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Energy efficient mechanism for LoRa networks

Christos Bouras[a,*], Apostolos Gkamas[b], Spyridon Aniceto Katsampiris Salgado[a]

[a] New Building of Computer Engineering and Informatics Department, Lab of Distributed Systems and Telematics, University of Patras, Kazantzaki street, Patras 26504, Achaia, Greece
[b] University Ecclesiastical Academy of Vella of Ioannina 45001, Ioannina, Greece

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A B S T R A C T

Internet of Things (IoT) is the ability of communication between objects and refers to a wide range of applications, such as the Search and Rescue (SAR) operations. SAR applications need long distance connectivity, thus can be benefited by Low Power Wide Area Networks (LPWAN). One LPWAN technology is called LoRa (Long Range). In this context, the WeSAR project has been created that provides a system for locating and rescuing people, especially those who belong to population groups with a very high probability of getting lost. The energy consumption of the wearable devices is important factor in the SAR operations, as the battery should last more than 50 hours. Therefore, the proposed system is based on LoRa technology, the user localization is based on LoRa using trilateration and Time Difference of Arrival (TDoA) instead of Geolocation Positioning System (GPS), as GPS increases the energy consumption, and we created an energy-efficient mechanism to tackle the problem of energy consumption. In this paper, an energy efficient mechanism for LoRa networks is presented, that is based on the user's state and the battery level of the wearable device. Realistic simulations have been conducted to evaluate the system for both one wearable device, and multiple wearable devices, using different mobility models. The results from the simulations have shown a decrease in the energy consumption in various node mobility models that were tested, without compromising the delivery ratio of the network, something important as the LoRa packets are used for the localization of the lost person.

1. Introduction

Internet of Things (IoT) is one of the domains of computer engineering and science that has been offering us a variety of capabilities and solutions to modern problems. So, it is clear that as the IoT market is enlarging, it will attract more and more attention to it. The IoT devices aim to offer solutions with technologies that can interconnect wireless devices over long distances. Low Power Wide Area Networks (LPWAN) are one of the trends of the future of IoT and there are many protocols and technologies such as Long Range (LoRa), NarrowBand-IoT (NB-IoT), Sigfox, Weightless (contains three LPWAN standards), NarrowBand Fidelity (NB-Fi), etc. [2].

LoRa [4] is a modern IoT technology that enables long range communications, while keeping energy consumption to quite low levels. LoRa is a spread spectrum modulation technique derived from Chirp Spread Spectrum (CSS) technology. Some challenges that LoRa is trying to deal with are e.g. the facility monitoring, the monitoring of energy consumption

* Corresponding author.
E-mail address: bouras@cti.gr (C. Bouras).

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in buildings, etc. LoRa technology has become nowadays one very important technology for applications based on IoT. The nodes in a LoRa network are connected directly to the gateway, in a star topology, to minimize the network complexity. LoRa consists of different parameters, such as Spreading Factor (SF), center frequency, coding rates, bandwidth. From these parameters, the node should choose the right ones in order to transmit successfully.

One of the applications that LPWAN technologies can contribute and be used are the Search and Rescue (SAR) systems. SAR is the process of rescuing people in danger and need help. Such systems need the cooperation of a wide range of domains and equipment based on the way and the area in which the person got lost, e.g. in the sea or in mountainous terrain. Apart from the more classic means of SAR, such as helicopters, boats, etc., modern means have been used, such as Unmanned Aerial Vehicles (UAV). This indicates that more innovative IoT solutions are used more and more nowadays. One solution that can benefit the area of SAR can be the use of wearables. This work has been implemented in the context of WeSAR project [24]. The WeSAR project was aims to deal with the problem of people with various diseases such as dementia, Alzheimer, autism, etc. getting lost in any sort of way (e.g. kids lost by their parent). It is common knowledge that people suffering from dementia usually “wander” around and eventually get lost. According to [25], about 60% of the people suffering from dementia can get lost. Moreover, children with autism spectrum disorder, according to the research conducted in [26], around 50% of them have tried to elope from adult supervision at least once, hence a tracking system can be beneficial. This situation can be very stressful for their caretakers too. So, taking the above into account, we strongly believe that the WeSAR system can help solve this huge problem and benefit a lot of people. WeSAR is a SAR system that aims to be used in conditions where people are lost and in danger. The wearable will inform the relatives or/and the authorities, that the users have moved out from a specified area. The target group of users for the system is the following: a) people with autism disorders, b) people with dementia, and c) toddlers and children in an amusement park where the probability of getting lost increases. The main design decisions for the WeSAR project wearable is the absence of GPS (due to the fact that a GPS module has increased energy needs) and the implementation of localization service based on LoRa module which is an energy efficient approach. Moreover, in SAR operation the localization accuracy provided by LoRa (tens of meters) is acceptable and there is no need for more accurate localization (e.g. GPS localization with important cost in terms of energy consumption). With this approach we can satisfy accurate localization (for SAR needs) and at the same time wearable device can last enough for the majority of the SAR operations, as mentioned in paper [3], even the battery life is not 100%.

The aim of this paper is to recommend an energy efficient mechanism for LoRa networks, as studied in the framework of the WeSAR project [24]. This mechanism attempts to reduce the energy consumption of the nodes (which subsequently results in an attempt to reduce the consumption of the wearable device). This mechanism is able to extend the battery life to a significant extent, so that the SAR workers can be able to reach the lost people. The data used in order to proof that the results are sufficient is presented in [3]. According to [3], the information accumulated in a 7-year study of all SAR operations, conducted in the state of Oregon, concluded that in order for a lost person to have moderate to high possibility of survival, the person must be found within 50 h from the time he was lost. Taking this into consideration, we describe both the architecture of the system and the energy efficient mechanism that aims to reach this target. Afterward, we implement the architecture using the Framework for Long Range (FLoRa) [5] simulator and extend it in order to match the capabilities and the cases we need to simulate. We use the FLoRa simulator, and this happens for a number of reasons. First, it is necessary to study the ideas for energy efficiency mechanisms and algorithms, before moving to costly implementations. This gives a lot of information about what to expect as results and the problems and limitations that need to be solved before the implementation. Also, in this way, it is possible to evaluate and to have some quantitative results for the system before the deployment dep. Moreover, it is possible to understand how a relevant real-life system can work in scale, as it is impossible to test the system with hundreds of nodes (500 nodes in our simulations), before the end of the project. By taking the necessary measurements of the energy expenditure and then according to these measurements, we can test the proposed mechanism in a scaled simulation environment. Through the simulations, we are going to check the scenarios where the nodes are stationary and have a mobility model according to the INET library [6]. Our nodes will move according to the Linear Mobility model with constant speed, and the Mass Mobility model. The values for the energy consumption model of the device come from the Dialog wearable DA 14681 Development Kit (DK) [7] which has been used for the implementation of WeSAR project prototype.

The rest of this work is organized as follows: The next section presents the related work and Section 3 describes the basics of LPWAN and more specifically LoRa technology. We briefly discuss the available simulation tools, and we present a brief comparison of the simulators available in the literature in Section 4. Section 5 presents the architecture of the system to be simulated and examined. Section 6 presents the simulation results of the proposed system, using three mobility models, one stationary and two different moving mobility models. Finally, Section 7 presents the conclusion and the future work.

2. Related work

As described before, LPWAN technologies come to bridge the gap between long range transmissions and energy efficiency. Some of the applications mentioned before are healthcare applications. In paper [8], the authors tried to tackle the energy consumption of GPS systems for tracking using LoRa technology. The system was intended to be used for the caretakers of people suffering from dementia. People with dementia can walk and get lost. In order to help the caretakers, extended battery life is needed, but GPS consumes a lot of energy. So, the authors of [8] have implemented a prototype that includes both GPS and LoRa.

The authors [9] present a study of the viability of machine learning techniques applied in GPS data, to forecast the possible routes of people suffering from dementia. The authors suggest that prediction models for each individual can be produced, according to the frequency in which the individual is wearing the wearable, thus GPS data is collected. Also, in paper [10] the authors implemented a fall detection system that is based on GPS, in order to transmit the location where the person fell. The main disadvantage of the works [9] and [10] is that the GPS, in contrast to the LoRa drains the battery of the IoT device quickly.

Another prototype that uses LoRa for healthcare purposes is presented in paper [11]. In this paper, the authors have used a health monitor development platform with Arduino Uno. The results were promising, and their system efficiently achieved to take the measurements by the health sensors, concluding that LoRa can be used for such applications.

Furthermore, SAR operations can be benefited by both drone technology and LoRa. In paper [12] the authors propose an end-to-end localization system that uses both LoRa and drones, in order to achieve high location estimation. The system supports a fully autonomous localization services that provides a 10-fold improvement in accuracy comparing with a fixed LoRa network, according to the authors. The estimation error was only about 2–4 m, in contrast to the 300 m error that the fixed LoRa network can have.

Authors in [13] propose a tracking system for people suffering from dementia. This system is a shoe-based rescue system. This system includes shoes, a gateway, and a cloud platform. The shoes contain three main parts: a GPS receiver, a micro-controller, and a LoRa transmitter. Information on the body temperature, location, and voltage is transmitted to the Lora gateway, and the gateway using Wireless Fidelity (WiFi) technology retransmits the data received from the shoe system to the cloud, using Message Queuing Telemetry Transport (MQTT) protocol. Families and healthcare providers can access the patient's data, as well as in previous locations in which the patient was found.

In paper [14], the authors have developed a system that is focused on maternal and neonatal care. They have used the LoRa technology to achieve this, reaping the benefits of using LoRa as an e-health technology. The main parts of their proposed system consist of the Maternal monitoring system and the Traffic monitoring system, sending messages via a LoRa gateway. The main goal of the system is to reduce the death rate of the mothers that are about to give birth, as important measures of the body of the mother and the fetus are transmitted while she is in the ambulance to the hospital. Then, the hospital is responsible to plan the most effective route according to the needs and the biometric values of the mother.

In paper [15], the authors have created a system for e-health purposes, having as transmission technology LoRa. Also, they have assimilated Artificial Intelligent techniques in e-health operations, such as deep learning. Specifically, in this paper, the authors used recurrent neural networks to detect if a patient falls. The neural network was trained with inertial inputs, and it was shown that the effectiveness reaches 90%.

Many kinds of research have been engaged in energy efficiency issues. In paper [16], the authors have concentrated on trying to achieve energy efficiency in the uplink transmissions. Specifically, in their work, they tried to provide SF allocation according to user scheduling. So, they match the user in a channel and then the SF is assigned based on the distance that was obtained from the implemented user scheduling algorithm. Moreover, in paper [17] an alternative ADR algorithm is proposed, one part of it running on the LoRa node, while the other is running on the server-side. The scenarios were about the deployment of LoRa networks in environments such as cities, where the distances between the LoRa nodes will be very small. But, in their setup only stationary nodes were used, something not very realistic for most of the applications. In this paper, the simulation scenarios apart from the stationary mobility model, other mobility models are also investigated.

Research has focused on software and energy-saving algorithms to be implemented either in software or in hardware solutions with a goal to minimize energy consumption. The proposed solution in paper [18] uses a hybrid technique that allows the IoT system to save energy by installing a low-power microcontroller module. This module is responsible to change the operating mode of the sensors, e.g. sleep mode depending on the application needs. Thus, the device will be awakened by a necessary condition according to the application (e.g. some sensor measurements or time activation).

In papers [19] and [20], there is an evaluation of the LoRa technology for mountainous SAR scenarios. The results yielded by their research show that the LoRa technology can be a very competitive solution and can perform even better than the today's SAR solutions for mountainous scenarios, such as the ARVA and RECCO solutions. Also, in paper [19] the authors evaluated the path loss model of LoRa for the mountainous terrain.

As far as the energy consumption is concerned, in paper [21], a Software Defined Network (SDN) protocol is proposed that aims to reserve the appropriate resources for the wireless sensor networks. The results from the simulations show a reduction in energy consumption. Paper [22] develops an innovative multi-cloud IoT algorithm named E2C2. The algorithm is focused on improving energy consumption, by searching and integrating the minimum number of IoT services that can meet their user's requirements. For the proposed algorithm, a modeling method was adopted and an analysis of user requirements. The algorithm was evaluated and compared with other four well-known algorithms (All clouds, Base cloud, Smart cloud, and COM2). The results of this comparison proved the superiority of their proposed algorithm with respect to performance. Last but not least, in paper [23] energy efficiency in real LoRa networks is discussed. The authors propose a dynamic adaptive network slicing mechanism in combination with a mechanism of optimization of LoRa parameters in each slice based on maximum likelihood estimation. The results showed improvements in different metrics such as energy consumption and throughput.

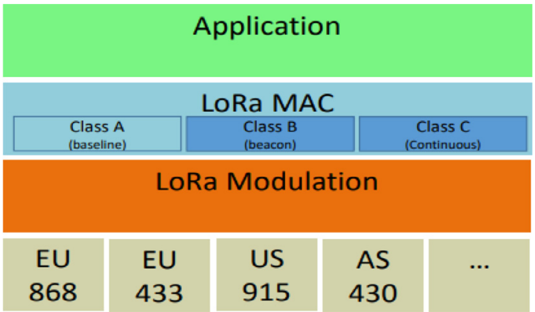

Fig. 1. LoRa Stack.

During the stage of defining the requirements for the system, it was made clear, that one of the absolutely necessary requirement was the extended life battery by every mean.

3. LPWAN and LoRa technology

3.1. LPWAN

Due to the increase in the use of IoT in different domains of modern society, different kinds of technologies have emerged. For example, for short-range radio transmissions, Zigbee and Bluetooth technologies are more and more used nowadays. On the other side, there are cellular networks, that can transmit over long-range, but the energy consumption is higher, and the cost of devices is also higher too.

Hence, as we refer to devices that in most cases are battery-constrained and the transmission needs to be over long ranges, a new category of networks has emerged, which is the LPWAN. Some of the most notable examples are LoRa, NB-IoT, Sigfox, and Weightless. Yet, among these technologies that belong to LPWAN, there exist discrete differences. According to the authors of [27], all of the LPWAN technologies try to achieve better energy efficiency, long-range transmission, scalability, and low cost, using different approaches to the way of the implementation. For example, LoRa and Sigfox are operating in the unlicensed spectrum, while NB-IoT is operating on the licensed spectrum developed by the 3GPP [27].

Thus, despite their common goals, there are some differences between their approaches. So, each technology can match better to different applications based on the specific needs and characteristics. According to [27], for logistics purposes, NB-IoT and LoRa technologies are more suitable, while for critical logistics monitoring, NB-IoT should be preferred. Also, for healthcare applications, NB-IoT and LoRa are very competitive solutions.

Concluding, LPWAN technologies can effectively deal with a range of problems, where other technologies struggle more or are very expensive, e.g. Wi-Fi or 5thGeneration (5 G).

3.2. LoRa technology

LoRa technology is a broader term that consists of two main parts. The first one is called LoRa that defines the physical layer of the technology and the modulation technique. The other part called Long Range Wide Area Network (LoRaWAN) refers to the open specification protocol developed by the LoRaWAN Alliance (see [1, 28]).

The physical layer of LoRa allows the communication between a node to the LoRa gateway in an energy-efficient manner and is ideal for battery operated devices over long distances. It can cover over 15 km Line of Sight (LoS) and is similar to CSS modulation allowing α trade-off between the data rate for sensitivity within a channel bandwidth. Moreover, from frequency shifting keying, LoRa provides low power features, while having increased coverage. One interesting capability of LoRa is that a gateway can receive a lot of signals at the same time, since the signals have different SF. The physical layer of the LoRa is proprietary by Semtech, so there is not a lot of knowledge accessible and the scientific community cannot access the documentation [1,29].

LoRAWAN defines the open-access communication protocol of the network and is the Medium Access Control (MAC) layer protocol. LoRaWAN uses a star network topology. The nodes are broadcasting their messages directly to the gateways. The messages are encrypted, and only the appropriate gateway can process each message. Then, the messages are sent via a backhaul technology over the Internet to the Network Server and then to the Application Server. If the Network Server receives copies of the same message from the same node through different gateways, it is up to it to decide which copy to transmit it to the Application Server. Also, LoRaWAN describes three Classes, which categorize the nodes in classes A, B, C. Each class has a different energy consumption impact, with A class consuming the least energy.

In Fig. 1, there is the LoRa protocol stack, and Fig. 2 shows an example of LoRa network.

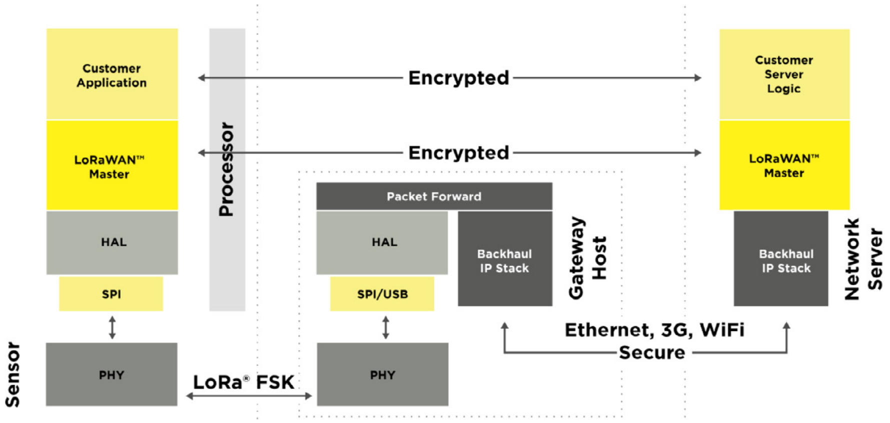

Fig. 2. The topology of a LoRa network [1].

4. LoRa simulators

There are several simulation environments open to the scientific community such as the PhySimulator, FloRa, Ns-3 module for LoRa, and LoRaSim. These simulators are briefly examined below.

4.1. Phsyimulator

The first examined simulator is named PHY Simulator and its goal is to implement the physical layer of LoRa. PhySimulator is created using the MATLAB language. The simulator tests the reception of two overlapping-interfering LoRa transmissions that use distinct SFs. After running the simulation, 8 figures are created, depecting the symbol, packet, and bit error rate. In particular, the output is the symbol, packet, and bit error rate for each SF that was assigned, interfered with any other SF [28].

4.2. FLoRa

The FLoRa simulator is based mainly on OMNeT++. OMNeT++ is a discrete event simulator that is distributed under the Academic Public License. Apart from the OMNeT++ framework, FLoRa uses the INET Framework. INET Framework is an open-source library for OMNeT++ and its purpose is to help researchers to conduct simulations and test their mechanisms using a variety of network protocols. FloRa is written in C++ and NED language [28]. NED is a language used in OMNeT++ that allows the programmers to describe the topology and the messages of the network. Moreover, one advantage of FLoRa is that the results can be exported in csv format, allowing easy result analysis through other tools, such as Python's Matplotlib.

4.3. NS-3 module

In literature, there is a ns-3 module that plugs in the ns-3 simulator. Ns-3 is a free discrete-event network simulator that is designed for academic and research purposes. It supports a large variety of protocols and networks including IP networks, and wireless simulations, as well. The creators designed the ns-3 module, trying to make it as modular as possible. Ns-3 allows the developers to work in both graphical interface and the command line. It is written in C++ and Python. This specific module is in compliance with class A of the LoRaWAN 1.0 specifications [28].

4.4. LoRaSim

The last tool described in this work is the LoRaSim simulator. LoRaSim is a discrete event simulator that aims to study the feasibility of scaling LoRa networks and the collisions. It is a widely used simulator, with several variations. It allows the placement of the LoRa nodes in a 2-dimensional grid. The LoRaSim is based on Python ver.2.7. This fact can be considered as a disadvantage as only version 3 of Python is updated. Furthermore, the simulator uses the NumPy, Matplotlib, and SimPy Python libraries. This tool simulates 4 simulation cases, each one resembles different properties of the network and the nodes. Specifically, there are simulations assuming only one gateway up to four gateways [28]. Table 1 presents a comparison of the aforementioned simulators.

After studying the aforementioned simulators, we concluded to use and extend the FLoRa simulator. The main reason is the fact that FLoRa has implemented many aspects of the end-to-end typical LoRa network. FLoRa apart from the nodes and the LoRa GW, includes the backhaul network for the communication from the LoRa GW to the network server and the network server itself. Moreover, its graphical user interface makes it competitive, if you compare FLoRa with LoRasim or

Table 1
Comparison of simulation environments [28].

Features	PhySimulator	FLoRa	Ns-3 module	LoRaSim
Event	discrete	discrete	discrete	discrete
License Type	free	Open source (study and research)	Open source	Creative Common Attributes 4.0
Language	Matlab	C++	C++, python	python
Operating System	Windows, Linux, MacOS	Windows, Linux, MacOS	Linux, MacOS, Windows through virtualization	Windows, Linux, MacOs
GUI	Only plots	yes	yes	Only plots
Energy Consumption statistics	no	yes	yes	no
Documentation	Ok	ok	average	ok
Number of published papers	2	1	1	2
Website	yes	yes	no	yes
Community Support	Good	Limited	Very Good	Limited

Fig. 3. The DA 14861 prototype with the jtag debugger.

phylorasimulator. The high fidelity of the FLoRa in terms of the network components, and the rich graphical interface made it the best choice for our needs.

5. Architecture

In this section, we are going to describe the architecture of the whole system, the parts of the system and how these parts are connected. As was described in Section 3, the users are people that are moving wearing wearable devices equipped with a LoRa antenna.

The wearables used in WeSAR project is the DA 14861 wearable DK made by Dialog. The currents and the voltages of each component we take into account derive from the datasheet of the DA 14861 [7] with a supply voltage of 3.8 V.

More specifically, we study the values of power consumption of the components DA 14861 System on Chip (SoC), Bluetooth Low Energy (BLE), Liquid-Crystal Display (LCD), Thin-Film-Transistor (TFT), display, Heart rate monitor (HRM) module, Quad serial peripheral interface (QSPI) flash memory, environmental sensor (BME280), magnetometer, microphone, and accelerometer/gyro, Real-Time Clock (RTC), capacitive touch controller and the General Purpose Input Output (GPIO) expander. In Fig. 3, our DA 14861 developer prototype is presented.

The way in which the wearables communicate with the use of LoRa is done as follows: the node, where in this case is the wearable device, sends the data using LoRaWAN. The packets are broadcasted to the LoRa gateways (GW). One LoRa GW located in the University of Patras, is presented in Fig. 4.

The LoRa gateways for the WeSAR project are provided by the University of Patras. Despite the fact that the data are broadcasted, only the correct recipient can decrypt the packets using the right decryption keys. One or more gateways listen indefinitely for LoRa packets. The correct gateway converts the packet to IP protocol and relays it to the default Network Server, using a backhaul technology such as WiFi or Ethernet. In our case, after research of the available network servers, we chose The Things Network (TTN) [30], a global LoRa open management network. Then, the data are sent to the right Application Server. In the case of our implementation in the WeSAR project, the Yodiwo's IoT Platform [31] will receive the packet and process it.

One of the issues that affect the energy consumption of the battery of modern IoT devices is the usage of sensors. One factor impacting power management, as it is described in [35], it is important to introduce in such solutions the idea of operation states.

It becomes apparent that it is quite important to dynamically change the operating state of the sensors according to the user situation and needs. In the model, the authors assume that sensors like accelerometer and medical sensors are boarded in the device. Fig. 5 presents a general overview of the implemented system.

Fig. 4. The GW located in the University of Patras

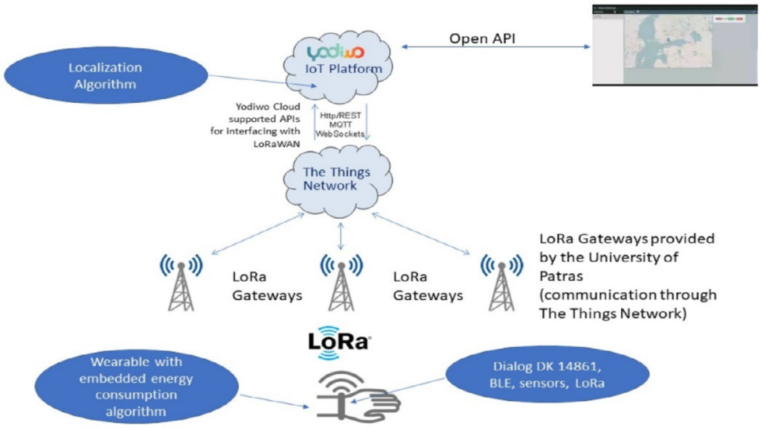

Fig. 5. General Architecture of WeSAR system

To achieve energy efficiency on the nodes, we define the following three states:

- Off: the device, in this state is switched off.
- Hibernate: no sensor is working in this state. Only the accelerometer is operating and triggered, the wearable goes to another state. We monitor the accelerometer in order to monitor a possible sharp fall of the person wearing the wearable (as far as possible) in order to give an alarm if necessary. There is an option in order to disable the accelerometer sensor.
- Normal: in this state, the sensors are taking measurements and transmit the measurements through LoRa to the application server.
- Emergency: in this state, all the sensors are turned off, apart from the sensors that help for the detection of the person that got lost.

Moreover, one important factor that affects energy consumption for IoT devices is the rate at which the sensors collect and send data. Consequently, there must be a difference in the rate at which data will be sent based on the user's condition and the mobile device itself, as well. All these changes are happening in the application server. The application server sends to the node the state in which it will be set, disabling or enabling components of the wearable to save battery life. In the cloud, a lot of parameters can be processed and one of them can is the battery level. For example, when the battery is low, the transmission frequency should be lower, so as to extend the battery life.

The way in which the device changes its state from one to another is defined in Fig. 6. Off state is ignored in transitions from one state to another because it is supposed to express the state where the device is turned completely off. If we take hibernate state as the start, it goes to the normal state in this way: the device in every X seconds switches from hibernate mode to normal and then goes back to hibernate mode. Each Y seconds from hibernate mode changes to normal state and the values are sent to the LoRa gateway. The X and Y values are calculated experimentally in each network because it is important to take into consideration the specific use case of the device, the device hardware, etc.

After sending the data, the wearable opens two downlink windows to receive the packets from the gateway. In emergency state the wearable device sends the values measured by the sensors to the LoRa gateway, and then the packets are sent to the Application Server. After sending the data, the mobile device waits again for any packets then switches to hibernate mode.

From normal mode the following transitions are made either in hibernate or emergency mode:

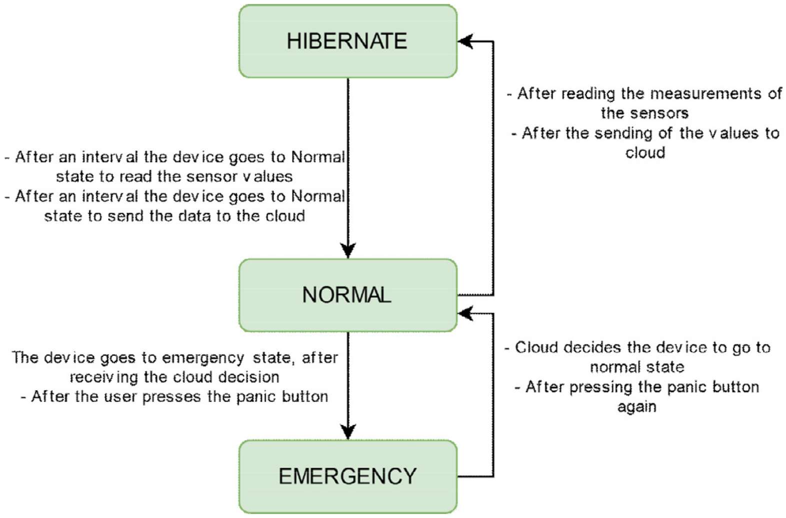

Fig. 6. State transition.

- After the X seconds, the devices go from normal to hibernate.
- After pressing the emergency button, or a user fall was detected, or high heart rate was detected by the device, or the user was found out of a predefined area, the device sends a message to the Cloud in order to go from normal to emergency state. We monitor the hear-rate in order to monitor the health of the person wearing the wearable (as far as possible) in order to give an alarm if necessary. There is an option in order to disable the heart-rate sensor.

The decision to switch to emergency mode is made by the cloud, after receiving the message from the device. The Application server sends a downlink message to the node. The message is stored in the gateway where when a downlink window opens the message is sent to the node. From the emergency mode, the following transitions are made to normal:

- By sending an appropriate message from the cloud, the wearable device goes into normal mode, e.g. in the case the user returned back to the predefined area.
- After pressing again, the emergency button, the portable device returns to normal mode.

Moreover, apart from the definition of the user states (if the user is in an emergency situation) one parameter that it is taken into consideration is the battery level. When the battery level is low the sensors should remain off for a longer period of time. The values of the parameters X, Y are changing dynamically, according to the user's state and the battery level. The increase of the battery life is explained and described in the next section. The pseudocode of the mechanism is presented below.

Pseudo code of the Mechanism

```
Cloud sends downlink to the node
If (BatteryLevel >= BATTERY_HIGH)
If (state = EMERGENCY)
Y = Y_emergency_high_battery; X = Y / value_emergency;
Else
Y = Y_normal; X = Y / value_normal
else if (BatteryLevel >= BATTERY_LOW)
If (state == EMERGENCY)
Y = Y_emergency_mid_battery; X=ϒ;
else
X = Y / value_emergency;
else
if (state == EMERGENCY)
Y = Y_emergency; X = Y;
else
X = Y;

if state == EMERGENCY:
suspend(unnecessary sensors for localization)
else:
activate(unnecessary sensors for localization)
```

Table 2
Current and power consumption.

Mode	Current (μA)	Power Consumption (μW)[a]
Sleep	90	342,0
Normal	21,106	80,202,8
Emergency	2300	8740,0

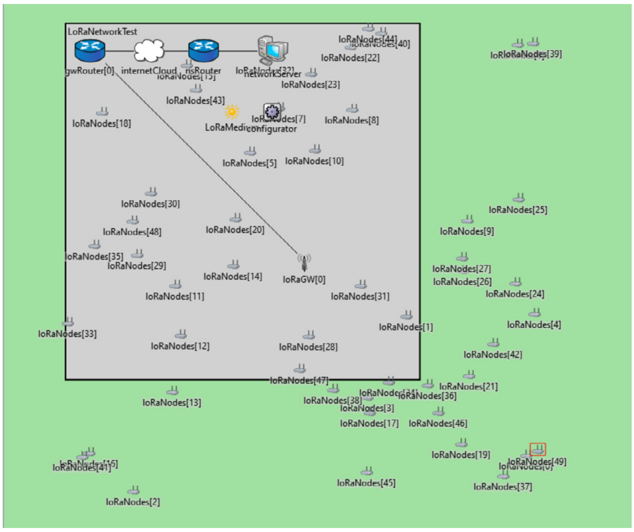

Fig. 7. An instance of the topology of the simulation.

6. Simulation results

As cited in previous sections, we try to simulate a LoRa network, where the nodes are embedded systems.

The LoRa module used in WeSAR wearable (Dialog DA 14861) is the Semtech SX 1272. According to the datasheet, depending on the activity, there exist different consumption levels [7]. Matching the abilities of the wearable to our system purpose, we have extracted the current average consumption for each state and the values are presented in Table 2. According to the equation:

$$P = VI \tag{1}$$

we can measure the power consumption through Voltage and Current.

The overhead values are taken into account in all operating states, in order the simulation to be closer to reality. So, LoRaEnergyConsumer.cc, LoRaEnergyConsumer.h files have been changed and updated, in order to have both the energy consumption of the transmission and the operating energy consumption of the embedded system. This was made feasible by updating various files, to inform the state of the node/ user to the necessary layers of the LoRa stack.

Moreover, as far as the path loss model is concerned, the Log Normal Shadowing Model for urban and sub-urban was used. To simulate better the urban and suburban cases, the deployment space in the simulation environment was different. In the case of the urban case, the deployment area was 480 m x 480 m, while in the case of the suburban environment was 9800 m x 9800 m. An instance of the simulation topology is presented in Fig. 7. In Eq. (2), the Log Normal Shadowing Model is presented. For the suburban case, the parameters were taken from the case of Oulu [33].

$$PL(d) = PL(d_0) + 10n\log_{10}\left(\frac{d}{d_0}\right) + X_\sigma \tag{2}$$

- $PL(d_0)$ the mean path loss for d_0 distance
- n: path loss exponent
- X_σ: zero-mean Gaussian distributed random variable with deviation σ.

The parameters we have used for our simulations are based on the results of the papers [17, 32] and [33] that describe the urban and sub-urban cases. In Table 3, the simulation parameters used in the simulations are shown. We run the simulations with the parameters of both urban and suburban environments. Also, we consider the ideal channel where the standard deviation of the path loss (σ) is zero.

These nodes were similar to the DA 14861 and equipped with the SX1272 by Semtech incorporated in the module LAMBDA-9S created by the RF solutions [34]. The simulations abide by the European regional parameters. We examined

Table 3
Parameters.

Parameter	Value
Carrier Frequency	868 MHz
Bandwidth	15 kHz
Code Rate	4/8
Transmission Power	2 dBm to 14dBm
Number of GWs	1
Number of nodes	100 to 500
Urban n	2.08
Suburban n	2.32
Urban PL(do)[dB]	127.41
Suburban PL(do)	128.95

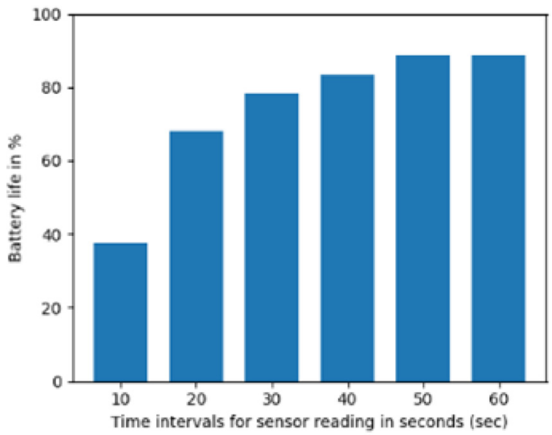

Fig. 8. The percentage of the battery life as X increases and Y equals 60 s.

the urban and sub-urban cases taking the values for the parameters shown in Table 3. In the first case, we had the majority of the nodes very close to one another, so as to simulate dense deployments, while for suburban the nodes are far from one another. In the network server, we have implemented the energy efficient mechanism, as shown in Fig. 5. As explained above, three mobility models where used StationaryMobility, LinearMobility, and MassMobility from the INET library [17]. The nodes were arranged in a random way, according to normal distribution. As far as the run time of the simulation is concerned, we run all the experiments with 7 simulation days, with 15 iterations each. Moreover, in order to simulate the transition of the user's states as presented in Fig. 5, we did the following: the network server checks the current state of the device and randomly, according to the Poisson distribution decides if it will change the state (by sending the appropriate message to the device) or to remain in the same state.

Last but not least, the impact of X and Y parameters discussed in the Section "Energy-Efficient mechanism" was investigated. Specifically, to study the effect of the X and Y parameters, we conducted some experiments in the basis of one wearable device. Firstly, the experiment ignored the emergency state. The experiment's duration was 86,400 s (1 day) and the X value had values 10 - 50 with 10 s steps while the Y had values 60 - 300 with 60 s step. In Fig 8, the percentage of the battery life remaining is presented as the value of X increases and the Y value is 60 s.

We run the experiment, with the power saving mechanism enabled and disabled for a period of 9 days. As Fig. 9 (the left plot) shows, the wearable's battery cannot last 2 days of use, when X has a fixed value. Using the energy saving mechanism (the user is in normal state) we achieve a reduction in consumption, resulting in the battery can be maintained for up to 8 days, as presented in Fig. 9 (right plot). Then we run the experiment assuming the user is in emergency state. The results presented in Fig. 10, show that the battery life can be extended up to 17 days (with the battery full charged). This extension can be lifesaving when the user is in danger, because it is important the battery to last 50 h at least. The battery is supposed to be fully charged in the experiments, but in real life the wearable device may be not fully charged, so it is necessary the battery to last 50 h when the user enters to the emergency state even with the wearable device being not fully charged. So, our results are promising.

6.1. Stationary mobility model

In all of the experiments, we had only one gateway and we tested the cases of 100–500 nodes with 100 nodes step. Two variables were tested, the average energy consumption of the nodes in the network and the delivery ratio. Delivery ratio is

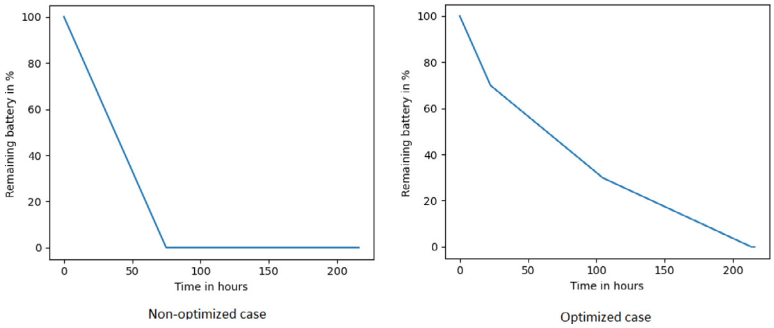

Fig. 9. The percentage of the battery life remaining. Left: non-optimized case, Right: optimized case.

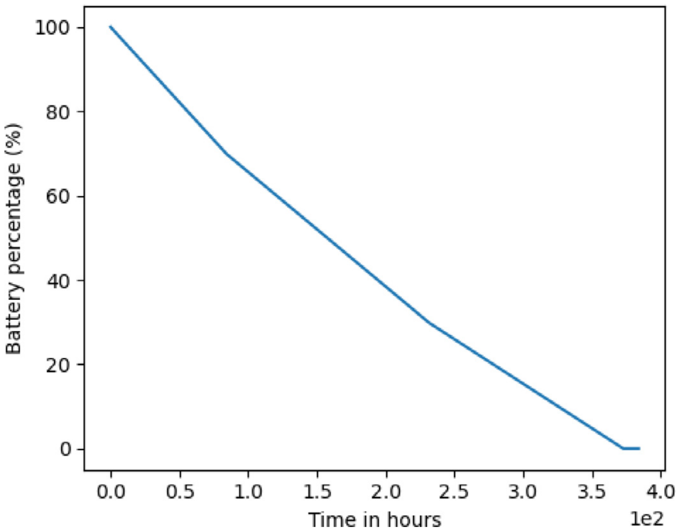

Fig. 10. Optimized case in emergency state.

defined as the ratio of the number of the messages received by the Network Server to the total number of the messages sent by the nodes. The main focus was to prove the optimization of energy efficiency, but it is also very important to understand and investigate the network performance, as well and as a result, the delivery ratio was taken into account. We used the LoRa technology in order to implement the mapping of the user state to the real-life wearable. We need to note that both cases are optimized according the level of battery, but in the non-optimized case the emergency state is ignored. Also, the result analysis is described in Section 8.4. The results in case the node are following the stationary mobility model are presented in Figs 11, 12 and 13.

6.2. Linear mobility model

Above we examined the case where the nodes were stationary, but in most cases, the nodes need to move. (e.g. tracking applications, SAR systems). In order to do this, we changed the mobility model of Stationary to LinearMobility. As it is shown in the documentation of INET [6], the LinearMobility model emulates the case of the node is moving in a specific predefined speed. Otherwise, constant acceleration can be used too. The nodes in this specific model are moving with a constant speed of 10 mps. All the other parameters in these experiments are the same as the previous ones. The results are shown in the following figures, namely Figs 14, 15 and 16.

6.3. Mass mobility model

Moreover, the mechanism was tested with nodes having the MassMobility model. As it is described in the documentation of INET [6], the MassMobility model emulates the case of the node is moving in a line where the node in a random time changes direction. The direction is also random. In contrast to the LinearMobility, MassMobility model does not have a specific speed, the speed is set randomly, too. In the simulation the parameters are:

- changeInterval = truncnormal(2 s, 0.5 s)

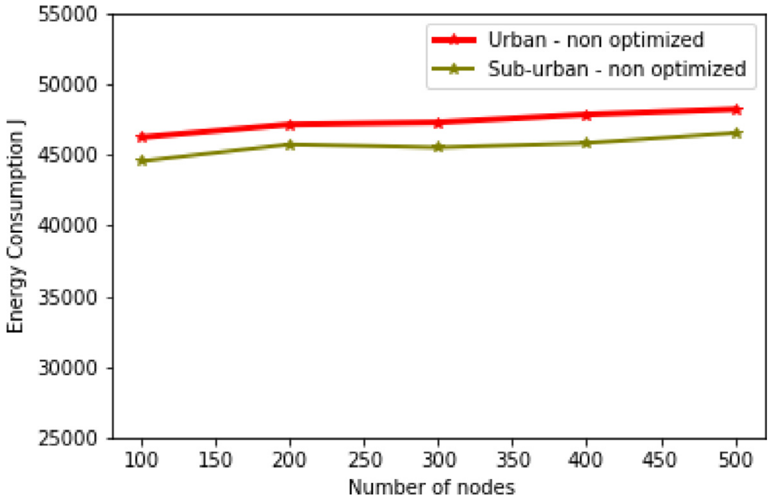

Fig. 11. Energy consumption for non-optimized urban and suburban case.

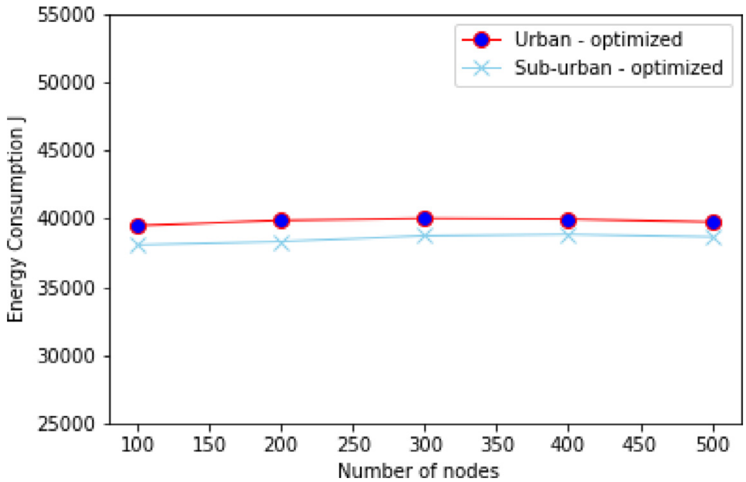

Fig. 12. Energy consumption for optimized cases.

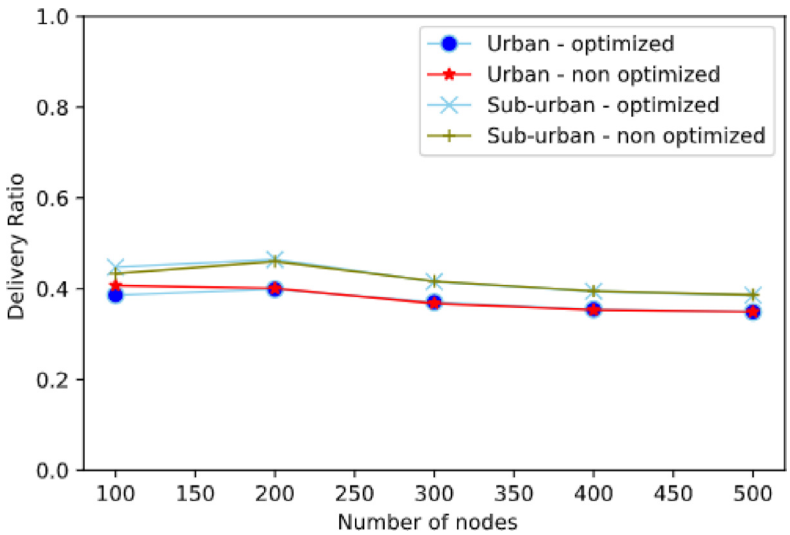

Fig. 13. Delivery ratio of all examined cases.

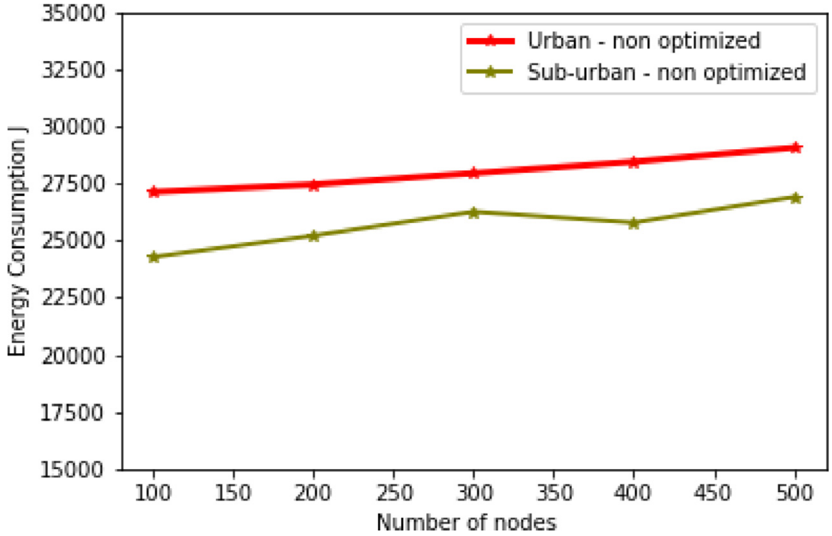

Fig. 14. Energy consumption for non-optimized cases.

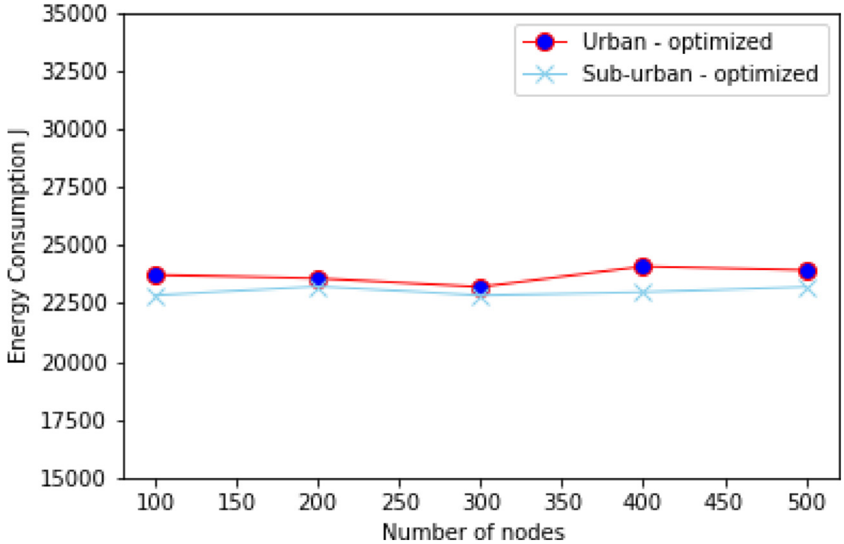

Fig. 15. Energy consumption for optimized cases.

- angleDelta = normal(0 deg, 30 deg),
- changeAngleBy = normal(0 deg, 30 deg)
- speed = truncnormal(15mps, 5mps)

7. Discussion

As we can see from the above figures, we can conclude that our system has improved the energy consumption of the LoRa nodes in both cases (urban, suburban, and in all 5 number of nodes used). Specifically, in Figs. 11 and 12, the energy consumption in urban and suburban case is presented and the nodes have the stationary mobility model. In Figs. 14 and 15, the energy consumption for the urban and suburban case is presented in the scenario of nodes having linear mobility model. The energy consumption for urban and suburban cases is depicted in Figs. 17 and 18, while the nodes have mass mobility model. The energy consumption curves in the optimized cases are showing decreased energy consumption in all cases (urban, suburban scenarios, and with different mobility models). Depending on the number of the nodes in some cases (e.g. more than 400 nodes in Fig. 18) there is an important improvement. We have to highlight in SAR scenario even a small improvement it is important (and in some cases makes the different for the rescue of the missing people).

Furthermore, the delivery ratio in the three mobility models used is shown in Figs. 13, 16 and 19. In each figure, the delivery ratio of the 4 cases is presented. The delivery ratio is not affected by the proposed mechanism, as the curves are

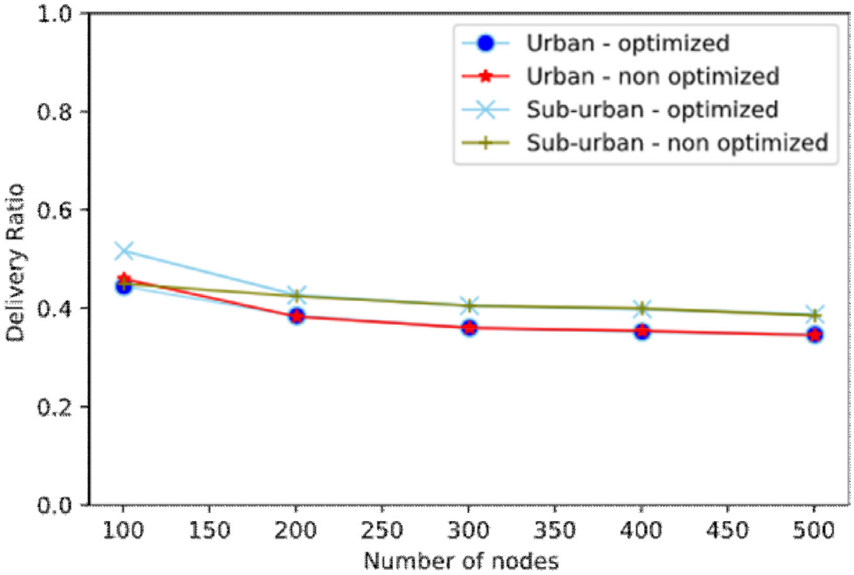

Fig. 16. The delivery ratio of each scenario.

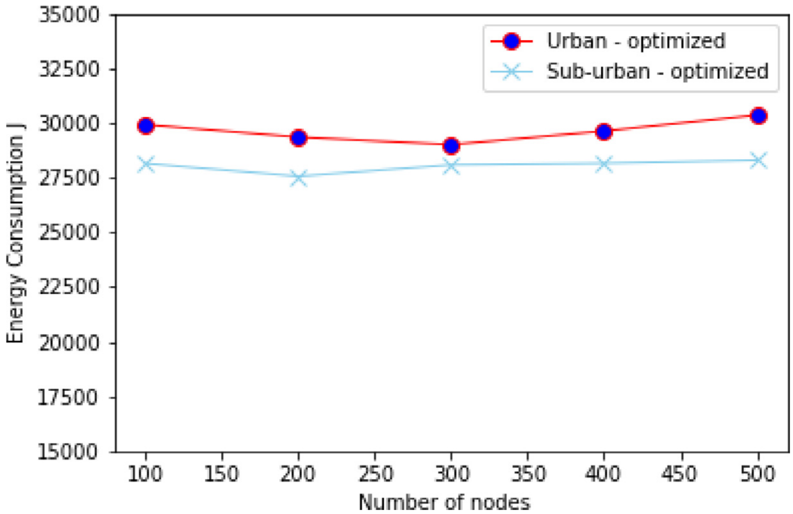

Fig. 17. Energy consumption for optimized cases.

almost identical in the optimized case and non-optimized case in each path loss model (urban and suburban). Thus, this kind of mechanism should be used in applications such as SAR cases, because it provides less energy consumption, while at the same time does not deteriorate the overall network performance, at least regarding the delivery ratio.

Generally, when studying the energy consumption of networks and nodes, it is essential to take into account the energy consumption of the embedded hardware as well, as it has a great impact on energy consumption and not only the transmission (especially for devices such as wearables that incorporate many sensors). Having state modes in real applications and nodes (devices like wearable devices) can provide a significant impact on reducing power consumption and is a technique that is necessary to be taken into high consideration.

It is our firm belief that while creating real-life systems, it is crucial to comprehend the people that are involved, the activities that are intended to undertake, the contexts in which they operate, and the available technology. In this way, understanding the user's needs and the use cases, one can map the user's use cases with the hardware's capabilities. This helps to better take advantage of the operation states of the devices. Thus, after understanding the behavior of the target group, it is possible to further reduce energy consumption. This arises another aspect, except for the use of sophisticated algorithms, energy efficiency can be achieved by studying the people's use cases. Moreover, if we compare the results in terms of energy consumption, comparing it with other technologies such as the work in [36], we have achieved better results. Specifically, in [36], the authors created a GPS tracker that incorporates a LoRa module for people suffering from

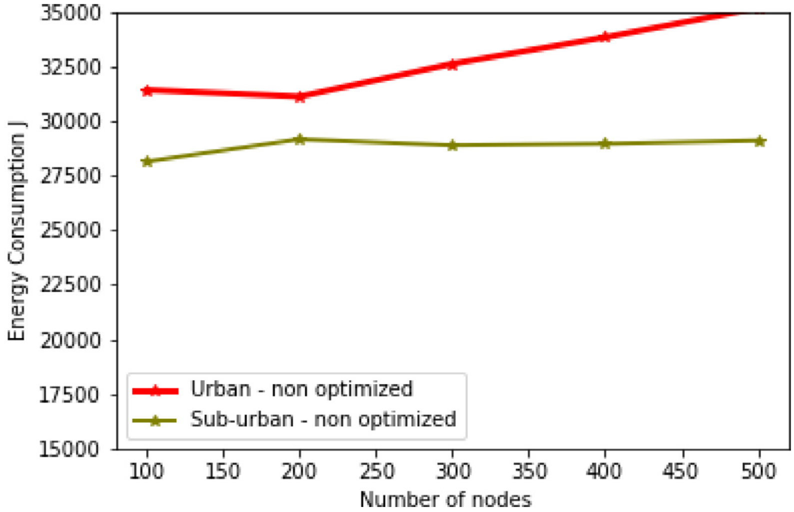

Fig. 18. Energy consumption for non-optimized cases.

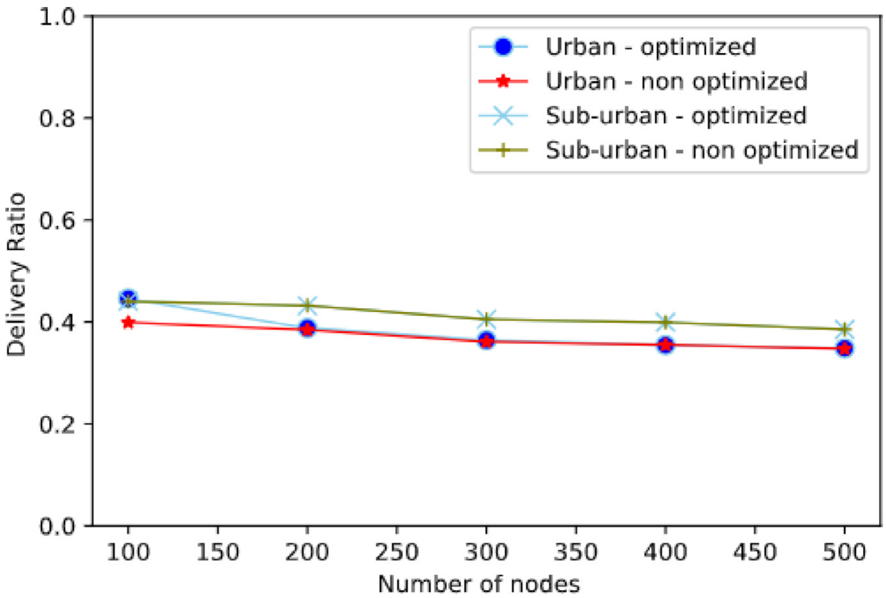

Fig. 19. Delivery ratio of each scenario.

dementia. Their results showed that the battery life of their system providing GPS tracking with a location update 60 s can last up to 40 h. In our system, with a 60 s update, we can achieve battery life up to 8 days in normal mode, while in emergency mode the battery can last up to 17 days. Also, applying Machine Learning algorithms for the localization, as explained in [37], the WeSAR system achieves acceptable localization accuracy as far as the RSSI values are concerned, and by using Time Difference of Arrival (TDoA) (the GWs used in WeSAR project support TDoA), the location estimation error drops around 50 m. Finally, it is important to note that the WeSAR's wearable device can last enough for the majority of the SAR operations, as mentioned in [3], even when the battery life is not 100%.

As a result, using a dynamic way for changing the operating states of the device from the main application can help to increase the battery life of the device something that can be lifesaving in SAR operations.

8. Conclusion

LoRa is one of the prominent solutions for long range low power communications. It is competitive with other LPWAN technologies such as Sigfox and NB IoT. It is common knowledge that the choice of the right parameters it is essential when designing network deployments and mechanisms. So, a simulator was used, in order to test and study the idea with lower risk before stepping towards the expensive implementation and investment, which is envisioned for later stages of the WeSAR project. In this paper, we used FLoRa to test our proposed algorithm, taking into account the architecture in which we are working on in the framework of project WeSAR.

In our case, our methodology was to represent and link the user states (user states came from the use cases) with the available hardware capabilities that we had we have in mind to use such as the DK of Dialog, DA 14861. Later, before we try to implement our ideas, we implemented the energy efficient mechanism in the simulation environment. Then, the mechanism was tested with the use of FLoRa simulation environment, showing that we can achieve better energy consumption, as far as the wearable devices are concerned, while we maintain the delivery ratio. Future work will be a large-scale study after the end of the implementation of WeSAR project, in order to test the mechanism with real data coming from hundreds of users. Also, the future work will include studying and developing more advanced algorithms and techniques, such as using Machine Learning techniques, in the framework of energy efficiency, packet loss of LoRa networks, and other metrics.Our approach will be similar in solving the energy efficiency problem in future work. Firstly, the authors will implement the mechanisms in a simulation environment and use datasets created by the simulation process. After they will implement it to the real system, depending on the available hardware. Then, it is intended to conduct an evaluation of the performance in terms of energy efficiency, localization accuracy, and the human interaction of the whole completed system.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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