Energy Efficient Mechanism over LoRa for Search and Rescue operations

1st Christos Bouras
Computer Engineering and Informatics
University of Patras
Patras, Greece
bouras@upatras.gr

2nd Apostolos Gkamas
University Ecclesiastical Academy of Vella
Ioannina, Greece
gkamas@aeavellas.gr

3rd Spyridon Aniceto Katsampiris Salgado
Computer Engineering and Informatics
University of Patras
Patras, Greece
ksalgado@ceid.upatras.gr

Abstract—**Search and Rescue (SAR) operations can be vastly benefited by the use of IoT and especially by Low Power Wide Area Networks (LPWAN) technologies, such as Long Range (LoRa). In this framework, the wearable device-based Search And Rescue system (WeSAR) project has been created. The main goals that WeSAR tries to improve are the localization accuracy and the energy efficiency of the wearable device. In this paper, the authors propose an energy-efficient mechanism for LoRa networks, taking into consideration the energy of a real wearable device, containing multiple sensors in a SAR scenario. In this work, we simulate the LoRa network, taking into consideration the various states of a wearable device and the impact of the sensors on the energy consumption, in order to have insights into the mechanism's efficiency with multiple nodes, up to 500 nodes. The experiment results reveal significant reductions in the energy consumption of the wearable device and improvement of battery life, in urban and suburban conditions, and in stationary and no stationary node mobility models.**

Keywords— LoRa, simulation, IoT, FLoRa, energy efficiency

I. INTRODUCTION

Internet of Things (IoT) is one computer engineering domain that faces rapid development, as IoT applications are growing. Many IoT applications, such as Search and Rescue (SAR) operations, need long-range and energy-efficient communication, and as a result, a new category of wireless technologies has been developed, called Low Power Wide Area Networks (LPWAN). Technologies that can be characterized as LPWAN, are the Narrow Band IoT (NB-IoT), SigFox, Long Range (LoRa) [1][2], and Weightless [3].

LoRa [4] is a new IoT technology that empowers long-range communications while providing important power efficiency. LoRa is based on Chirp Spread Spectrum modulation (CSS) technique. LoRa Technology enables smart IoT applications that copes with a variety of modern challenges. In LoRa networks, the nodes usually connect directly to the gateway, in a star topology, in contrast to other technologies that use other topologies, such as mesh.

One LPWAN application is Search and Rescue (SAR) systems. SAR is the process of locating and rescuing people that are in danger. IoT and the use of wearable devices can help SAR operations. In paper [5] a path loss formulation and study for SAR scenarios in mountainous terrain based on LoRa networks has been conducted. In paper [6] the authors investigated and implemented a tracking system for search and rescue workers, based on various wireless technologies, such as Ultra-WideBand (UWB), LoRa, and NB-IoT. In paper [7] a feasibility study was conducted about the use of LoRa for emergency services. The issue of energy efficiency in LPWANs has engaged researchers all over the world. Authors in [8] analyze a SIGFOX-based heterogeneous network architecture for low-power devices and extensive experimentation and energy modeling have been performed. Authors in [9] analyze the feasibility of over-the-air (partial) software updates for three LPWAN technologies (LoRa, SigFox, and IEEE-802.15.4g) and discuss the best-suited update method for different scenarios. Finally, the authors in [10] analyze the flexibility of LoRa and propose various strategies to adapt its radio parameters (such as the spreading factor, bandwidth, and transmission power) to different deployment scenarios. The authors compute the energy consumption of LoRa transceivers using various radio configurations in both star and mesh topologies.

This work presents the findings of Wearable based Search And Rescue system (WeSAR) project [11], in terms of energy consumption. WeSAR is designed to tackle the problem of people suffering from dementia, autism spectrum disorders, etc. getting lost. Such a system is very significant, as about 50% of the people suffering from autism spectrum disorders have tried to elope from their parental supervision [12], something that can be dangerous for both the people that eloped and stressful for their caretakers. These factors have been the driving force for the WeSAR system. Two important aspects of a SAR system are energy consumption and localization accuracy, two aspects that have been taken into consideration in the WeSAR project. The aim of this paper is to propose an energy-efficient mechanism for LoRa networks that tries to reduce the energy consumption of the end nodes (the wearable devices). To the best of our knowledge, there is not any similar research that focuses on LoRa energy efficiency for SAR application. After the description of the proposed architecture and the energy-efficient mechanism, we simulate this architecture using the FLoRa network simulator [13] and extend it in order to better match the capabilities and the cases we need to simulate. The LoRa network simulation is important for WeSAR system design and implementation, because it allows the study of the performance of the proposed energy-efficient mechanism, before moving to costly implementation. This gives insight into the problems that need to be solved before the implementation. In addition, the system can be evaluated and have some quantitative results for the system in the earlier stage, for many nodes up to 500, something not feasible for the time being. The energy consumption model of the device is derived from the Dialog wearable DA 14681 [14] which will be used in the context of the WeSAR's project. It is important to mention, in contrast with most of the related work, that during our experiments we took into consideration also the energy consumption of the

978-0-7381-1316-6/21/$31.00 ©2021 European Union

embedded hardware and not only the energy consumption of transmission, in order to have more accurate results. Finally, in contrary to [15] [16], the mechanism has been tested not only assuming the nodes to be stationary but also with other node mobility models.

The rest of this work is organized as follows: Section 2 briefly describes the basics of LoRa technology. We briefly discuss the available tools for simulation and the simulator we finally used in Section 3. Section 4 presents the architecture of the system to be simulated and examined. After that, Section 5 presents the energy-efficient mechanism we propose. Section 6 presents the simulation results of the system. Finally, Section 7 presents the conclusion and the future work of our paper.

II. LORA TECHNOLOGY

LoRa technology consists of two main parts. The first one called LoRa, being the modulation technique represents the physical layer, while the second part called LoRaWAN refers to the open specification protocol developed by the LoRaWAN Alliance [1], [17]. The physical layer of LoRa aims to provide the ability to communicate in an energy-efficient way for energy-constrained devices over long distances, supposedly coverage capability over 15 km Line of Sight (LoS). It is similar to CSS modulation allowing to provide a trade-off among the data rate, energy consumption, and coverage. The physical layer of the LoRa is proprietary, and the documentation is not freely available to the scientific community [1][17]. In contrast to the physical layer of LoRa, LoRaWAN is promoted by the LoRa Alliance [1] that is consisted of various companies such as Semtech, IBM, etc. It defines the communication protocol of the network and is a Medium Access Control (MAC) layer protocol. One of the main characteristics is the fact that is open access.

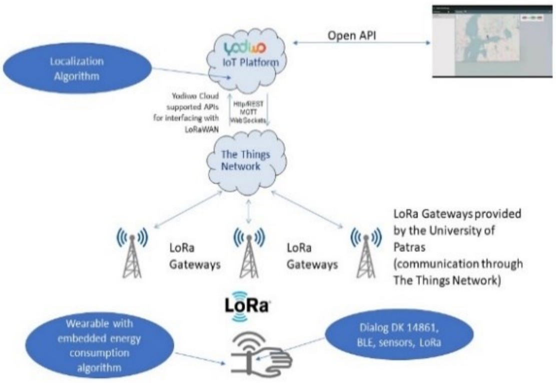

Fig. 1. General Architecture of WeSAR system

III. LORA SIMULATORS

There are different LoRa simulators available to the scientific community. In our previous work [18] we have made a comparison of the features of the PhySimulator, FloRa, and LoRaSim simulators in terms of operating system support, programming language use, the license type, the Graphical User Interface (GUI), etc. Based on [18] we choose to use the FLoRa simulator for our simulations. The FLoRa simulator is based on OMNeT++, a discrete event simulation library that is distributed under the Academic Public License. Despite the OMNeT++ framework, FLoRa, is based also on the INET Framework [19], which is an open-source library for an accurate model for various network technologies and protocols. The above features are crucial because allow the simulation of all the layers of LoRa, plus through INET library it gives quite realistic modeling of the backhaul part of the system. Finally, it gives statistics for the energy consumption, through a GUI. FloRa is written in C++ and NED language. It allows the ability to add LoRa nodes, network servers, and LoRa Gateways [13]. Furthermore, its modules aim to simulate the physical layer and the LoraWan MAC protocol. FLoRa provides a very good graphical interface because it is based on the OMNeT ++ and a graphical representation of the network.

IV. ARCHITECTURE

The WeSAR system architecture consists of wearables devices, equipped with LoRa transceivers. After an evaluation of the available solutions, the consortium has concluded the use of the DA 14861 wearable in which a LoRa module will be added. The LoRa gateways that were used in the project are the MultiTech Conduit LoRa Gateways [20]. The communication of the wearables through LoRa is done as follows: the wearable device transmits data with the use of LoRaWAN protocol. The encrypted data that are broadcasted can only be read by the end recipient who has the appropriate decryption keys. When a Gateway receives a packet via LoRa, it converts it to an IP packet and relays it to the Network Server. The Things Network (TTN) [21], a global LoRa open management network, plays this role, in WeSAR system. After that, the Application Server, Yodiwo's IoT Platform [22] in the case of WeSAR project, will receive the packet and process it.

Fig. 2. Left: the DA 14861 wearable device with the jtag debugger, Right: the conduit LoRa Gateway located in the University of Patras campus

The user/supervisor will be able to monitor the location of the person having the wearable device through the web or the mobile application. The application takes the information from Yodiwo's Cloud infrastructure in which the data are stored. Specifically, the biometric data of the sensors is kept, and the estimation of the user locations is done in the cloud. Fig. 1 presents the architecture of the WeSAR system, and Fig. 2 on the left presents the DA 14861 wearable device with the jtag debugger, and in the right the LoRa Conduit Gateway, in the University of Patras.

V. ENERGY EFFICIENT MECHANISM

One of the factors contributing to the battery life of IoT devices is the use of sensors. Especially for wearables devices with many sensors, it is important to understand which sensors are important depending on the use case of each scenario. In a SAR scenario firstly, the user's states need to be defined. In WeSAR system, the following user states are assumed: (1) No danger: The user uses the wearable device in various activities. The device sends the position and the biometric information to the LoRa GW. The communication rate should depend on the battery level. Thus, depending on the battery level, the rate decreases as the battery life decreases. (2)

Emergency: a) The user is out of a predefined region, set by the administrator. b) The user wearing the wearable device presses the panic button. c) The responsible person for the user using the wearable e.g. the parents of the child wearing the wearable device, sets an emergency state.

The wearable device has various sensors that affect battery life and are not useful for the detection of the user. In order to achieve energy efficiency on the devices, we define the following three operating states: (1) Idle: in this state, the wearable device sensors are on sleep mode, consuming the least energy. (2) Normal: in this state, the wearable device sensors are measuring and the LoRa module transmits the measurements to the cloud. This wearable's state is perfectly matched with the no danger scenario for the user wearing it. (3) Emergency: in this state, all the sensors are switched off, except for the sensors that are crucial for the detection of the user, in order to expand the battery's life. The device is set in this state when the user is in an emergency.

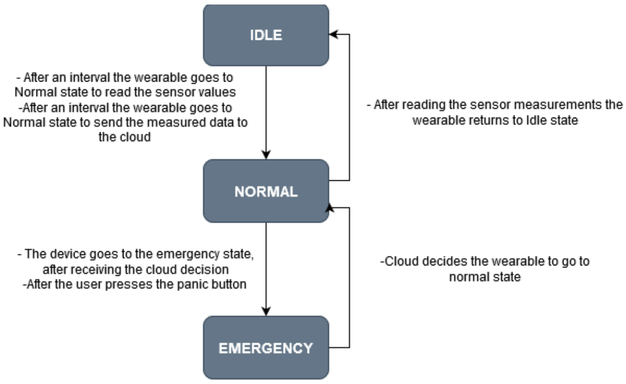

Fig. 3. State transition of the architecture

A decisive factor for energy consumption is the rate at which the sensors collect and send data. Therefore, it is important to dynamically change the rate based on the user's and wearable's state. This rate is determined by an algorithm running in the cloud.

Among other things, the following will be considered: When switching from normal to emergency state, data transmission rate increases, as it is vital for finding the user, resulting in reduced battery life. The increase of the data transmission can help to capture the route of the person that got lost. Especially, for the cases where the people can move e.g. children that have left a specified region, it is helpful to know the child's location. Since these changes are made based on the algorithm that will be executed in the cloud, it can change depending on the state of the battery so that the rate in each state is not always the same but optimized according to the existing conditions. For example, if the battery is below a value e.g. at 30 % in normal / idle mode, the transmission rate would be lower than if the battery was 90 %. This also extends to emergency mode, where the rate of data transmission is adjusted depending on the battery level. When the battery is low, the transmission frequency should be lower.

Now, we need to define the way the device can transit from one state to another. Fig. 3 shows the state transition mechanism. Starting from the idle state, the transition to normal is as follows: Every x seconds switches from the idle state to normal, to read sensor values, and then switches back to idle mode. Also, in each y seconds, the wearable switches from idle states to normal and after reading the sensor values, the wearable transmits the data. After sending the data, the wearable device waits for any messages from the cloud, according to the LoRaWAN protocol, and then returns to the idle state. From the normal state the wearable can transit to the emergency state for the following reasons a) the cloud sends a downlink message that dictates that the wearable needs to be in the emergency state. When the wearable is in the emergency state, it returns to the normal state when the appropriate downlink message from the cloud is sent. The supervisor sets the state through the web or mobile application. The pseudocode of the mechanism is presented, giving more details about how the energy consumption mechanism works.

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=Y;
     else
         X = Y / value_emergency;
 else
     if (state == EMERGENCY)
         Y = Y_emergency; X=Y; sensors);
     else
         X = Y;
if state == EMERGENCY:
   suspend(unnecessary sensors for localization)
else:
    activateAllSensors()
```

VI. SIMULATION RESULTS

As we have already mentioned, the LoRa network simulation is important for WeSAR system design and implementation, because it allows the study of the performance of the proposed energy-efficient mechanism, before moving to costly implementation. This gives insight into the problems that need to be solved before the implementation. In addition, the system can be evaluated and have some quantitative results for the system in the earlier stage, for many nodes up to 500, something not feasible for the time being. In order to simulate an accurate scenario of the WeSAR system, we have to simulate also the wearable device which is based on DA 14861 made by Dialog. 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 1. According to the equation:

$$P = V\,I$$

we can measure the power consumption through Voltage and Current.

TABLE 1 THE CURRENT AND POWER CONSUMPTION

Mode	Current (µA)	Power Consumption (µW)
Hibernate	90	342
Normal	21.106	80.202,8
Emergency	2.300	8.740

The above values are taken into account in all states, for the simulation to be more realistic. So, we have changed and updated the LoRaEnergyConsumer.cc, LoRaEnergyConsumer.h files, in order to have both the energy consumption of the transmission and the operating energy consumption of the embedded system, thus making the approach more realistic.

The path loss model we used is based on the Log Normal Shadowing Model for urban and suburban. The Log Normal Shadowing Model is shown in the Eq. 2. In the suburban case, the parameters were taken for the case of Oulu [15].

$$PL(d) = PL(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma \quad Eq.2$$

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

The parameters we have used for our simulations are based on the results of the papers [15], and [16] that describe the urban and sub-urban cases. In Table 2, the used simulation parameters are presented. The system was tested in both urban and suburban environments.

TABLE 2 LORA PARAMETERS

Parameter	Value
Carrier Frequency	868 MHz
Bandwidth	125 kHz
Code Rate	4/8
Transmission Power	2 to 14 dBm
Number of Gateways	1
Number of nodes	100 to 500
Urban n	2.08
Sub-urban n	2.32
Urban PL(d_0)[dBm]	127.41
SuburbanPL(d_0)	128.95

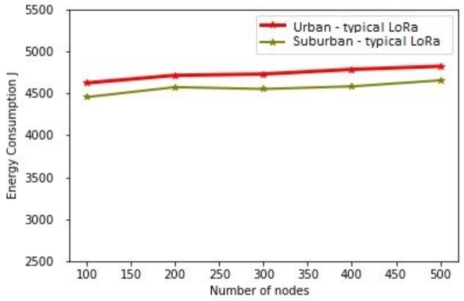

Fig. 4. Average energy consumption per nodes for typical LoRa system

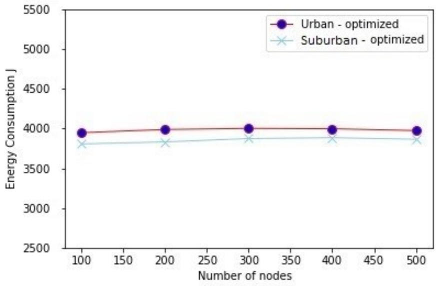

Fig. 5. Energy consumption for optimized cases

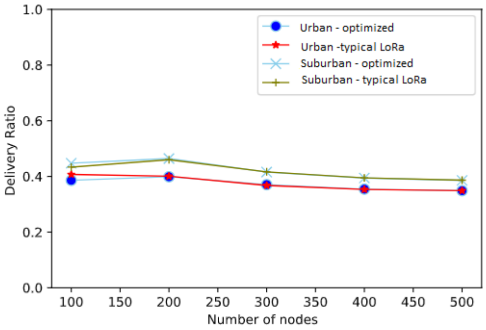

Fig. 6. The delivery ratio in each case for stationary mobility scenario

In all of our experiments, we only had one gateway and we tested the cases of 100-500 nodes with 100 nodes step. In terms of node mobility, we tested three mobility models based on the INET [19] mobility models. We were interested in testing two important metrics. The first metric is the energy consumption of the nodes. As mentioned before, the simulation was of high fidelity, simulating the energy consumption of the modules of the wearable. The second metric was the delivery ratio. The delivery ratio is calculated as the ratio of the packets received by the Network server successfully, divided by the sum of the total packets sent by the nodes. Moreover, in order to simulate urban conditions apart from the LoRa values presented in Table 2, the specified area assigned for the nodes deployment was 480*480 m^2 and for the suburban scenario, the area was 9600*9600 m^2. The energy-efficient mechanism was implemented in the network server as shown in the state diagram of Fig. 3. The transition of the user's states was implemented as follows: the network server checks the current state of the device and randomly, following the Poisson distribution decides if it will change the Emergency state (by sending the appropriate message to the device) or to remain in the same state. The sequence of the available states is shown in Fig. 3.

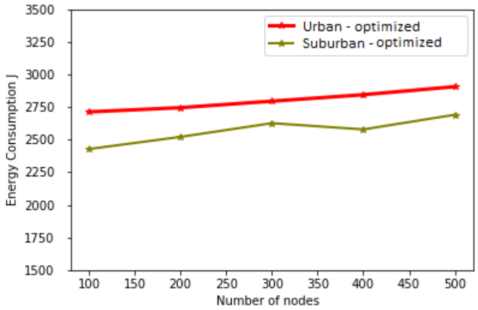

Fig. 7 Energy consumption for typical LoRa

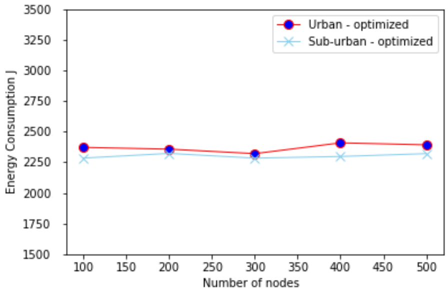

Fig. 8 Energy consumption for optimized cases in the linear mobility scenario

In the first scenario presented, the mobility model of the nodes in the simulation was the StationaryMobility model [19]. In this model, the nodes were arranged randomly, according to the normal distribution and the nodes did not move. The results for the stationary mobility model are presented in Fig. 4, 5,6.

As in many applications, the nodes are moving (e.g. tracking applications, SAR systems), we changed the mobility model of Stationary to LinearMobility. As it is presented in the documentation of INET [19], the LinearMobility model emulates the case of the node is moving at 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 Fig. 7, Fig. 8, and Fig. 9.

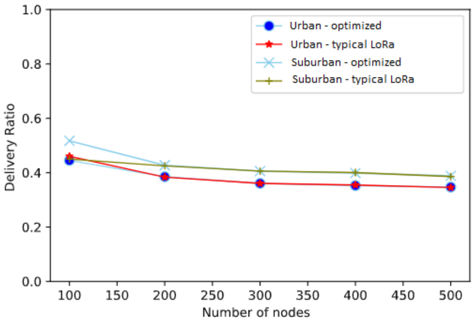

Fig. 9 The delivery ratio of each case in Linear mobility scenario

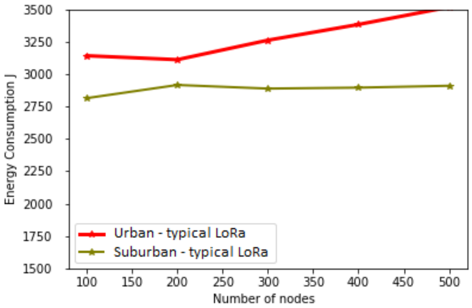

Fig. 10 Energy consumption for typical LoRa in Mass mobility scenario

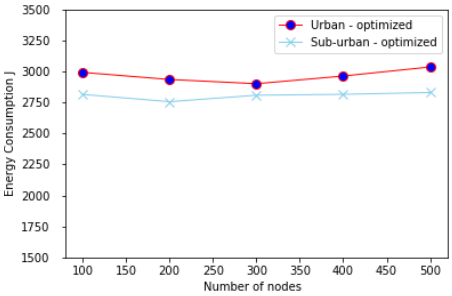

Fig. 11 Energy consumption for optimized cases in Mass mobility scenario

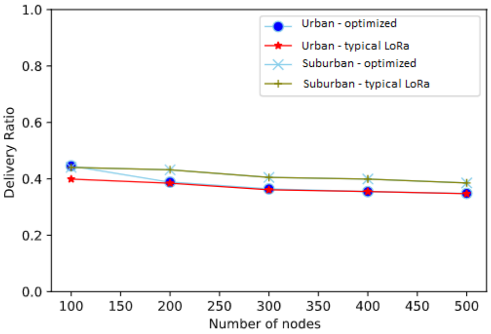

Fig. 12 Delivery ratio of each case in Mass mobility scenario

Moreover, the mechanism was tested with nodes having the MassMobility model. As it is described in the documentation of INET [19], the MassMobility model emulates the case of a node with mass with inertia and momentum. In contrast to the LinearMobility, MassMobility model does not have a specific speed, the speed is set randomly according to the normal distribution, too. Also, the moving period before making a turn is normally distributed with an average period of 2 seconds and a standard deviation of 0.5 seconds. In the simulation the parameters are:

- changeInterval = truncnormal(2s, 0.5s)
- angleDelta = normal(0deg, 30deg),
- changeAngleBy = normal(0deg, 30deg)
- speed = truncnormal(15mps, 5mps)

The results of the experiment with Mass mobility model are presented in Fig. 10, 11 ,12.

In Fig. 4, 7, 10, the average energy consumption per node in the two path loss models for the typical LoRa deployment case is presented, for the Stationary mobility, Linear mobility, and Mass mobility scenarios respectively. In Fig. 5, 8, 11 the average energy consumption for the optimized case is presented for both urban and suburban cases is presented, for the Stationary, Linear, and Mass mobility models respectively. 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 all three mobility models. Furthermore, in Fig. 6, 9, 12, the delivery ratio is presented for the Stationary, Linear, and Mass mobility models. The delivery ratio is not decreased and is not affected by the mechanism, both in urban and suburban scenarios. The figures show that the delivery ratio is almost identical in the optimized and typical LoRa deployment cases. Therefore, the proposed mechanism in a SAR case can be lifesaving for the lost person because it decreases the energy consumption while maintaining the same delivery ratio. A decrease in the delivery ratio could be fatal because it can affect the accuracy of detection algorithms. It is our firm belief that while designing real-life systems, it is crucial to understand 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, you can map the user's use cases with the hardware's capabilities. Thus, after understanding the behavior of the target group you can further reduce the energy consumption. This arise another aspect, except for the use of algorithms, energy efficiency can be achieved by studying the people's use cases and the problem itself.

VII. CONCLUSION AND FUTURE WORK

In this paper, we used the FLoRa simulator, to test and study the proposed mechanism with lower risk before stepping toward the expensive implementation and investment. We tested the mechanism with the use of FLoRa simulation environment [13], for both urban and suburban conditions, and in three node mobility models, showing that we can achieve better energy consumption. Last but not least, it is worth mentioning that the simulation setup was high fidelity in contrast to the simulations usually conducted in the literature, as generally it is not taken into consideration all the components of a real wearable, rather only the LoRa module.

Future work will be the extension of the experiments of the proposed mechanism to the real conditions and a comparison of the results will be examined. Also, studying and creating more sophisticated algorithms and techniques, such as using machine learning techniques in the framework of energy efficiency of LoRa networks will be a top priority.

ACKNOWLEDGMENT

This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH - CREATE - INNOVATE (project code: T1EDK-01520).

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