Exploring the energy efficiency for Search and Rescue operations over LoRa

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***Abstract*—The Internet of Things (IoT) is one of the pioneering domains of Computer Science and Engineering, that comes to solve a plethora of real-life problems. One of the most promising technologies that aim to provide long-distance transmission while retaining energy consumption at low levels, is Long Range (LoRa). In this paper, a thorough study of the energy efficiency in LoRa based Search and Rescue (SAR) project for people with special needs, called Wearable based Search And Rescue system (WeSAR) is presented. After research the authors propose a LoRa based system, taking into consideration the energy efficiency. The results of the proposed mechanism are encouraging in terms of energy consumption, and the battery can last enough for the majority of the SAR operations, even when the battery is not fully charged. Also, there is no deterioration in terms of the delivery ratio of the network which is important for localization algorithms.**

Keywords—LoRa, LPWAN, IoT, Search and Rescue

I. INTRODUCTION

As the Internet of Things (IoT) market is expanding rapidly, creating numerous technologies to support the notion of IoT. Many applications have been created, such as Industry 4.0, Smart Homes, Search and Rescue (SAR) operations, etc. The heterogeneity of IoT has enabled the creation of various wireless technologies, such as Low Power Wide Area Networks (LPWAN) [1]. LPWAN technologies come to fill the gap between the short-range wireless technologies, such as Bluetooth and Wireless-Fidelity (Wi-Fi) [2], and the long-range cellular wireless technologies, such as Long-Term Evolution (LTE). A very competitive LPWAN technology is Long-Range (LoRa) [3] technology. As presented in paper [4] the SAR operations can have different durations, ranging from a couple of hours to several days. Thus, the energy consumption of the IoT device is crucial.

The WeSAR project is created in order to help the SAR operations. The WeSAR project helps the monitoring and localization of people that have a high probability to elope from the attention of their supervisors, such as in the cases of children suffering from spectrum order disorders, or elderly people suffering from dementia. In the WeSAR project, a LoRa based system is proposed for SAR operations achieving two main goals: high location accuracy and energy efficiency. This is achieved by using solely LoRa without Global Positioning System (GPS), as GPS drains the battery quickly, and changing the wearable's devices parameters dynamically. As far as the location algorithms are concerned, novel algorithms are used, to deal with the lack of GPS. The main parts are the Yodiwo's cloud platform [5], The Things Network (TTN) that is the network server platform that is used, the wearable device that is the Dialog's DA 14861 [6], in which the WeSAR partner Econais incorporated a LoRa module, the localization algorithms, and the energy-saving mechanism.

The WeSAR project relates to the following papers. In paper [7] an IoT based application has been developed for SAR operations. In contrast to other works, the user of the IoT device is the rescue dogs. The IoT device equipped with different sensors gives the rescuer critical information about the dog's health, while the dogs are searching, and gives the ability to give a signal to the dogs to return. In paper [8] the authors use IoT in combination with unmanned aerial vehicle (UAV) for SAR operations. Specifically, with the use of UAVs, supportive information is provided to the rescuers. In paper [9] the authors have investigated the LoRa path loss models for mountainous terrains, in order to understand the feasibility of using LoRa for SAR operations in skiing scenarios. The results were promising, thus LoRa could be used for such scenarios. Also, in paper [10] the authors proposed a tracking system that uses both GPS and LoRa technologies for people suffering from dementia. As the Experiments section show the proposed approach achieves longer battery life compared to paper [10].

The main goal of this paper is to present the findings of project WeSAR, in term of energy consumption optimization. In this paper, the energy consumption of the Dialog's DA 14861 wearable (in which the WeSAR device is based) in LoRa networks has been studied. Furthermore, taking into account the paper [4], the authors of this paper tried to propose an energy-efficient mechanism that could expand the battery's life as far as the max SAR duration described in the paper [4]. The most important things that affect the energy consumption are the rate of the data transmission over the LoRa, and the rate of the sensor measurements. So, the trade-off between the rate of the data transmission and the rate of the sensor measurements was investigated, taking into consideration the findings of the paper [4] and the user's needs and states (e.g. if the user is in the emergency state, etc.). Furthermore, we extended the energy profile of the End Devices (ED)s of the LoRasim simulator, to match both the hardware characteristics of the Dialog's DA 14861 and the user's states. The extended version of the LoRasim was used to test the proposed mechanism with many EDs, as it is impossible to test the mechanism with a large number of real EDs at the moment, for both urban and suburban conditions.

II. ARCHITECTURE

A. WeSAR system architecture

In this section, the WeSAR system architecture is presented. The system consists of 4 main parts: a) End

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Devices (ED), which in the context of the WeSAR project are wearables based on Dialog's DA 14861 platform. The consortium has integrated LoRa modules in the wearables, as the wearables are not equipped with the LoRa modules natively. b) The Gateway (GW), which is a device responsible for translating the packets transmitted through LoRa to Internet packets and vice versa. The GW relays the LoRa packets to the respective Network Server (NS). c) The NS is a server responsible to supervise and set the network parameters. In the WeSAR project, The Things Network (TTN) [12] is used as the NS. d) The Application Server (AS) is responsible for the WeSAR applications, and the Yodiwo's Cloud platform [5] is used. Moreover, the localization algorithms that are based on Machine Learning (ML) techniques are running in Yodiwo's cloud platform. In Fig. 1 the general WeSAR architecture is presented.

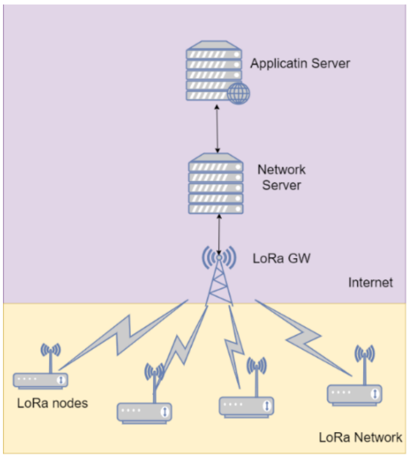

Fig. 1. The General WeSAR architecture

B. *Simulation environment*

TABLE 1 LORA PARAMETERS USED IN THE SIMULATIONS

Parameters	Values
Carrier Frequency	868 MHz
Bandwidth	125 kHz
Coding Rate	4/8
Transmission Power	2-14 dBm
Packet size	20 Bytes
d_0 (urban case)	40 meters
d_0(suburban case)	1000 meters
$PL(d_0)$ (urban case)	127.41 dB
$PL(d_0)$ (suburban case)	128.95 dB

The reason that the simulation is necessary is that it gives information before the implementation, and in contrast to real deployments, we can scale to many EDs and GWs up to 500 EDs, something impossible for the time being in the WeSAR project as it hasn't been rolled out commercially yet. The simulation environment that was used - LoRaSim [14] - was chosen based on the paper [13]. As far as the LoRa simulation, the LoRaSim simulates the EDs and GWs, without including the NS and AS. Furthermore, the modeling of LoRa links includes the path loss where in this case the log-distance path loss model is used, and is presented in Eq.1, with parameters shown in Table 1. $PL(d)$ represents the path loss for distance d, the $PL(d_0)$ is the path loss for a reference distance d_0, the n is the path loss exponent, and X_σ is a random Gaussian variable with a standard deviation σ, representing the Shadowing effect. Transmission is considered successful if the received signal power by the GW is greater than the sensitivity. As far the signal interference is concerned, two signals that use different Spreading Factors (SF) can be received successfully simultaneously by the GW. If the signals have the same SF values, then the signals collide. Apart from the SF orthogonality, the capture effect is taken into consideration. The capture effect in LoRa networks dictates that two signals that interfere with the same SF value, will not collide as expected if one of the two signals is strong enough. The stronger signal will overlap the weaker and it will be received by the GW.

$$PL(d) = PL(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma \qquad Eq.1$$

III. ENERGY CONSUMPTION OPTIMIZATION MECHANISM

A. *The mechanism formulation*

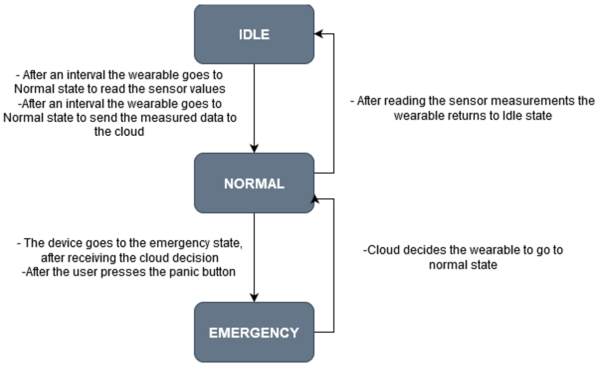

Fig. 2. The transition of the wearable device's state

To expand the battery life, firstly, it is assumed that the user's wearable can be in three states a) Idle b) Normal c) Emergency. In the Idle state, the sensors of the wearable are in the idle state and consuming the least energy, and in normal the sensors are taking measurements, thus consuming a greater amount of energy. In the emergency state, the wearable is shutting the unnecessary for a SAR operation sensor, such as the pedometer. This happens for two reasons. The first is that by suspending the operation of not vital sensors, the battery life is expanding. Secondly, the transmission rate can be increased, as it would be useful for the user localization process, thus the LoRa module is prioritized. An increase in the transmission rate leads to an increase in energy consumption, so it is necessary to shut down the sensors that are not vital. In Fig. 2 the state transition is depicted. The wearable device is in the idle state for a period and then moves to the normal state to take the sensor measurements or to take the sensor measurements and transmit them through LoRa. Then it returns to the idle state. When the user is in danger or exited the predefined region, then the wearable device moves to the emergency state. When the danger stops to exist, the wearable device returns to the normal state.

B. *Simulation environment: the extensions made for WeSAR*

Although the LoRaSim is one of the most well-known simulators of LoRa networks, we needed to make changes to make it more realistic. Thus, the energy consumption model was changed. The energy consumption is calculated as follows:

$$E_{idle} = \sum T_{sleep} * P_{sleep}$$

$$E_{air} = \sum T_{airtime} * (P_{normal} + P_{LoRa})$$

$$E_{normal} = \sum T_{normal} * P_{normal}$$

$$E_{Emergency} = \sum T_{Emergency} * P_{Emergency}$$

Where: E_{Idle}: Energy consumption in idle state, E_{air}: Energy consumption in transmission, E_{Normal} : Energy consumption in normal state and $E_{Emergency}$: Energy consumption in an emergency state. As far as the battery model is concerned, a simplified linear model is considered, as proposed in paper [19].

Fig. 3. MultiTech Conduit LoRa Gateway located in the University of Patras

TABLE 3 POWER CONSUMPTION OF THE DIALOG'S DA 14861 IN THE DIFFERENT STATES

Mode	Current(μA)	Power Consumption (μW)
Sleep	90	342
Normal	21106	80202.8
Emergency	2300	8740

As for the power consumption model, the power consumption values and the voltage are based on the transceiver SX 1272, manufactured by Semtech and incorporated in the wearable DA 14861. Each ED, in terms of data transmission, can be in one of the following three states a) transmission b) idle and c) packet reception. Table 2 shows the energy consumption values of the wearable DA 14861. In particular, a prototype of the wearable device is presented in Fig 3 with the jtag debugger (in the left), and the GW used is the MultiTech Conduit LoRa GW [15] and is shown in Fig.3 (in the right).

IV. EXPERIMENTS

Two crucial parameters that are affecting the energy consumption in the wearable device, are the transmission intervals (let be Y) and the sensor measurement intervals (let be X). As we have already mentioned, the main scope of this paper is the optimization of energy consumption based on the optimization of the X and Y mentioned above. In order to study the impact of these parameters, various simulations have been conducted. Firstly, the simulations included only one ED and assumed that ED operated only in the normal state. The experiment lasted for 86400 seconds (1 day) and the X parameter had values 10 - 50 with 10 seconds step whereas the Y parameter had values 60 - 300 with 60-second step. As shown in Fig. 4, for a particular Y, as X increases, there is a decrease in energy consumption, but this decrease is not linear with the increase of X. This happens because, in order to send the data, the sensor measurements are taken. Therefore, the values $X\epsilon\left(\frac{Y}{2}, Y\right)$, are not considered, because, in the time Y, the sensors will be measured, as well. Finally, looking at the diagrams we notice that we have a decrease again when X = Y.

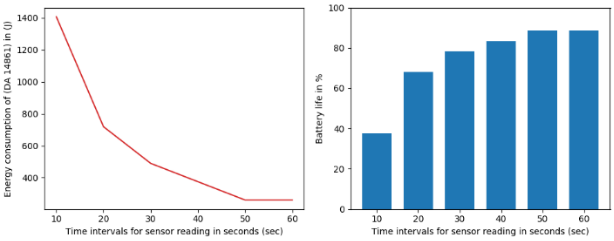

Fig. 4 Power consumption for X 10-60 seconds and Y 60 seconds

Based on the above observations, a mechanism for reducing energy consumption was developed based on the battery level of the device and is presented below.

Pseudo code of the Mechanism

```
Cloud sends downlink to the ED
 If (BatteryLevel >= BATTERY_HIGH)
     If (state is 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 is EMERGENCY)
          Y = Y_emergency; X=Y
      else
          X = Y;
```

To evaluate the above mechanism, an experiment was performed for 777600 seconds, i.e. for a period of 9 days. As Fig. 5 shows, the wearable device can operate until 2 days before running out of energy, when X has a fixed value. If the energy saving mechanism is enabled, a reduction in consumption is achieved, resulting in the battery can last for up to 8 days, as presented in Fig. 6.

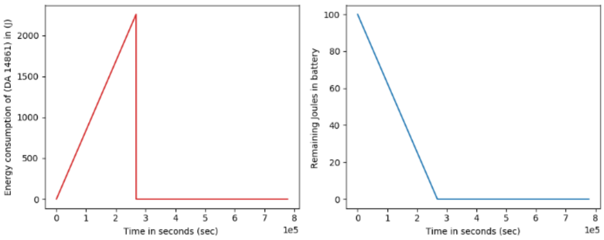

Fig. 5 Power consumption and battery percentage for two days of use, without the power saving mechanism, while the user is in Normal mode

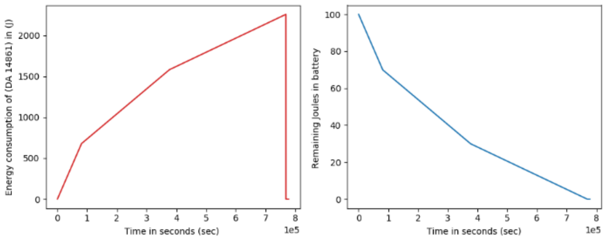

Fig. 6 Power consumption and battery percentage for 9 days of use, with the energy saving mechanism, while the user is in Normal mode

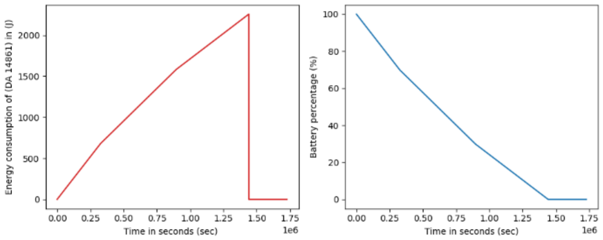

Fig. 7 Power consumption and battery percentage for 20 days, with the energy-saving mechanism, while the user is in the Emergency state

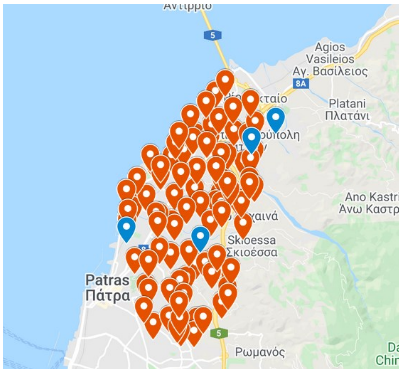

Fig. 8. The topology of the GWs (in blue) and EDs (orange) in Patras

Furthermore, the simulations included the emergency state. The characteristic of the emergency is the increase of the transmission rate, thus leading to an increase in energy consumption. So, to deal with the increase of the energy consumption due to the higher transmission rate, the unnecessary sensors are suspended. Fig. 7 shows the power consumption and the percentage of the battery when the user is in the emergency state, and the power saving mechanism is activated. As it turns out, the battery can last about 15 days. In order to examine the effect of the aforementioned mechanism in other aspects, we tested the mechanism in a simulation setup with multiple EDs and 4 GWs, using as a metric the Data Extraction Rate (DER) and the average energy consumption of EDs. DER is defined as the ratio of received messages to transmitted messages over a period of time [16]. These two metrics were used because both metrics are very crucial in SAR scenarios. As explained, the extension of the battery life can be lifesaving for the user, but delivery DER is important as well because the localization algorithms are based on the packets that the EDs send. The area in which the EDs and the GWs are placed in Patras and Rion, in Greece.

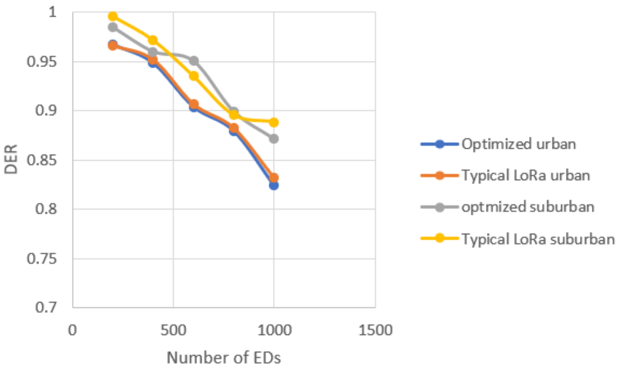

Fig. 9 DER for the typical LoRa deployment and the optimized version

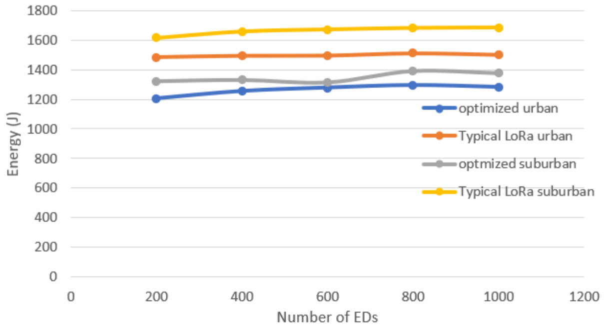

Fig. 10 Average consumption of the EDs.

The number of EDs is as low as 200 and as high as 1000. The number of the GWs is 4 because in the WeSAR project 4 GWs are available and are necessary for the research of the EDs localization using the method of Time Difference of Arrival (TDoA). The localization research is conducted by a partner member. In Fig. 8, the topology of the simulation is presented, with 4 GWs and 100 EDs. The points with orange color are the EDs, whereas the blue points are the GWs. Each EDs randomly chooses a Y value from the set {60, 120, 180, 240, 300} seconds. Here it is necessary to note that the system abides by the ISM restrictions. So, the Y values adapt under the ISM restrictions. Specifically, when the uplink transmissions must have SF value 12 the options 60, or 120 seconds are not supported, as these values do not comply with the 1% duty cycle. Also, the following assumptions were made: a) the topology was assumed to be two dimensional (thus in only the latitude and the longitude are taken into account), b) no obstacles were assumed to be present between the EDs and the GWs c) ideal channel was assumed (without the shadowing), thus in the simulations the reason that packets were lost was the collisions between packets having the same SF value, c) we suppose that the EDs change the SF and the transmission power values according to their distance from the GW (See more in paper [16]).

A. Discussion

The paper [4] studies the existence of a rule for the selection of SAR operations based on the search time duration, in order to maximize the rescue of the living missing people. According to this work [4], for a large number of survivors n = 1439, the average value of the search duration is 7.9 hours with a maximum duration of 323 hours or about 13 days. Specifically, by an estimated cut-off point of 51 hours, almost all the survivors have been located, whereas by 100 hours almost all the lost persons, dead or alive have been located (not rescued). Therefore, the battery life using the consumption mechanism in Emergency mode is sufficient for most cases. It is worth noting that in many cases using this mechanism can help the SAR operations, even though the wearable's battery is not fully charged, because in many cases even with 50% battery life, it is enough to last until the SAR operations are conducted.

Additionally, if we discuss the comparison of this system in contrast with other systems, we have achieved better energy consumption. Particularly, in work [10], the authors implemented a monitoring system consisting of a GPS module and a LoRa module aiming at people suffering from dementia. Their results showed that the battery life of their system providing GPS tracking with a location update of 60 seconds can last up to 40 hours. In our system, with a 60 seconds 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. Despite the absence of a GPS module in our system, we maintain high localization accuracy. This happens for two main reasons: a) Machine Learning algorithms for the localization was applied, as explained in paper [17], the WeSAR system achieves acceptable localization accuracy as far as the RSSI values are concerned, b) and by using Time Difference of Arrival (TDoA), the location estimation error drops around 50 meters. Moreover, if the proposed system is compared in the system described in the work of the paper [9], in the emergency mode they claim that the battery life can last around 5 hours, while in this paper's proposed system can last more by far more. Last but not least, in Fig. 9 the DER is presented for the optimized case and a typical LoRa deployment, for the urban and suburban cases. As presented, the DER is not affected by the proposed mechanism, as the two lines are almost identical in the urban and suburban cases. This happens because we do not change any LoRa parameter that can lead to collisions (such as the SF). Moreover, in Fig. 10, the average consumption of the EDs is presented for the typical and optimized cases for urban and suburban conditions. Here, there is a significant reduction in energy consumption in both urban and suburban conditions.

V. CONCLUSION AND FUTURE WORK

In this paper a mechanism to reduce the energy consumption of EDs that are being used for monitoring of people that have a great probability to be lost. After obtaining some data concerning the wearable device, the LoRasim simulator was extended to test the proposed mechanism and understand the behavior in cases with many EDs. For future work, it is intended to collect data from the real deployment for a large number of EDs to verify our simulation-based results. Also, in real large-scale deployment will be incorporated with Machine Learning techniques [18], [20] in order to evaluate if it is possible to further decrease the energy consumption by combining these two methods.

ACKNOWLEDGMENT

This research has been co‐financed by the European Regional Development Fund of 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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