Master's degree in "ICT for Internet and Multimedia"

Internet of Things and Smart Cities

IoT and LoRa for eHealth

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Life & Health

Abstract

This paper has been made for the "Internet of things and smart cities" course at the University of Padova.
Given the importance eHealth has assumed in the recent years, in this paper I present how IoT can be used in the healthcare field in particular using LoRa.

Introduction

Without any doubts, IoT is heavily present in every aspect of our life, from the microwave to the cars: everything is connected in many different ways.
This short paper is focused on how IoT has been used for health application and human life parameter monitoring, how we are currently dealing with the huge amount of data the sensors generates and it is deepen the LoRa usage aspect for such applications.
The paper is so structured: in the first section there is an introduction to IoT, eHealth, LoRa and even if this aspect won't be developed further, Fog computing because of the crucial role it covers in other common application. The second section is dedicated to an overview of LoRa in IoT for healthcare and three representative cases of application. The last section is dedicated to the final thoughts and conclusion.

1 eHealth, IoT & LoRa

A very briefly introduction to IoT and eHealth in § 1.1, Fog computing in § 1.2, LoRa and LoRaWAN in § 1.3.

1.1 IoT for Healthcare

The *Internet of Things* (IoT) and *eHealth* are two of the three main concept revolving around this paper. There isn't an universally accepted definition of IoT, and entering in this topic with more depth would require a paper on its own. So, for simplicity we report the IEEE-IOT definition more suited for this paper:

"An IoT is a network that connects uniquely identifiable "Things" to the Internet. The "Things" have sensing/actuation and potential programmability capabilities. Through the exploitation of unique identification and sensing, information about the "Thing" can be collected and the state of the "Thing" can be changed from anywhere, any time, by anything." [1]

For this report, the "Things" are sensors monitoring a particular human parameter such as a EEG, ECG, blood pressure, oxygenation, temperature or any other aspect involving the healthcare world like a GPS tracking a patient position. Also, the main assumption we are taking are:

- most of the sensors are not connected to an electrical grid, they require charging;

- the sensors communicate with each other too, and even this communication should be reliable and efficient;
- IoT should use IP.

These sensors are tools that can help improve prevention, diagnoses and treatment for a pathology in a patient, but also just monitoring him/her. So this, and a ICT-based solution brought to life *eHealth*, defined back in 1999 by Eysenbach as

> *e-health is an emerging field in the intersection of medical informatics, public health and business, referring to health services and information delivered or enhanced through the Internet and related technologies. In a broader sense, the term characterizes not only a technical development, but also a state-of-mind, a way of thinking, an attitude, and a commitment for networked, global thinking, to improve health care locally, regionally, and worldwide by using information and communication technology.* [2]

Currently the main field of application for IoT in healthcare are diagnostic, treatment support and remote monitoring; the market size for this devices, related software and services is expected to grow of 300 billions US dollars by 2020 [3]. The graph in figure 2.2 shows more in details the subdivision.

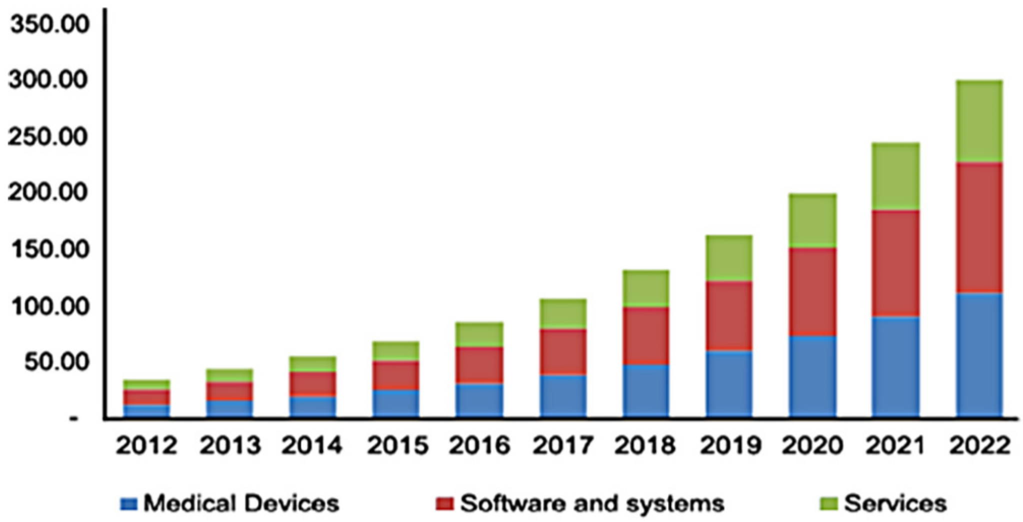

Figure 1: *North America IoT in Healthcare Market Growth in USA billions of dollars. Grand View Research [3]*

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1.2 Fog computing

In the second section more details about IoT for eHealth issues are enumerated, but since the importance of how we should deal with a huge amount of recorded data

it's a very discussed problem, here is reported a short paragraph about a possible solution.
According to Cisco, billions of IoT devices are generating more than 2 exabytes of data each day and

> *"Today's cloud models are not designed for the volume, variety, and velocity of data that the IoT generates"* [4].

Although the cloud computing paradigm brings the possibility to create low-cost solutions for eHealth monitoring, its delay could also lead to a failure in the health system [5].
For this reason, the **Fog layer** has been introduced between the Device and the Cloud layer (fig 1.2), and it's composed of *fog nodes* which have the task to collect data at extreme edges and analyse/act on the data in less than a second.
The fog nodes can be any device with network connectivity able to compute and storage data; these devices can be [4]:

- closest to IoT devices: the response time is in milliseconds, the data is not stored, only a restricted area is covered, like a city block;
- fog aggregation nodes: provide a simple analysis of the received data, which is stored for hours or some days. Their area coverage is wider.

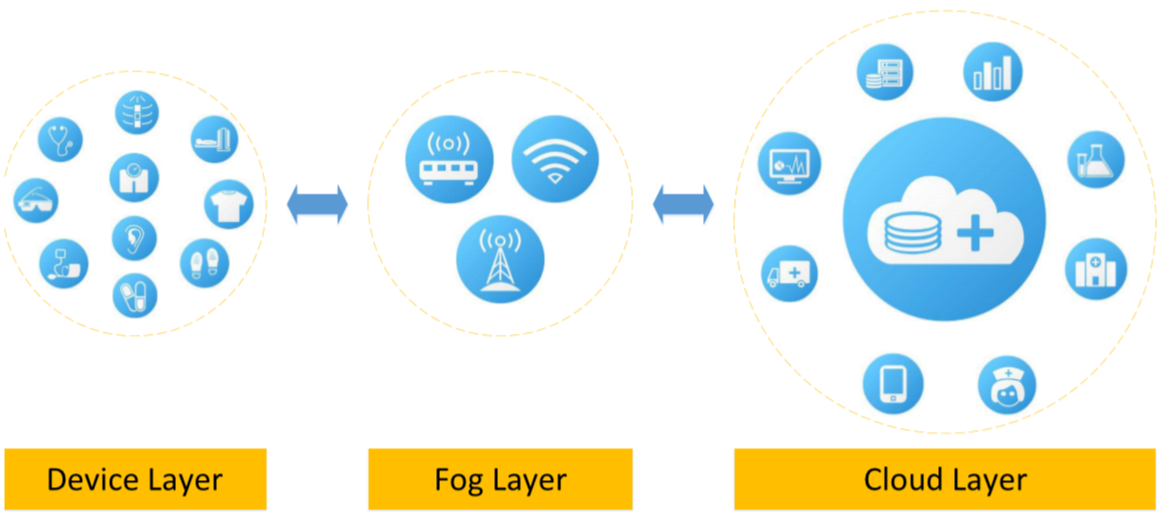

Figure 2: *Simple representation of the device layer, fog layer and cloud layer [6]*
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In the table 1 are reported different tasks for eHealth IoT divided by layer for a better distinction. Da Silva et al. [5] sought in 2018 the state and application of Fog computing for healthcare and reported:

- most of the applications are related to patient monitoring,
- the fog is used for works that need low latency, real-time analysis,
- due to the high number of devices, more work is required in the fields of interoperability and standardization.

Device layer	**Fog layer**	**Cloud layer**
vital signs	data preprocessing	data storage
sleep monitoring	local notification	data analytics
environmental info	protocol conversation	decision making
fall detection and activities	data filtering and mining	medical caregiver interface

Table 1: The device, fog and cloud layer elements [3]

1.3 LoRa and LoRaWAN

As for IoT, talking about LoRa and LoRaWAN would be very extensive so just for a better comprehension of the following topic, few concept and definitions are reported. Also, if not otherwise specified, the reference paper is *Long-range IoT technologies: the dawn of LoRa* ^{TM} [7].

Low power wide area network, LPWAN, technologies are wireless communication protocols with the aim to cover wide areas while using low power and a low bit rate. *Long Range* LoRa is a member of this group, and its essential ingredients are:

- LoRa End device: the sensors connected via one or more LoRa Gateway;
- LoRa Gateways: devices that connect the end devices to the NetServer;
- LoRa NetServer: network server controlling everything of the network, such as security and radio resources.

LoRa Physical Layer (PHY) is based on a modulation scheme called Chirp Spread Spectrum, which is a patented modulation technique, and works in the 863-870 MHz in Europe, 902-928 MHz in the US; its modulation it's currently owned by Semtech. LoRa MAC layer, better known as **LoRaWAN**, it's based on an ALOHA protocol managed by the LoRa NetServer that is able to find the best energy efficiency and link robustness adapting the transmission rate of the sensor devices, this feature is called *Adaptive Data Rate* ADR.

The most important aspects of this technology are [8]:

- the ability to cover areas of kilometres;
- the devices operates with very low energy;
- can be used both to create private and public network.

The system latency is too big for time-critic application so we won't be able to use it for transmitting an EEG or ECG, but it's main application is for monitoring patient's data in small payloads and sent to servers with a very small sampling rate [8]. In the table 2 is reported a comparison with the data traffic generated by different devices, just to get an idea of the different data weights.

Type of sensor	Data size generated at one measurement (bytes)	Traffic amount (kbytes/day)
ECG	22k (30s)	21312
EEG	45k (30s)	43200
Blood pressure	4	28
Thermometer	2	27
Spirometer	2	27
Total	~67k	64594

Table 2: Table with the amount of data generated by different sensor sources [8].

2 IoT for Healthcare using LoRa

In this section is presented an overview on IoT using LoRa for eHealth and some relative issues in § 2.1, three cases of studies for this topic in § 2.2.

2.1 Overview for IoT in eHealth

IoT-based healthcare services have the potential to provide remote health monitoring at home, rehabilitation programs, elderly and chronic diseases care. Various medical devices used for monitoring or imaging could provide help for diagnosing a patient. Although many studies and commercial solutions rely on 6LoWPAN [9], in this paper we focus on LoRa technology utilization.
In *LoRaWAN as an e-health communication technology* [10] is said that LoRaWAN can be used for **real time** services only if both the payload and the Spreading Factor SF are very small (SF σ 7,8), so this technology can't be used for time critic applications. It can be used for many others such as blood pressure monitoring or oxygenations since the payload required is very small and can be sent to Health Care centres with a modest sampling rate.
With an operative coverage of 2-15km, LoRa for remote monitoring could be very interesting in particular in poor countries or remote areas where moving a patient

could be very expensive, but also in all the cases of chronic sickness or pathologies that requires a permanent monitoring without urgent and immediate care. This also means less bed occupied in the health clinics which help them saving money. Commercial solutions are already available, for example Semtech since 2016 is very active in enabling cheap LoRa technologies for private networks.
Another essential characteristic of LoRaWAN, in common with every LPWAN technology, is the ability to use very low energy. The graph 2.1 shows a comparison of different technologies regarding their maximum throughput: compared to the more famous Wi-Fi standard, LoRa has a terrific coverage, but the throughput is very low. Also, it is interesting to notice that a simple AAA can be a power source for a sensor node. Using a XRange device from NetBlocks composed by a LoRa transceiver and a low power micro controller, the researchers from the Lancaster University estimated a lifetime of 6.2 years using a 5400mAh AA battery transmitting a 10B payload and 12.25 symbols preamble with a duration of 991.23ms every 15min[11]. In early 2019 a battery-free LoRaWAN project with wireless sensing nodes and their network is proposed by Loubet G. et al. [12] by using a far-field wireless power transmission technique. It is a very simple temperature and humidity sensor, but very representative of this LoRa aspect.

LoRa for eHealth IoT related application has been proven to be reliable in many scenarios as the examples later described in this paper, but in some cases it has been reported as not suitable for some tasks. Valach and Macko [13] discourage the usage of LoRa in a fall-detection application since it is unreliable when the sensor and the gateway are placed in different floors.

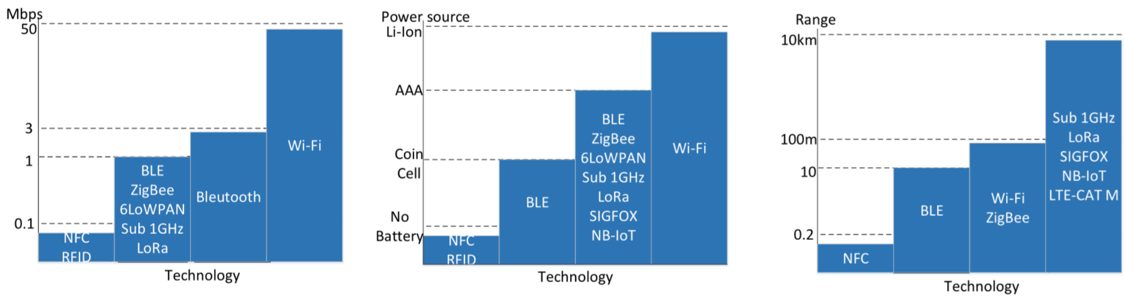


Figure 3: *Comparison of different technology in terms of maximum throughput, power source required and range [9].*

Issues

Many difficulties surrounds the IoT eHealth system, some of them are [6]:

- multidisciplinary knowledge: bioengineering, data analytic, network design are the intersection of this field;
- data variety to manage: ECG record use XML, IoT devices for imaging use many image formats;
- **Human machine interface**: an IoT sensor node for eHealth could be used by the patient or a medical personnel without the ideal technical background, so the device has to have an intuitive interface for the human input;
- lack of standardization for the integration and exchange of eHealth informations, so it's difficult to integrate essential services like Electronic Health Records;
- lack of standardization in the communication layer, protocol stack, PHY and MAC layer. The organizations currently working in this fields are the Information Technology and Innovation Foundation IETF, European Telecommunication Standards Institute ETSI and the Internet Protocol for Smart Objects IPSO [9]

It is also crucial an implementation of an *Identity management Service*, a platform to carry out the access and consent management of the caregiver, practitioners and medical personnel.

2.2 IoT eHealth applications

In this section i present some case studies related to IoT and eHealth.

A Case Study from Kikwit, DR Congo

In the LoRa Alliance second annual Global IoT challenge for innovation, in 2017 [14] one of the finalist was MediFridge, a project for a LoRa based network tracking the temperature of blood products.
This project is reported in the paper since it provides an example of an implementation outside the rural urban area in the USA or EU where LoRa is used the most: it is placed in Kikwit, Democratic Republic of Congo (DR Congo).
The pilot project was made with the collaboration of the Provincial Centre for Blood Transfusion (CPTS - Centre Provincial de Transfusion Sanguine) that now relies on a network of fridges powered by some solar panels around the regions. The operators manually check the temperature of the fridges twice per day, so the CPTS wish to

do this task automatically and coordinate supply levels and stock movements more efficiently. Another problem is that while the blood is carried to a place, no monitoring of the temperature is recorded. The blood can only stay in the CPTS center because it's the only reliable place since the sand could cover the solar panel and reduce the efficiency of the refrigerators.
GSM coverage is absent in many rural areas so it's not a reliable solution right now. So for its low cost, long range, low power consumption, the low power wide area networks are required, and the only choice is LoRa since SigFox is also not available.
Equipment, configured as in table 2.2):

- At the CPTS office was installed a Multitech Conduit MTCDT-H5 gateway and a LoRa mCard with a Taoglas 5dBi antenna. The antenna was mounted $\sim$ 5m above ground level.
- As monitor devices has been used some μPnP-WAN boards: they have some sensors for the temperatures and a RN2483 LoRa radio module attached.

MultiTech LoRa gateway settings	
Setting	Value
LoRaWAN class	Class A
Modulation	LoRa
Frequency	868Mhz
Radio Power	+26dBm

a)

RN2483 settings	
Setting	Value
LoRaWAN class	Class A
Modulation	LoRa
Frequency	868MHz
Radio Power	+14dBm
Spreading factor	SF12
CRC	on
Coding rate	4/8
Receive bandwidth	125kHz

b)

Table 3: *a) configuration for the gateway; b) Configuration for the RN2483 LoRa module for the μPnP-WAN boards [15].*

Experiment:

- It has been used a mesh-based topology as in figure 2.2, to assure the biggest area was covered.
- A sensor reading was performed every 15min; the data was transmitted to the central gateway and then stored.
- Provide an alert every time the temperature of a fridge goes above 5°.

Results and observations:

- The system works fine, there is the need to train local people to maintain it.
- The range test shows that the μPnP-WAN coverage radius is not consistent with the LoRa gateway: could it be for the interferences in the environment, maybe a higher altitude could improve this aspect;
- They didn't use the common semantics to store and organize the data, it would have been useful for a future possible integration with hospitals or clinics.

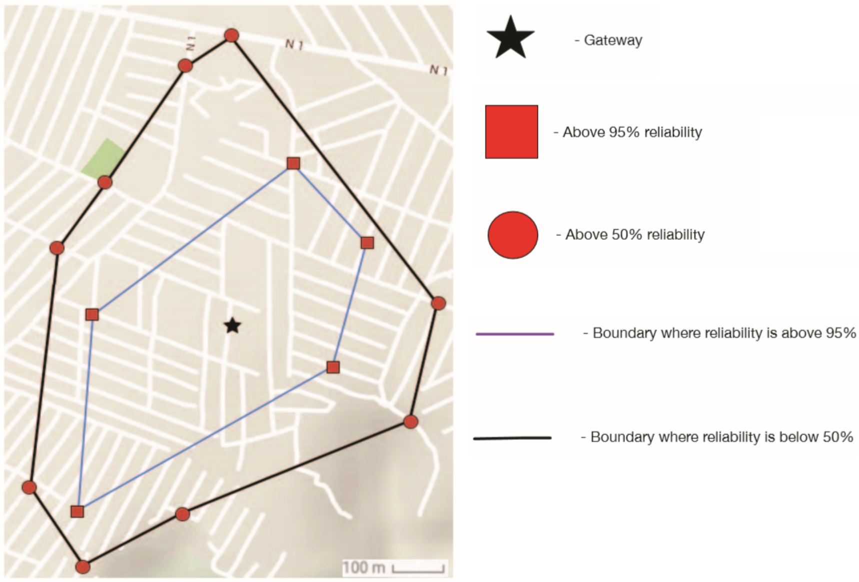


Figure 4: *Range test in DR Congo [15].*

Basic monitoring in rural areas

In *IoT-based Health Monitoring via LoRaWAN* [16] Mdhaffar A. et al. propose a LoRaWAN monitor system for blood pressure, glucose and temperature. They mainly focus on the average covered area and the power consumption, but also on guaranteeing the privacy of the patients.
The IoT4HC is the eHealth architecture presented and it's very simple as showed in figure 2.2. This paper also compare LoRaWAN and GPRS, but not 3G nor 4G: they are too expensive for just the transmission of small amount of data.
Equipment:

- The end node has 4 modules: eHealth sensor (thermometer, glucometer and blood pressure) for the actual measurement; Arduino Mega micro controller; LoRa transceiver, for the transmission of the data packets; eHealth "shield" to collect the data.

- The LoRaWAN gateway is made with a raspberry Pi3 connected to a LoRa antenna and a LoRA iC880a RF concentrator that is in charge of receiving the packets. Via the raspberry Pi3 the data is transmitted via Ethernet or WiFi to a LoRa server over the internet.

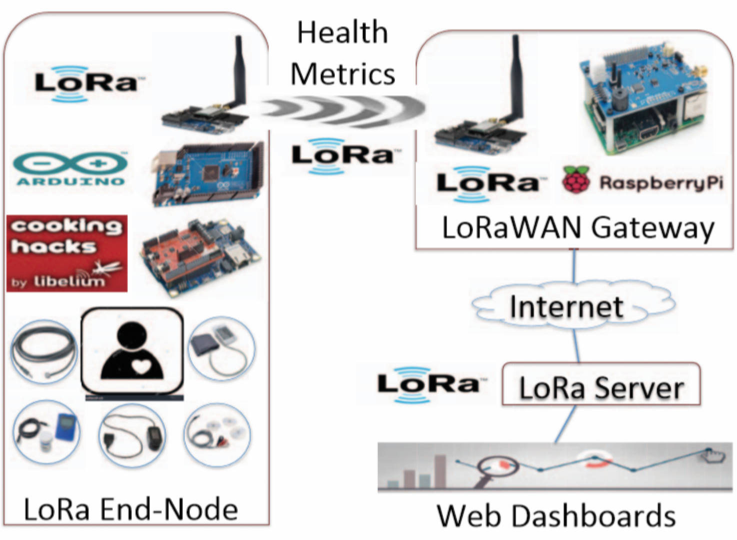


Figure 5: *IoT4HC architecture [16].*

Experiment:

- The first task was to check the total area covered by the gateway. The gateway was put on the third floor of a building, 12m altitude.

- The second task was meant to measure the power consumption of the IoT4HC system: the sending process last for 500ms and sends 93 bytes. The results are stored in a Mongo database and a simple interface for the doctor evaluation has been developed in Node and AngularJS (JavaScript).

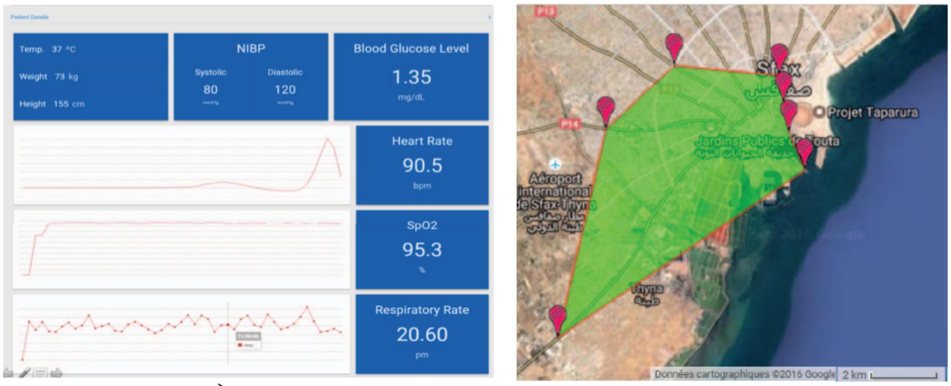
Results and observations:

- The covered area, as showed in 2.2 b, is 33 km^2 using 3 dBi gain antennas.

- The power consumption is at least 10 times lower than a solution using GPRS.

- The IoT4HC system works very well to monitor chronic diseases, but the collected data can't exceed a frame of 246 bytes. So it's not usable for ECG or EEG continuously.

- Future improvements will be: alerts to medical doctor if a parameter is out of it's normal boundaries; locally store ECG and EEG records and just send an alert message if a problem occurs.



a) b)

Figure 6: *a) the web interface to check the data acquired; b) covered area [16].*

Covering a whole campus area

Mikhaylov1 K. et al. evaluates the LoRa LPWAN for indoor remote monitoring [17]. As for the others experiences, only tools already available in the market where used. In 2017, it was the first experiment in LPWAN technologies in *non-line-of sight* (NLOS) for indoor monitoring of human-centric applications.
This experiment has been done in two take: the first one in 2015 and the second one in 2016. In the first one, a researcher carried a sensor node attached on his arm around the Linnanmaa campus of the University of Oulu in Finland; he had to perform his normal life task and the results proved that LoRaWAN is able to operate indoor, so the following task was to measure the performance and reliability of the system.
Equipment:

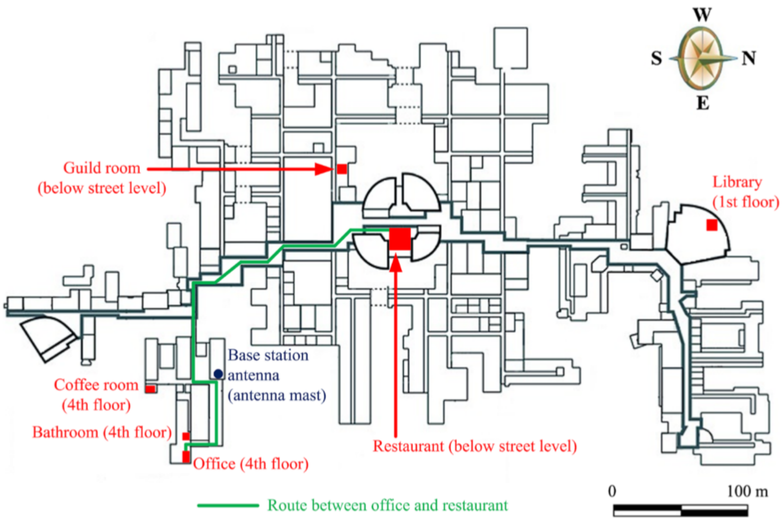
- The sensor node was made with a SX1272 Semtech's transceiver connected to a planar-F printed circuit board antenna and a LoRaMote. This module is a stand alone node powered by AAA batteries. During the measurements, every 5s a message was sent to the base station. 6 channels were tested, and for each one was calculated the time of use;
- As base station, a Kerlink's LoRa IoT station was used; the antenna, a bi-conical Aerial D100-1000 (2dBi gain), was put approximately 24m from the ground. The base station was configured to listen to the six channels of the sensor node and the acquired data was downloaded for analysis;
- for the power consumption of the sensor node was used a Keysight's N6705B DC power analyser.

Experiment:

- Simply analyse the packet error rate when the sensor node is in different locations and under mobility;
- Amount of energy consumed by the sensor node using different modulations, bandwidths, spreading factors and transmit power.

Results and observations:

- The coverage results, in figure 2.2, shows the whole campus is covered with a single base station.
  When the target was moving, a 5% packet error rate was found at a distance 75 - 150m from the base station;
- The power test showed the importance of the LoRa adaptive data rate (ADR) feature not only in power saving but also in the stability of the communication link.



Location	Distance to the BS (m)	No. of Tx packets	No. of Rx packets	Packet error rate (%)
Office (4th floor)	65 ± 5	1796	1758	2.1
Bathroom (4th floor)	54 ± 2	331	329	0.6
Coffee room (4th floor)	52 ± 5	736	717	2.6
Main restaurant (below street level)	180 ± 30	1245	1193	4.2
Main library (1st floor)	390 ± 30	878	831	5.3
Guild room (below street level)	195 ± 15	340	322	5.3
Total	–	5326	5150	3.3

Figure 7: *The covered area and the results in particular locations [17].*

3 Conclusion

This paper talked about IoT, fog computing paradigm, eHealth and showed how using LoRa technologies can be useful and convenient. Some applications of LoRa for IoT in eHealth have been described with their equipments, the aim of the experiments and the results.
LoRa can successfully handle small payloads and data rates for various eHealth application with an astonishing small amount of power, high reliability and coverage. This subject has been revealed to be an hot topic and in development, so the hope is to see more of it in the near future in many possible non critical scenarios for monitoring and taking care of patients remotely to decrease the costs not only for the health clinics/hospitals, but for the end users too.

References

[1] Roberto Minerva, Abyi Biru, and Domenico Rotondi. Towards a definition of the Internet of Things (IoT). *IEEE IoT Initiative white paper*, (1):86, 2015.

[2] Gunther Eysenbach. What is e-health? *Journal of Medical Internet Research*, 3(2):e20, jun 2001.

[3] Farshad Firouzi, Amir M Rahmani, K Mankodiya, M Badaroglu, G.V. Merrett, P. Wong, and Bahar Farahani. Internet-of-Things and big data for smarter healthcare: From device to architecture, applications and analytics. *Future Generation Computer Systems*, 78:583–586, jan 2018.

[4] Cisco. Fog Computing and the Internet of Things: Extend the Cloud to Where the Things Are. *Cisco online: https://www.cisco.com/c/dam/en_us/solutions/trends/iot/docs/computing-overview.pdf*, 2015.

[5] Cicero Alves da Silva and Gibeon Soares de Aquino Junior. Fog Computing in Healthcare: A Review. In *2018 IEEE Symposium on Computers and Communications (ISCC)*, volume 2018-June, pages 01126–01131. IEEE, jun 2018.

[6] Farshad Firouzi, Bahar Farahani, Mohamed Ibrahim, and Krishnendu Chakrabarty. Keynote Paper: From EDA to IoT eHealth: Promises, Challenges, and Solutions. *IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems*, 37(12):2965–2978, dec 2018.

[7] Lorenzo Vangelista, Andrea Zanella, and Michele Zorzi. Long-Range IoT Technologies: The Dawn of LoRa™. Number Fabulous, pages 51–58. 2015.

[8] Lei You, Chungui Liu, and Sen Tong. Community Medical Network (CMN): Architecture and implementation. In *2011 Global Mobile Congress*, pages 1–6. IEEE, oct 2011.

[9] S. M. Riazul Islam, Daehan Kwak, Md Humaun Kabir, Mahmud Hossain, and Kyung-Sup Kwak. The Internet of Things for Health Care: A Comprehensive Survey. *IEEE Access*, 3:678–708, 2015.

[10] M. Talha Buyukakkaslar, Mehmet Ali Erturk, Muhammed Ali Aydin, and Luca Vollero. LoRaWAN as an e-Health Communication Technology. In *2017 IEEE 41st Annual Computer Software and Applications Conference (COMPSAC)*, volume 2, pages 310–313. IEEE, jul 2017.

[11] Martin Bor, John Vidler, and Utz Roedig. Lora for the internet of things. In *Proceedings of the 2016 International Conference on Embedded Wireless Systems and Networks*, EWSN '16, pages 361–366, USA, 2016. Junction Publishing.

[12] Gaël Loubet, Alexandru Takacs, Ethan Gardner, Andrea De Luca, Florin Udrea, and Daniela Dragomirescu. LoRaWAN Battery-Free Wireless Sensors Network Designed for Structural Health Monitoring in the Construction Domain. *Sensors*, 19(7):1510, mar 2019.

[13] A. Valach and D. Macko. Exploration of the LoRa Technology Utilization Possibilities in Healthcare IoT Devices. In *2018 16th International Conference on Emerging eLearning Technologies and Applications (ICETA)*, pages 623–628. IEEE, nov 2018.

[14] Hamid Harroud, Geoffrey Coulson, and Domenico Ferrari. *Emerging Technologies for Developing Countries*, volume pages 45-56 of *Developing the IoT to Support the Health Sector: A Case Study from Kikwit, DR Congo*. Springer International Publishing, Cham, 2018.

[15] Gowri Sankar Ramachandran, Fan Yang, Piers Lawrence, Sam Michiels, Wouter Joosen, and Danny Hughes. μPnP-WAN: Experiences with LoRa and its deployment in DR Congo. In *2017 9th International Conference on Communication Systems and Networks (COMSNETS)*, pages 63–70. IEEE, jan 2017.

[16] Afef Mdhaffar, Tarak Chaari, Kaouthar Larbi, Mohamed Jmaiel, and Bernd Freisleben. IoT-based health monitoring via LoRaWAN. In *IEEE EUROCON 2017 -17th International Conference on Smart Technologies*, number July, pages 519–524. IEEE, jul 2017.

[17] Juha Petäjäjärvi, Konstantin Mikhaylov, Rumana Yasmin, Matti Hämäläinen, and Jari Iinatti. Evaluation of LoRa LPWAN Technology for Indoor Remote Health and Wellbeing Monitoring. *International Journal of Wireless Information Networks*, 24(2):153–165, jun 2017.

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