Geolocation Solver of IoT Devices for Active and Assisted Living

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***Abstract*— Latest enhancements in IoT devices and in communication technologies, has brought new ideas that are capable of providing advanced sensing of the surrounding environment. On the other hand, average life expectancy has grown, resulting in a considerable increase in the number of elderly people. Consequently, there is a constant search for new solutions, to support an Active and Assisted Living (AAL) of these people. This paper aims to propose a solution to help in knowing the location of IoT devices that could be helping these people. The proposed solution takes into consideration the risk factors of the target persons, at any given time and as well as the technical constraints of the device, such as available power and communications. Thus, a profile-based decision is taken autonomously either by the device or its integrated system to ensure the use of the best geolocation technology in each situation.**

Keywords: Internet of Things, Low Power Wide Area Networks, Geolocation, Active and Assisted Living

I. INTRODUCTION

By 2050 the amount of people with dementia will be tripled to 132 million, with societal economic costs accounting for 1% of global GDP [1]. Dementia is characterized by progressive loss of memory, as well as other mental faculties including language, judgment, planning, social interaction, and leads to serious problems in coping with activities of daily living, including orientation and wayfinding simple tasks. One of the most common forms of disruption, for people with this health status is wandering. According to the Alzheimer's Association, 6 in 10 people with dementia will wander [2]. This problem induces a great risk to the safety, well-being and reduces drastically the quality of life of the person, therefore is a critical concern for caregivers, and family having a major impact on their lives. Even though there is still no cure, efforts can be made to help prevent such behaviours, that's why there is a continuous search for solutions to support an Active and Assisted Living of such people, not only the ones with dementia but more extensive to all the elderly population.

Alongside with a fast-growing in the elderly populations across the world, caused by the augmented life expectancy, there is also an expected increasing number of Internet of Things (IoT) devices, these devices can be key components to mitigate some of the problems caused by this ageing. These devices have special requirements and technical constraints, such as low power consumption or low-cost hardware, but they can provide valuable sensor data over long distances, and the ability to retrieve location data, which is especially useful for the Carelink [3] project. This project consists of an innovative personal tracking for people with dementia (PwD), where a wearable device is currently being developed, alongside with an online platform, where it will be possible to observe the actual position of the PwD as well as define safe and unsafe areas. When the PwD crosses outside a safe geo-fence zone, the carer will receive an SMS notification, with the information to locate the PwD, in case of emergency.

With the use of these devices, it is possible to detect, try to predict and prevent risk behaviours, such as falls or wandering events. Additionally, with the ability to geolocate the PwDs, there is the opportunity to discover wandering patterns, helping to prevent such events in the future, thus ensuring a better quality of life for the PwD and for those responsible for them.

II. RELATED WORK

Most studies in the area of geolocation have focused on the use of a single technology, or technique. Then there are the ones that uses multiple technologies and techniques, but seems that do not explore so much the dynamic change of the working technology in functioning mode.

The following four examples, focus only in different individual technologies and techniques. The last two focus either in multiple technologies, or multiple techniques, but as already emphasized, without taking into consideration the use of multiple techniques and technologies simultaneously.

In [4] an IoT tracking system is presented, using LoRa[5] where the geolocation is calculated through a multilateration algorithm, using the gateways timestamp, with an accuracy of around 100m in a stationary test scenario.

In [6] the performance and accuracy of the Google Geolocation API [7], for geolocation using Wi-Fi [8] access points(APs) is evaluated, the results in an urban environment, achieving a maximum accuracy of 20 meters, minimal 187 meters and median 39 meters, for this test a minimum of three Wi-Fi APs is recommended.

In [9], an indoor localization monitoring system is presented and a wearable device was developed, using FleckTM-3 wireless sensor platform, with a position error of 1 to 3.5 meters. The main disadvantage of this solution is that only works indoors, and the technology is similar to ZigBee so only works for short-range applications.

In [10], was developed an indoor position system based on Raspberry Pi and an MPU6050, used has BLE beacon, and with the use of Raspberry Pi as BLE scanner, measuring the RSSI, the results for indoor activity were 99% of accuracy in knowing in which division the patience was.

In [11] a dataset of messages was created from LoRa and Sigfox containing the GPS coordinates, and respective RSSI (Received Signal Strength Indication). The results of the median error in an urban scenario were 514.83 meters for Sigfox and 273.03 meters for LoRa.

In [12], a Hybrid (Time of Flight and RSSI) approach for Geolocation system using LoRa, and the results are similar to the work mentioned in [11], with a median error of 272 meters.

III. Research Question

One of the objectives of this work is to evaluate the use of technologies as LoRa, Wi-Fi, Global Navigation Satellite System (GNSS) integrated with other sensor data, available from the localization devices such as the remaining battery level and accelerometer parameters. From this the idea is to define different operation modes in relation to different energy consumptions with the objective to improve the overall energy consumption of the device.

The selection of each operation mode is dependent on the following conditions: for LoRa, the number of gateways available; for GNSS, the number of satellites available to fix the location; and for Wi-Fi, the minimum amount of APs in range, to perform the assisted location.

Can the geolocation technologies, dependent on the usage scenario, be managed dynamically to improve the precision of the location, and the energy consumptions of the wearable devices?

IV. Methodology

To respond to the presented research question, a Geolocation model able to autonomously decide the best location method is proposed. To reach a model able of the mentioned autonomous feature, it must address distinct variables as remaining battery and the availability of communication technologies. Such availability can be analysed through advanced sensing of the surrounding radio signals. This means that the model has to be aware of the environment in which the device is working. Such environment main characteristics relates to indoor or outdoor and rural or urban.

These characteristics have a direct impact in what kind of technology has to be used in each working moment or environment. Thus, the idea is to define a model that responds to all of these situations, and consequently develop a correspondent profile-based decision system able to act accordingly.

The development of the presented solution in this paper focuses only in the urban and rural environment. Thus its testing used geolocation technologies such as GNSS, Wi-Fi and LoRa. Furthermore, these tests will consist in the gathering information from different location coordinates, at different speeds as well as stationary, to evaluate the performance of the different technologies against each other.

Additionally, these tests were integrated in the Carelink project presented in the introduction. It used a geo-fencing polygon, defined by the carer of the PwD. Consequently, the device communicates with the Carelink platform to give its position and receive support on the technologies to use accordingly to the profiles of the PwD user. Thus, at the end, these tests were conducted with real patients in real life trials. To perform these communication between the devices and the Carelink platform it was used LoRa and NB-IoT [13].

V. The Proposed Model and System

To develop the solution described, it was defined a model to characterize and formalize the different types of solutions called stages . Later an implementation following the model defined occurred creating the so-called profile-based decision system.

The model intends to define what technologies to use and how the geolocation data from different sources should be processed, so that it can later be used for knowing the actual position of the PwD wearing the device. This model is composed by three different functional stages, called: “hierarchical”, “advanced” and “smart”.

In the first stage, the function relates to the decision of the best location technology using their own approximate accuracy values (specifications), meaning an “hierarchical” choice.

The second stage formalises the location decision function based in two characteristics at the same time: the battery level of the device and the location accuracy for the chosen technology, thus being more “advanced”. In this stage, the geolocation function should be capable of knowing the remaining battery. In case the person is in a dangerous situation, for example, in an area previously assigned as unsafe, do the balance between the highest accuracy location and the more power efficient location.

In the last stage, a more advanced location function is formalised. Its decision capability for choosing the available technologies are based in the surrounding environment, thus including other types of data as physiological or even weather data. For example, if a PwD is not showing any activity by a long period of time, it is night time and he/she is in a safe place, as home it can be deducted that the person is sleeping, and therefore the sampling time for the location can be reduced, thus saving battery.

Another situation is in case of by combining additional sensor data, like an accelerometer that can detect if the person has fallen, priority can be given to the method with the best precision, because of this dangerous situation.

In conclusion, this last stage combine a set of different factors to categorize and do a profile-based decision. This relates to a previous work reported in [14], which addresses the problem of creating adaptable power profiles for wearable localization devices also establishing a relation to different levels of dementia of the PwD users.

Based on the presented model the authors started to develop the profile-based decision system. In this phase it only includes the “hierarchical” functional stage. Its first architecture version is illustrated in Figure 1. Although some tests related to the second stage were performed and are also described later in this paper.

The first step in the proposed system is to collect sensor data from the PwD wearing the device. Afterwards, a specific transmission method is selected, of which the options may vary from LoRa to NB-IoT.

The second step is to combine the previous information in the proposed Geolocation solver, in order to get the best location possible. The aforementioned Carelink platform is responsible for managing the device, and ensure the high availability needed, in order to always know the location of the PwD, especially when he/she is lost.

The geolocation information is then passed to the tracking service, and then the final step is sending the response from the tracking service to the GUI.

In the GUI, the user responsible for the PwD can be alerted, when a geo-fencing alert is raised.

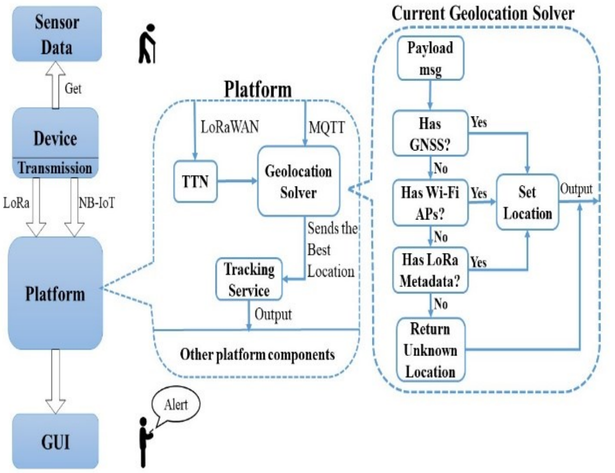

Figure 1. Profile-based decision System Architecture – Hierarchical version

The right dotted square represented in Figure 1 shows the workflow behind the "Geolocation Solver" block. An input is received containing a JSON object, which contains the status of the device, in the format shown in Figure 2.


```
{
    "timestamp": "YYYY-MM-DDThh:mm:ssZ",
    "location": {
        "lat": float,
        "lon": float,
        "alt": float,
        "hdop": float,
        "vdop": float,
        "pdop": float
    },
    "batteryLevel": integer,
    "accompanied": boolean,
    "sensor": {
        "accelerometer": {
            "x": float,
            "y": float,
            "z": float
        }
    },
    "wifiAPs": {
        "mac_1": string,
        "rssi_1": integer,
        "mac_2": string,
        "rssi_2": integer,
        "mac_3": string,
        "rssi_3": integer
    }
}
```


Figure 2. JSON Status payload

In the "Has GNSS?" block (Figure 1), the location field (Figure 2) is analysed, the coordinates provided are validated in case the latitude and longitude fields are different from zero, which is the default value for no GNSS location data, being then passed to the "Set Location" block. In case this field is empty, or the coordinates are not valid, the following block is "Has Wi-Fi APs?".

In this step the Wi-Fi APs field, from the above-mentioned JSON is checked. If it is different from null, this payload is utilized, for performing the assisted location based on the Wi-Fi data. This data will then be sent to three different APIs, using a load balancer based in the sequential Round Robin to obtain the best information for the location. The round robin solution is used to give capability to the system to perform multiple location at the same time and chose the best one. The three used APIs to accomplish this were: Google Geolocation API [7], Here Position API [15] and OpenCelliD Cellular Geolocation API [16].

If the communication method in use is LoRa, then the LoRa metadata will also be used to apply a different geolocation algorithm, such as multilateration, based on received signal strength or the time of difference of arrival. The result is the approximate device location. For this last method to work, with reliability, a minimum of three LoRa gateways in range is needed.

The location data, passed by either one of the three previous blocks ("Has GNSS?", "Has Wi-Fi APs", "Has LoRa Metadata") to the "Set Location" block, is then analysed according to the rules defined by the corresponding functional stage ("hierarchical", "smart", "advanced").

The functional stage used was "hierarchical" that can perform a hierarchical location, based in the information received earlier. Being the hierarchical steps, GNSS, Wi-Fi and LoRa, and this operation is based on the average accuracy of location, for each method.

Therefore, the location with higher priority is the one from GNSS, and the one with less priority is the LoRa Metadata. In the scenario where all of the three previous blocks return an invalid location, it is returned location unknown. After this operation, the information is then sent to the "Tracking Service" on the platform.

VI. RESULTS

The work presented by the authors intends to combine different location technologies and techniques. The result is an overall location solution, that provides enhancements in terms of precision and performance, meeting the dynamic changes of the utilization scenarios with optimal device configurations. It also integrates energy profiles to control and reduce the energy consumptions of the devices, thus answering the proposed research question.

The tests executed consist in connecting the wearable device to the Carelink [3] platform, using the "hierarchical" geolocation function to provide the best location to the platform. The wearable device in use, was based in the FiPy [17] development board, and it was used in the form of belt box. Three tests were used to determine the location accuracy of the previous methods, obtaining the following results (see Table 1):

a) The location results for the GNSS, after using the device in a clear day, and perform a 4.3 km walk in a rural outdoor environment, at an average walking speed of 5 km/h, gathering data from 100 location points, had an accuracy between 5m to 20m, with an average of 10m.

b) The Wi-Fi assisted location test was done outdoor, in an urban environment, at an average walking speed of 5 km/h, with a distance of 2.8 km, collecting about 80 location points. The final accuracy for this method was a maximum of 15m, and a minimum of 200m, with an average of 30m.

c) The last method LoRa had the lowest accuracy, has expected by the authors, with a maximum of 30m and minimum of 3000m being the average 300m. The test occurred in an urban outdoor environment, at an average walking speed of 5 km/h, with a distance of 2 km, collecting around 50 location points.

As a result of this observation it can be concluded that in a specific case the Wi-Fi could be more precise than the GNSS. This means that sometimes the better expected technologies are not the best in some specific cases. This case relates to examples when people/users are entering in their homes where Wi-Fi sources become more precise than the GNSS. This can be verified in Table 1 (red values), where the min accuracy of GNSS is higher than the max accuracy of Wi-Fi.

Table I
Geolocation Results Comparison

	Max Accuracy	Min Accuracy	Average Accuracy	Location Points
GNSS	5 m	20 m	10 m	100
Wi-Fi	15 m	200 m	30 m	80
LoRa	30 m	3000 m	300 m	50

The authors, after the tests for the location accuracy of the Geolocation Solver system. Also performed tests of the communication resilience, and the battery consumption to prepare the next phase of the implementation, the “Advanced” functional stage.

The communication tests were conducted to the two different methods: LoRa and NB-IoT. In order to test the communication resilience, the communication fallback capabilities were evaluated. If the device loses the NB-IoT link it should fallback to using the LoRa stack. In case the communication network changes, then the Geolocation Solver service should be able to handle the data transition and continue the processing of information. Additionally, it should also be possible to force the change of the communication technology based on the energy efficiency settings.

The first test consisted in using the device outdoor, with good NB-IoT signal strength, and then enter an underground parking lot, which was previously tested and had no NB-IoT coverage. A LoRa gateway was set inside the parking lot, in order to provide LoRa coverage. The test was conducted 5 times, and the device always changed to LoRa after a predefined connection time-out of the NB-IoT.

With this expected result, in the system side was possible to observe that with the change of communication, and the type of received message the system was capable of returning the same output.

The second test consisted in sending a downlink message in a JSON format, to the device with the communication technology and a boolean value, such as: “{"ltenb": "False", "lora": "True"}”. In the device side, the response is similar to the previous test. The device receives and decodes the JSON information, and starts the connection to the LoRa network, if the LoRa connection is not successful, the device reboots and starts transmitting again with NB-IoT.

The initial battery tests used LoRa as communication, because it is possible to use as geolocation method, and used a LiPo 3.7V 800mAh battery.

The first test revealed a duration of 8 hours and 30 minutes, for this operation mode. This mode consists in having activated the GNSS, Sensors (accelerometer) and perform the scan for Wi-Fi APs. This first mode is the one with better precision, but in the other hand is the one which requires more power.

In the second operation mode, only the GNSS and the sensors are activated, thus the duration was 9 hours, an increase of 5.88% in battery duration, without using Wi-Fi APs assisted location method.

The last operation mode, only LoRa communication was used, with a fixed payload of 110 Bytes, the same length as the previous test. The configurations in use were the following: for the sampling time 30 seconds, the antenna was an external one (Molex ISM 105262, omnidirectional with 0.4 dBi Peak Gain at 868 MHZ), spreading factor 7, bandwidth 125 KHz, the first three channels in 868.1 MHz, the coding rate 4/5. For the LoRa class was chosen class C with a transmission power of 14 dBm. Obtaining the total duration of 12 hours, the best of all the test, but at the same time is the least accurate, according to table 1.

The previous work done by [14], shows it is possible to have a pre-defined set of power consumption profiles, all of this in the wearable localization device. The goal of the work presented in this paper is to have the Geolocation Solver dynamically managing the operation modes, that combined with power consumption profiles, will create the energy profiles, that consist in a set of rules to improve the battery duration or the results precision.

After this phase of testing, the model needed to be validated. The first results for this model validation, only for the first functional stage, obtained during the initial phase of trials, were a total of over 50000 received messages from 10/02/2020 until 10/03/2020. The difference between the input received messages and the output sent messages was less than 1%. The implemented system was able to support spikes of simultaneously received messages from different devices, and the version in the test was able to process 1 message per 2 seconds. These first tests were conducted using 4 devices, used by 4 PwDs in real life trials. To conclude the model was able to dynamically choose the best location available.

VII. Conclusion

In this research, the authors presented the work to create a geolocation solver model, with three functional stages (“hierarchical”, “smart”, “advanced”), for wearable IoT devices. The implementation of this model, is capable of dynamically choose the best geolocation technology in each situation, for this to happen different operation modes were used. With these operation modes it is possible to improve accuracy and energy consumption.

Initial location tests were undertaken, to evaluate the accuracy results, of different geolocation techniques. The first with better average accuracy was GNSS with 10 meters. The second test was for Wi-Fi assisted location, this method scans the radio environment looking for Wi-Fi access points and based on the know location of such access points returns the approximate location for the device, the average result was 30 meters. The last one with the similar working principle as Wi-Fi was LoRa, the average accuracy was 300 meters.

The results for the tests, were preformed using as microcontroller, the FiPy [17] with the Pytrack [18] localization shield. This shield has a GNSS that is the Quectel L76-L [19] , and the antenna used for the GNSS was the internal one. Different hardware configurations will have different results.

The system was capable of hierarchically choose the best location and respond to information from different communication methods and data sources. Concluding the implementation of the "hierarchical" functional stage.

The initial tests for the implementation of the "advanced" stage, were undertaken, testing the battery consumption and communication resilience.

The results identified by the authors, prove a battery duration of up to 12 hours, when using the LoRa assisted location method, with a 30 seconds period between transmissions. For the communication resilience was conclude that the device was capable of dynamically change the communication method, and the system was able to handle the data transition.

The identified drawbacks of this work, were the maximum number of messages processed per second, and the fact that the Wi-Fi and LoRa locations were depended from third party providers.

The use case of this Geolocation solver, is for knowing the location of wearable devices, used by people who suffer from dementia, as it was tested in real life trials.

Finally, by analysing the developed system and its results, it is possible to verify that the approach is promising, and the defined model has provided an appropriate starting point for further research and applications in the field of assisted living location.

A. Future Work

Future work will focus on performing more tests , in order to discover possible faults or bottlenecks related to the ability of the system to process messages.

For the device future tests are required, to assess the location performance, of the different methods in indoor environments.

Further studies of the Geolocation Solver should be realised, in order to implement the "advanced" stage proposed in the solution. This comprises the development and testing of more operation modes, in order to have a profile based decision, taking into account variables such as if the PwD is at home or outside, if the person is accompanied or is alone, and the time of day.

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