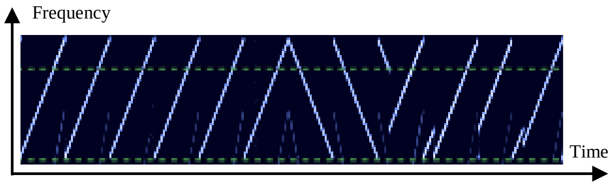


Fig 3: Example of observed LoRa transmitted frame during the labwork

Finally, LoRaWAN® defines the open communication protocol that allows LoRa nodes to communicate with the Internet. To do so, the nodes communicate through a gateway that listen over all the frequencies, all the SF (6 to 12) and all the available bandwidth (currently 3: 125KHz, 250KHz and 500KHz).

4.2 Hardware components used

The first elements that are used in this project include the Dragino LoRa™ IoT Development Kit (868 MHz) available in Elektor store (for 125€). As seen in Fig. 4, the kit is composed of different sensors, a gateway to connect to the internet as well as two Arduino Uno board and two LoRa™ shield transceivers. One of them contains a GPS module that can be used to add a moving dimension on the intended application.

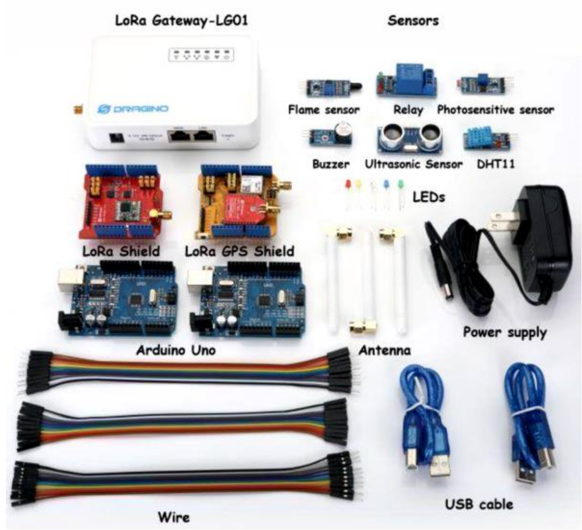


Fig 4: LoRa IoT development kit from Dragino [5]

The second element used for this labwork is a RTL-SDR dongle as seen in Fig. 5. It is a very cheap USB dongle (around 10-20€) that was originally used for TNT reception (DVB-T TV tuner). Antti Palosaari, Eric Fry and Osmocom revealed in 2012 that they can be converted into a real broadband radio receiver via the SDR (Software Defined Radio) mode. It is basically a computer based radio scanner (or sniffer) for receiving live radio signals. Based on the ability to listen over a large frequency band, community has developed several applications such as NOAA (National Oceanic and Atmospheric) weather satellite images download, music (FM band) decoding, AM decoding, etc. For this labwork, we use the RTL-SDR to observe transmitted LoRa frames as seen during the lecture and as shown in Fig. 3.

Fig 5: RTL-SDR USB dongle

4.3 Software/Apps used

The labwork relies on several available software/apps that include:

- Arduino IDE, to easily deploy IoT applications
- SDR Console, to visualize LoRa frame with RTL-SDR dongle
- The Things Network [6], to manage data sent over the LoRaWAN® protocol
- Cayenne myDevices [7], to visualize transmitted data over LoRaWAN®

We selected these applications/software as they are open source and free to use, giving the opportunities to students to use them at home or for future projects.

4.4 Labwork introduction

The labwork is divided into five parts and aims at studying/understanding the basic principles of LoRa™ and LoRaWAN®. Precisely, students learn how to:

- Setup a communication between two LoRa nodes
- Use RTL-SDR dongle to analyze LoRa™ physical layer
- Setup a gateway and use the "*The Things Network*" to collect information
- Use a simple application/dashboard to visualize transmitted information

The synoptic of the labwork is available in Fig. 6.

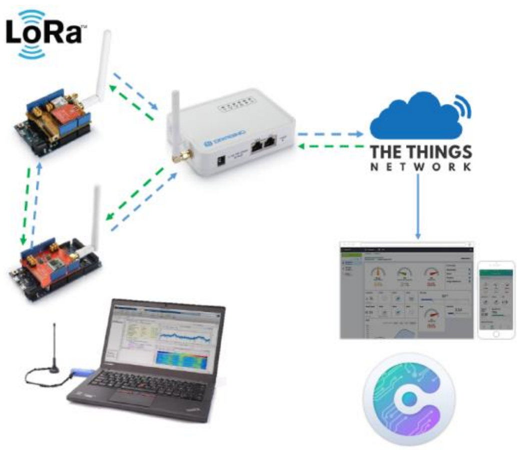
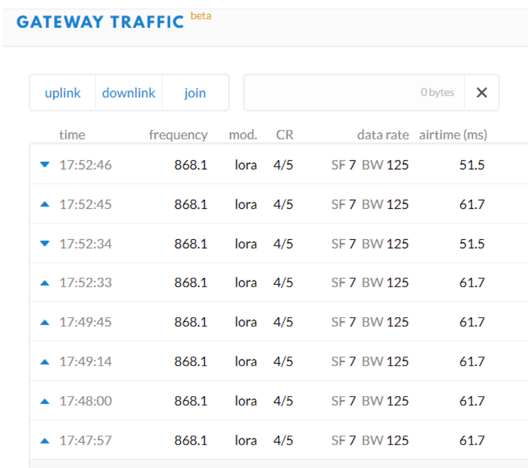


Fig 6: Synoptic of the labwork

First, the students, grouped by 3, set up communication between nodes and then use an RTL-SDR dongle to observe and retrieve LoRa transmitted frame. In this first approach, transmission frequency (868.1MHz) as well as SF and available bandwidth are given (SF=7, BW=125KHz). We ask the students to choose one secret sentence for their emitter and transmitter. Since all the students use the same frequency and SF, they will face the problem of receiving the secret messages from all the groups. Based on the PAPR approach, we ask them to explain the problem, analyze it and propose solution to avoid it. In the same way, during LoRa frames observation with RTL-SDR dongle, students will face the problem of short communication time as well as multiple signal visualization due to: first, the selected bandwidth and SF and second, the other groups that are also transmitting. Therefore, they need to first understand where is their signal, why it is not as expected (as in Fig. 3) and how to change parameters to be able to correctly visualize the LoRa frames.
Then, based on theoretical knowledge from lectures, we ask them to set up a protocol to evaluate the maximum range between two nodes using LoRa. We expect from the students, that they keep in mind the environment for measurement (indoor/outdoor, line of sight, etc.) as well as trying and showing differences between the use of different spreading factor (SF).
Once the node-to-node communication has been understood, students learn how to setup a gateway connected to the "*The Things Network*" which is an open source community LoRaWAN® network for the Internet of Things. It is based on the fact that "*you are the network*" meaning that once the gateway is set up it can be used by anybody. Unfortunately for this labwork, the given Dragino gateways from the LoRa IoT kit can only listen to one frequency and one SF at a time. By setting up the gateways and looking at the received LoRa packet on TTN as seen in Fig. 7, we expect that students may be able to identify this problem. The solution consists in buying or building a gateway that can listen to all frequencies and all SF at the same time. The latter solution may be considered as part of the labwork for next years.


GATEWAY TRAFFIC beta

uplink downlink join 0 bytes

time	frequency	mod.	CR	data rate	airtime (ms)
▼ 17:52:46	868.1	lora	4/5	SF 7 BW 125	51.5
▲ 17:52:45	868.1	lora	4/5	SF 7 BW 125	61.7
▼ 17:52:34	868.1	lora	4/5	SF 7 BW 125	51.5
▲ 17:52:33	868.1	lora	4/5	SF 7 BW 125	61.7
▲ 17:49:45	868.1	lora	4/5	SF 7 BW 125	61.7
▲ 17:49:14	868.1	lora	4/5	SF 7 BW 125	61.7
▲ 17:48:00	868.1	lora	4/5	SF 7 BW 125	61.7
▲ 17:47:57	868.1	lora	4/5	SF 7 BW 125	61.7

Fig 7: Received LoRa packets over LoRaWAN® on TTN

Finally, students use Cayenne myDevices which is an online website/smartphone application that allows to visualize in real time information such as measurement from the LoRa node (temperature, humidity, luminosity, etc.) or location of a LoRa node. This simple procedure only requires a few setups such as changing the payload format on TTN to be understood by Cayenne. Example of visualized information can be seen in Fig. 8.

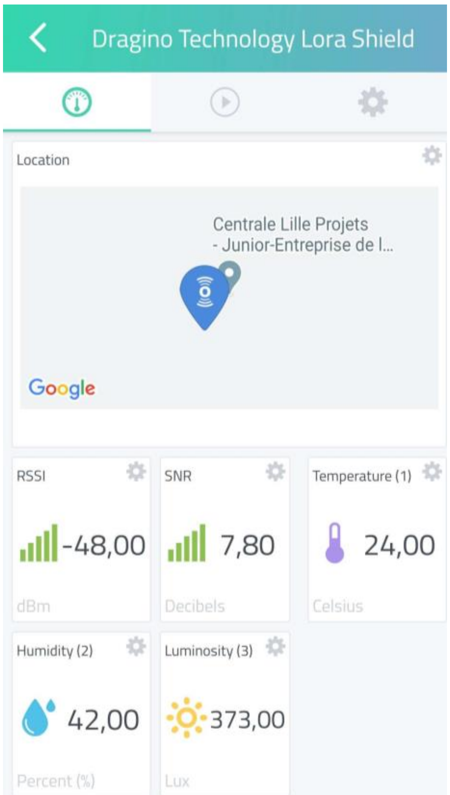


Fig 8: Data visualization over Cayenne myDevices

5 STUDENT FEEDBACKS

To assess the relevance of this new lecture, we asked the students to answer a quick questionnaire at the end of the module (Appendix). First of all, we asked the students if the objectives were clearly presented at the beginning of the lecture and if they were achieved at the end, what they appreciated, what should be improved, comments on the lecture/evaluation/labwork and their general impression about the lecture. All the students answered the survey and average results are presented in the Appendix.

Results showed that objectives were clearly defined and achieved. Students really enjoyed the labwork and the PAPR approach with a well-balanced amount of theoretical and practical knowledge as well as the evaluation format (presentation of a wireless technologies in group). They also asked for more labwork for this module as they were not able to completely finish it for some groups. They also liked to have a global vision of the different wireless technologies at the end of this lecture.

6 CONCLUSION

We presented in this paper a new IoT lecture for Centrale Lille for the third year students of the École Centrale de Lille curriculum as well as for the Master's degree students in Centrale Lille. This lecture allows them to acquire and understand basics knowledge on advanced communication networks such as cellular, LPWAN technologies for the IoT and UHS communications. Results showed that the PAPR approach coupled with a very practical labwork were really appreciated by the students.

Overall, students seemed to be really satisfied by this lecture. A quick feedback questionnaire was given during the last labwork that underlined the importance of well-balanced practical and theoretical knowledge.

Finally, as it is the first year of this lecture, we give further improvements that may be considered for next years:

1) Try to pair the IoT module with the RF one (e.g., with the design of specific antennas for LoRa), a maximum range contest between student could be considered
2) Go deeper into the LoRa™ physical layer by using open source version of LoRa [8] on GNU Radio-based USRP
3) Transform or add labworks' hours to use a project based approach by letting the students thinking about an IoT use-case, selecting the wireless technology that fits their use-case and by letting them designing their own proof of concept
4) Add more concepts around energy consumption since this is a key aspect in the "*Smart systems and smart environments thematic*".

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APPENDIX

Feedback questionnaire
Mobile Networks, IoT and UHS

Date:

The objectives of the lectures were ___________ announced

Perfectly**: 10/13**	Partially**: 3/13**	Not really**: 0/13**	Not at all**: 0/13**

I _________ understood the objectives of the lectures

Perfectly**: 9/13**	Partially**: 4/13**	Not really**: 0/13**	Not at all**: 0/13**

Evaluations were ___________ in line with teaching objectives

Perfectly**: 9/13**	Partially**: 3/13**	Not really**: 1/13**	Not at all**: 0/13**

I appreciated (examples):

The oral presentation (autonomous work)
The way the labwork was done
The good balance between practice and theory

What should be improved (examples):

More hours for the labworks
Maybe less theory, focus on one protocol?
Add new technology such as NB-IoT

Comments:

Thank you for this lecture
It was interesting especially the link between the labwork and the lectures

I've learned (scale out of 10: 0=nothing, 10=a lot)

							■		

I think that this lecture will be __________

Very useful**: 7/13**	Useful**: 6/13**	Useless**: 0/13**	Totally useless**: 0/13**

General impression

Excellent**: 6/13**	Good**: 6/13**	Fair**: 1/13**	Terrible**: 0/13**

Estimated spent time for independent or personal work

20h