Search and Rescue System Based on NB-IoT Wearable Device

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ABSTRACT

This chapter presents the design and development of a search and rescue (SAR) system, for the location and provision of aid to people who are missing or in imminent danger, especially those belonging to population groups with a particularly high probability of getting lost. With the use of Low-Power Wide Area Network (LPWAN) technology, such as Narrow Band Internet of Things (NB-IoT), authors are able to provide search and rescue solutions for individuals, especially those belonging to groups of people who are more likely to get lost. The central part of the system is a modular "wearable (portable)" device, while in the framework of the implementation of this system authors have seriously taken into consideration the aspects of energy efficiency in order to provide better battery life.

Keywords: energy efficiency, geolocation, IoT, LPWAN, NB-IoT, Search and Rescue, wearable, WeSAR

INTRODUCTION

Nowadays, Internet of Things (IoT) has been established in our everyday life, as it offers several capabilities. So, more and more devices and systems are being created in order to offer solutions that need technologies that can interconnect wireless devices over long distances. One candidate that tries to solve this is Narrow Band Internet of Things (NB-IoT) technology as part of 5G networks. So, it is necessary to study this kind of technology, because the IoT market is gaining exponential popularity introducing more solutions, and our lives can be improved in various ways.

Among other applications, NB-IoT provides some very appealing applications in the field of search and rescue (SAR). NB-IoT's low power consumption and long range transmission can support many SAR scenarios including emergency situations due to natural disasters, missing people, accidents both on land or sea areas, supports of children wandering, and support of people with specific diseases like dementia.

This chapter presents the design and development of a SAR system, named WeSAR (Wearable Based Search And Rescue system), for the location and provision of aid to people who are missing or in imminent danger, especially those belonging to population groups with a particularly high probability of getting lost. The central part of the system is a modular "wearable (portable)" device, while the algorithms for locating the person(s) carrying the device and indicating her/his/their vital signs/condition will play an important role in its effectiveness.

The basic feature of the WeSAR wearable device, in the framework of project WeSAR, is its basic communication capability with base stations located even at several kilometers away from the device using low-power and long-range communication protocols like NB-IoT. In addition, the basic parameters of communication, such as the rate and power of data transmission, will be tailored to the specific conditions of the application, so that the battery life of the device functions properly for several days and even weeks.

The development of the algorithms will be done using simulation to detect underperformance and optimize the results. The implementation of the prototype will be based on the combination of modules on a dedicated IoT development board. Software development will be done through a continuous integration methodology to test the developing system at an early stage.
The WeSAR system will be used in situations where people are at risk, due to moving away from a controlled area. These cases can be due to the impaired mental state or inability to react, while they are away from their familiar environment. Indicatively:

- People in autism spectrum disorders (Lord, C.et al. (2000)).
- People suffering from some form of dementia (Cummings, J. L. (1990)).
- Toddlers and children wandering in large open-air entertainment places.
- Workers at work sites or other sites with high levels of activity and increased risk.
- Missing people out of range of local or broadband networks, such as in the case of maritime accidents.

The WeSAR wearable communication with the base station will be two-way so that the missing person knows that his position has been received as well as to receive instructions or estimated rescue time. The device will support an emergency alert function with the press of a panic button. With the appropriate sensors, it will be able to inform rescuers about the physical condition of the missing person so that, in conjunction with positioning, they can make the right decisions about rescue strategy.
The two main approaches to providing data access in IoT have been based on either multi-hop mesh networks using short-range communication technologies in the unlicensed spectrum or long-range legacy cellular technologies operating in the corresponding licensed frequency bands. Recently, these reference models have been challenged by a new type of wireless connectivity, characterized by low-rate, long-range transmission technologies in the unlicensed sub-gigahertz frequency bands, used to realize access networks with star topology referred to as Low-Power WANs (LPWANs).
The WeSAR wearable can be implemented in two versions regarding the wearable communication protocol with the base station. The first version will use LoRa (Long Range) (Bor et al. (2016)) technology and the second one NB-IoT. The two technologies have similar characteristics and focus on long-distance coverage and low consumption of the devices that use them. For both versions the prototype will use the same reference design that will have a slot for the connection of one of the above-mentioned wireless network access technologies. The reason for the two versions is because of the different approach to the missing algorithm and the "owner" / "administrator" of the network, which in the case of NB-IoT is usually a licensed mobile provider while in the case of LoRa it can be private without dependence on network providers.
This publication is based on the WeSAR project (Wearable based Search And Rescue system - WeSAR (2019)). The WeSAR project's goal is to design and develop a search and rescue (SAR) system to locate and provide assistance to people who are missing or in imminent danger, particularly those belonging to population groups with a particularly high likelihood of getting lost. A lightweight "wearable" device is the core part of the system, while the algorithms to identify the person(s) carrying the device and show their vital signs / condition may play an important role in their effectiveness. The key feature of the WeSAR wearable device is its basic communication capability with base stations only a few kilometers away from the device (using low-power and long-range communication protocols, including LoRa and NB-IoT in particular). Furthermore, the basic communication parameters, such as data transmission rate and power, will be tailored to the application's specific conditions so that the device's battery life will function properly for several days and even weeks.
The ultimate goal is to create a family of wearables and tags of various types (clothing, wristband, badges) for low consumption and long-range monitoring and rescue, with dozens of applications in urban or non-urban environments. Equally important is the creation of a tracking platform over IoT networks

that can be used in the future as a basis for other applications such as freight, vehicle and asset tracking in a closed or open environment.
This chapter presents the following in the next paragraphs:

- Related work section: The incentives for the creation of the WeSAR system stem primarily from the high demand for methods of monitoring and updating the activities of individuals whose lives may be at risk and secondly from the need for safe handling of assets and goods. Whether they are individuals or objects, the features and requirements of such systems are common. The increasing demand for such systems is confirmed by a large number of products and research projects that have been implemented in recent years. NB-IoT is an ideal candidate for such solutions for this kind of application, thus is used in a variety of these projects. The related work section presents related works to the WeSAR system.

- Motivation section: The main goal is to design and develop a system for identifying and rescuing individuals, especially those belonging to population groups with a particularly high probability of being lost, focusing on energy efficiency of the wearable, in the different states that the user can be such as emergency, or in normal state were the user just uses the wearable and he is not in danger. The motivation section presents in detail the motivation behind the WeSAR system.

- System architecture section: This section provides the architecture of the WeSAR system. The overview of the proposed system that is being implemented in the framework of the WeSAR project is the following: The wearable communicates with the IoT management platform through the cellular base stations that support NB-IoT transmissions. From there the packets are transferred to the core network of the mobile operator where metadata is exported and processed. In addition, this section provides details about the main components of the system is the user's wearable, the Mobile Network Operator (MNO), the IoT management platform and the user's smartphone, that when the user wants can connect the wearable through Bluetooth Low Energy (BLE) to the smartphone.

- Modules of WeSAR system section: This section provides in detail all the parameters related to the hardware architecture of the portable device, which is the basic unit of the WeSAR system. The choice of all wearable peripherals is very important as the device is oriented to be "wearable", so there is a limitation in size, and it will also be battery-powered, so there is a limit on power consumption.

- Algorithms for optimization of energy consumption section: Power consumption is a particularly important factor in mobile devices in order to achieve optimum battery management and thus longer operating life, which is particularly important in the context of the WeSAR system as in the event of an emergency (emergency transition) or the wearable device should be able to remain active for as long as possible until the rescue of the user has taken place.

- Algorithms for location detection section: in such types of networks, low power, and long range, the localization can be more challenging. Firstly, the Received Signal Strength Indicator (RSSI) has been used for fingerprinting localization where RSSI measurements of Global Position System (GPS) anchor nodes have been used as landmarks to classify other nodes into one of the GPS nodes classes. There are various methods, algorithms, and mechanisms, some involving machine learning and trilateration used for such applications.

- Future research directions section: Future research directions are the expansion of the WeSAR system to other devices apart from the wristband wearable device, and improving the algorithms for energy consumption, etc. In addition, other LPWAN technologies, like LoRA will be investigated.

- Conclusion section: The WeSAR system integrates a variety of methods, technologies, and algorithms, in order to create a system that will affect in a very positive way the everyday life of people. Also, it focuses on a very crucial challenge that IoT has to face, the problem of energy consumption of battery constrained devices.

RELATED WORK

The incentive for the creation of the WeSAR system stems primarily from the high demand for such systems of monitoring and updating the activities of individuals whose lives may be at risk such people in the autism spectrum disorders for whom, it has been reported that, at a percentage of 49%, they have disappeared or have been at risk due to a tendency to flee, at least once since the age of 4, people suffering from some form of dementia who statistically have at least 60% chance of being lost outdoors. Toddlers and children wandering in large open-air entertainment places, risking falling victims to malicious actions unable to self-defend. Whether they are individuals or objects, the features and requirements of such systems are common. In this section authors are going to mention and describe the State of the Art in this area, describing existing projects and research publications.

Projects

The first project authors examine is Skyfire (Skyfire (2019)). This product aims to provide search and rescue systems with the use of drones that use onboard cameras. Particularly, the equipment that Skyfire provides is cameras and drones used in rescue missions and are divided into two categories, firefighting drones, and police drones. Fire drones are supposed to be in the air in seconds so they can assess the situation quickly, efficiently, safely long before other vehicles arrive and can lay supplies, rescue vests, tow ropes, and more to people that are in danger. Police drones intend to make it possible to safely and effectively handle hazardous situations without the need to put human lives at risk, such as inspecting suspicious parcels, handling explosives or chemical leaks, and fires.

Moreover, the Search With Aerial Rc Multi-Rotor (SWARM) (SWARM (2019)) is a network of volunteers offering camera drones and their time when a rescue mission must be conducted. Their main mission is to provide drones and provide on-air search platforms with continuous search and rescue operations. Each of the drones has high-resolution cameras, and through built-in video recording or First-Person View (FPV) technology, they can capture in real-time. Once the exact location is detected, the coordinates can be transmitted back to the ground crew. The average flight times are usually between 10-25 minutes giving the pilot enough time to scan an area.

Also, Elpas Security Solutions (Elpas (2019)) provides a set of products, with specialized features per application. Some of the applications need some special equipment such as infant protection charm for maternity hospitals, lone worker transmitters for security forces, enhanced local controller for indoor and high-risk security bracelet for people in hospitals

The ICARUS: Integrated Components for Assisted Rescue and Unmanned Search operations (EU project, 2012 – 2016) project (ICARUS (2019)) aims to develop technologies for unmanned human search and rescue systems. The main goal is to develop robots for data collection and reconnaissance because these robots will be the first to reach the critical area and for rescue support. Unmanned robots will travel individually or cooperatively following high-level commands from the base station. They will communicate with the station and with each other. They will carry sensors for tracking people and other sensors. At the base station the data will be processed in combination with geographical information.

The LYNCEUS: People Localization for saving in ship evacuation during emergency (EU project, 2012-2015) project (LYNCEUS (2019)) studies ultra-low-power wireless body area network technologies for tracking and monitoring people on ships in order to rescue and evacuate ships in critical situations. It aims to develop onboard passenger surveillance systems in emergency situations through lifeboat sensors and detect them if they are found at sea via UAVs (drones).

The goal of CLOSE-SEARCH: Accurate and safe EGNOS-SoL navigation for UAV-based low-cost SAR operations (EU project, 2010-2012) project (CLOSE-SEARCH (2019)) is to develop a small drone with GPS and EGNOS (European Geostationary Navigation Overlay Service)-based navigation system to

support remote detection and rescue operations in remote or inaccessible areas by other means. The system will serve locations such as ski mountains, tourist areas, and civil protection buildings.
The MOBNET: MOBileNET work for people's location in natural and man-made disasters (EU project, 2016-2018) project (MOBNET (2019)) will design a detection and rescue (SAR) system to detect isolated victims in situations such as earthquakes, hurricanes, avalanches, etc. with the help of UAVs (drones). It will also help in finding smugglers hiding in buildings. The system will use the European Global Navigation Satellite (EGNSS) systems (Galileo and EGNOS) and Digital Cellular Technologies (DCT). EGNSS and DCT technologies will be synchronized for precise location determination. Such synchronization is not currently available, and innovative EGNSS / DCT methods will be sought. In addition, an effective and reliable connection between the UAVs and the control center will be designed.

Papers

In this section authors are going to discuss the state of the art from the point of the research papers in the literature. First of all, authors start with the work of H. Y. K. Lau et al. (2009), which discuss a system of robot-assisted emergency search and rescue systems. Intelligent robots, equipped with advanced and numerous sensors, are attracting more and more attention from researchers and rescuers. In this work, the design and development of an original distributed wireless sensor network system for mobile search and rescue robots is presented. The robots can navigate in cases of disaster autonomously and search for humans using its thermal sensor. The wireless sensor network helps monitor the robot's position by analyzing signal strength.
In the work of Y. D. Kim et al. (2018), the authors described a smart disaster response in Vehicular Tunnels. Recently, the number of tunnels is increasing due to urbanization. For this reason, accidents in tunnels are also increasing. For example, in a large tunnel more than 1 km long, it is very difficult to pinpoint the exact location of a fire or accident vehicle, and the air force. In this work, they analyze various types of accidents that may occur in tunnels and suggest detection techniques. For the early detection of accidents, they suggest various sensors using IoT technology and wireless sensor networks to connect them. These sensors can detect not only fire but also the location of the vehicle in which fire was started in real-time.
Lahouli, R. et al. (2019) have designed a real-time positioning system to help firefighters to do SAR operations. Due to the fact that geolocation using Global Navigation Satellite System (GNSS) can be difficult, in cases where SAR operations are conducted in forests or indoors, etc., the proposed system enhances the positioning's accuracy, using different wireless technologies. In this work, a solution that helps the measurements of the distances among the firefighters has been created based on Ultra-wideband (UWB) technology. These measurements are sent to the brigade leader using LPWAN technology, such as LoRa and NB-IoT. Furthermore, J. A. del Peral-Rosado et al. (2017) studies the NB-IoT Ranging performance in Long Term Evolution (LTE) Femtocell Networks. The standardization of cellular technologies for IoT applications aims to complement existing solutions, such as Lora, Sigfox, to meet market needs. IoT applications require positioning functions in demanding environments where GPS cannot be used, and other ways of implementing these functions are being sought. These tracking capabilities are based on triplication methods, such as the observed arrival time difference (OTDoA) with NB-IoT configurations, which achieves positional accuracy of up to 50 meters thereby satisfying the tracking requirements for search teams or rescue teams.
In this paper R. Saahithyan et al. (2016), discuss energy-efficient algorithms in extended-coverage-GSM for low data-rate IoT devices. IoT is a fast-growing technology and is expected to have billions of connected devices by 2020. Mobile networks are important infrastructures for connecting the Internet providing greater WiFi coverage, reliability, and security. Narrow Band-LTE (NB-LTE) technology is of particular interest as the communication infrastructure for the expected huge number of low cost and low data rate devices. These IoT devices are expected to have extended life battery, i.e. more than 5 years. This work proposes a new idea for reducing energy consumption for an IoT device supported by EC-

GSM. The simulation results reveal a significant reduction in power consumption, approximately 40% on IoT devices compared to existing techniques.

As far as localization is concerned, Sallouha et al. (2017) discuss the localization algorithms in NB-IoT. Specifically, the authors provide a system where RSSI measurements are used in the fingerprinting localization method, using GPS meta-data of some of the nodes. In their system model, not all nodes are GPS equipped. Furthermore, they have tried to implement a system where peer-to-peer localization is achieved. In the second case, higher accuracy is provided, with the drawback of increasing the cost of such solutions in terms of energy and traffic congestion.

In this paper X. Lin et al. (2017) discuss the localization of the IoT focusing on the challenges that need to be dealt with. The authors claim that using for example sounding reference signals or narrowband physical random access signals can lead to better localization accuracy. Also, it is proposed that OTDOA can lead to higher positioning accuracy. Last but not least, as authors move towards the 5G era, it is stated that the synergy between 5G technology with the NB-IoT in terms of positioning it would be quite beneficial.Apart from the above, other LPWAN technologies such as LoRaWAN, have contributed to positioning. Research efforts have been given to enhance positioning accuracy, having as outcome methods of localization that could be implemented and tested in NB-IoT, too. For example, in this work I.Daramouskas et al. (2019) describe a variety of localization methods that apply to LPWAN. Methods using distance measurements such as multilateration, trilateration, Particle Swarm Optimization, and Social Learning Particle Swarm Optimization, are described. As far as methods using angle measurements are concerned, the triangulation method is described.

MOTIVATION FOR THE WESAR

Very often, there isn't one media report or multiple, of an individual with Alzheimer's malady or related dementia who has disappeared. As the frequency of Alzheimer's ailment keeps on expanding, it pursues that this conduct will rise in like manner—putting a powerless populace in danger of damage or passing if not found rapidly. Everyone with dementia who can stroll just like the individuals who keep on driving is in danger of getting lost. Past legitimately affecting the individual with dementia, this conduct presents far-reaching suggestions for different divisions, particularly family guardians, medicinal services experts, and law authorization. Expanding consideration is being centered around the way that social indications of Alzheimer's illness, including meandering and missing episodes, are a significant wellspring of parental figure burnout. Too, for law authorization, this is a genuine and expensive open wellbeing issue that will just compound as the sickness attacks more lives. Developing innovation—in the case of using radio sign, worldwide situating satellites or cell triangulation, or a blend of these advances—can aid search and salvage by pinpointing the area of an individual outfitted with one of these dynamic following frameworks. Bringing issues to light of this conduct and dispersing data about accessible techniques hold the guarantee of eventually sparing expenses and, additionally, lives.

The above facts lead to the design and implementation of the WeSAR system, which will be used in situations where people are at risk, due to moving away from a controlled area. These cases can be due to the impaired mental state or inability to react is in jeopardy, while they are away from their familiar environment. Indicatively:

- People in the autism spectrum disorders for whom, it has been reported that, at a percentage of 49%, they have disappeared or have been at risk due to a tendency to flee, at least once since the age of 4.
- People suffering from some form of dementia who statistically have at least 60% chance of being lost outdoors.
- Toddlers and children wandering in large open-air entertainment places, risking falling victims to malicious actions in order to self-defend.
- Workers at work sites or other sites with high levels of activity and increased risk.

- Missing people out of range of local or broadband networks, such as in the case of maritime accidents. In these cases, missing people carrying the wearable WeSAR can be tracked by mobile stations, e.g. drones, which will execute the positioning algorithms.
- Real-time monitoring of end-devices for example wearables can give us a clear overview of the current position of this vulnerable group of people. The IoT based solutions for such monitoring concepts through WiFi have been proposed in several works as described above.

SYSTEM ARCHITECTURE OF WESAR

The general architecture of the WeSAR system requires the use of different communication network technologies in a multilevel architecture. As such, the architecture is based on the distinction of layers, the analysis of the requirements of each, and the rules of communication between them. The architecture of the WeSAR system (WeSAR (2019)) consists of the following:

1. **User Device Layer:** Authors consider the lower layer of WeSAR architecture to be the source of the vital information for the whole system. This layer applies to user devices, which are divided into commercial (e.g. smartphones) and development devices (e.g. WeSAR wearable).
2. **Network Transponders Layer:** For the development and optimum performance of the service, the wearable device will need to communicate with the Internet over multiple types of networks. The location of their transponders is an important parameter for locating carrier devices.
3. **Network Management Servers Layer:** It is the layer at which network providers manage their connections to users' wearables and provide information on the top levels that support applications.
4. **IoT Cloud Platform Layer:** At this layer, communication with network providers for messaging with users' wearable is implemented, support for storing information in databases, access by multiple users with different permissions, implementation of dataflow, and communicating with administrator and observer devices.
5. **Application Service Layer:** Application service managers, as well as observers with rights to use the service that are a subset of these managers, will be able to manage wearable devices, alert, exchange messages, and supervise wearables by implementing this layer and their historical data or current situations.

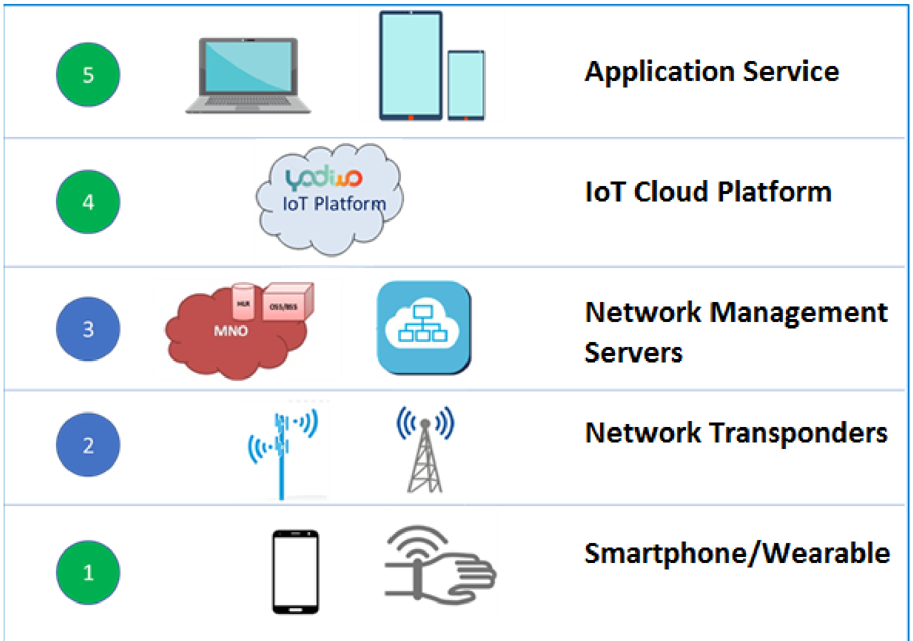

Figure 1. WeSAR Architecture.

The WeSAR system consists of the following modules (see figure 2):

- Wearable device: Thinking about wearable devices usually refers to devices such as smartwatches and bracelets that can be used for multiple applications concepts (sensor monitoring, location tracking etc.). Such devices can be worn from any person, anywhere, and have the ability to connect and communicate with the network. Anyone can connect this device either directly if they have a built-in connection or through another device, especially a smartphone that uses wireless technology such as Wi-Fi or Bluetooth. More information about the WeSAR wearable device can be found in the section “WeSAR wearable architecture”.

- NB-IoT system: One or more gateways listen indefinitely for NB-IoT packets, convert it to IP protocol, and relay it to the default network management server. The Application Server, in the WeSAR project, is Yodiwo's IoT Platform, will receive the package and:

  - It will store it in a database.
  - Execute the positioning algorithm, using the metadata sent through the MNO. The more stations heard the handset pack, the better the chances of successful positioning.
  - Will examine the data and initiate an alert or briefing process by E-mail, SMS, Push notification, etc.
  - Adapt, if necessary, the active sensors, the read frequency of the sensors, and the frequency of sending information by sending an appropriate message to the wearable to optimize power consumption on the wearable, it will send the data to the dashboard.

  Although it is easy to transmit and receive data planes between the device and the Cloud Platform, since communication is part of the IP stack, obtaining metadata such as RSSI and Signal To Noise (SNR) is more difficult and requires collaboration with a network provider MNO. This is because instead of a broker network the signal from the mobile device is received from one or more cell base stations that have enabled NB-IoT reception. From there, the packets are transferred to the core network of the mobile provider where similar metadata export processes are performed. In order to integrate with the provider's core network, it is also necessary that such an agreement be considered during the WeSAR processing phase.

- Cloud service: The platform will keep historical records of communication with the smartphone application so it can report other useful data for further investigation of critical situations. For example, if the application's continuous communication with the platform reports a sudden loss of connection to the mobile device via BLE, the last time the two devices were in communication and the position of the smartphone at that time would have been recorded. Also, from the historical data of the last positions, it will be possible for the administrator to understand whether the mobile user was in or out of the "permitted area" shortly before the communication between the smartphone and the mobile device was lost. Both the administrator and the observer will be able to:
    - Set the device's "range of motion" radius. "Permissible area" is defined as any circular area on the map whose center is a "device base" with a radius set.
    - Specify how the alert (e.g. email, SMS, Skype) will be alerted if a mobile device is found outside of all permitted areas.
    - Maintains its own portable devices in its account.
    - A portable device cannot be simultaneously linked to the accounts of two independent administrators.
- Base Station: The base station is the link between the wearable device and the management subsystem. It has two-way communication with both the device and the management subsystem that relates either to the transmission of raw data received from the device or to the receipt of the estimated location of the wearables from the management subsystem. It may also take place at the receiving station if the receiving stations communicate with each other.
- Processing and Data Management Subsystem (WeSAR Dashboard): The processing subsystem should receive the processed data based on techniques, RSSI, Angle of Arrival (AoA), Time of Arrival (ToA), Time Difference of Arrival (TDoA) between remote GateWay (GW) and evaluate its location based on mathematical formulas or using stochastic procedures. It will then calculate or detect possible errors and implement debugging methods. The management subsystem receives the raw data of the wearable devices through the receiving stations and is responsible for properly structuring the information for each wearable in the system. The information structure is about grouping the data by device as well as internally for each device per receiving station communicating it. Finally, it is responsible for creating logs or entering data into a database.

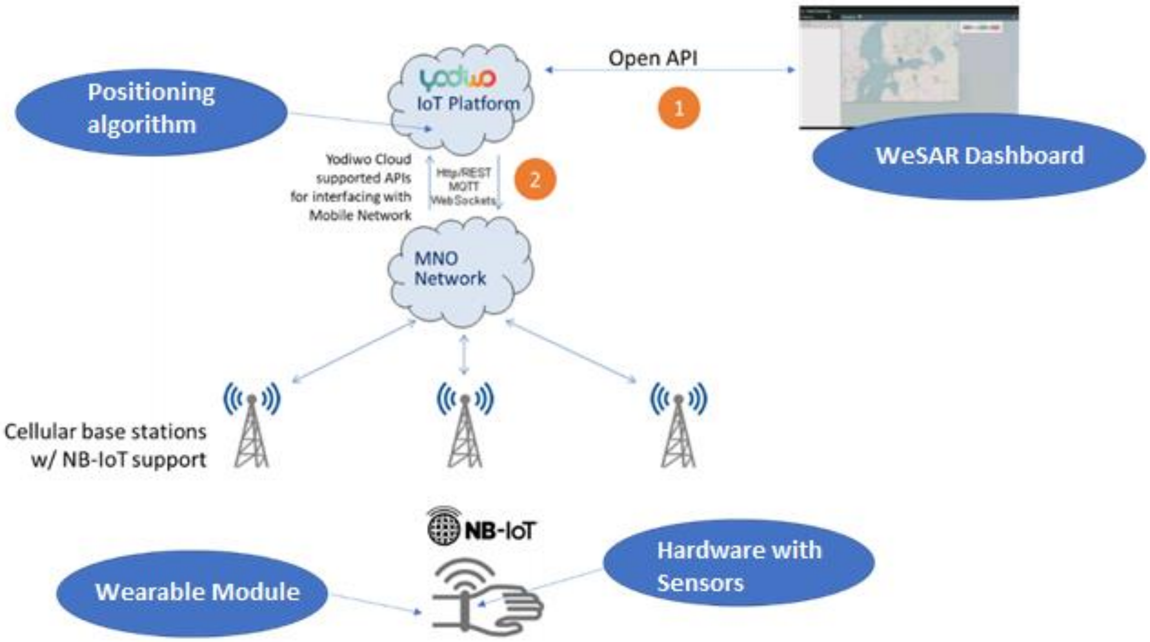

Figure 2. WeSAR modules

In addition, the WeSAR system will perform the following functions:

- Location Tracking in Real-Time: The wearable device is responsible to perform its positioning function with some limitations due to the resources available. The wearable device will calculate its position based on the signal of more than three GW stations and if it is outside a safe area an alert will be issued.
- Real-Time Device Monitoring: Real-time device monitoring is implemented both in the management subsystem and the wearable device. In the management subsystem the monitoring function will be implemented. If it is detected that a portable device is located outside a safe area or is likely to be located outside, it will be able to monitor the current and previous locations of the device and alert the rescue team accordingly. The wearable device will be able to monitor and track in real-time, whereby a relative will be able to monitor in real-time its current and previous location or other information depending on the sensors the portable device has (pulses, humidity). etc.)
- System State Detection: The system state detection is implemented both in the management subsystem and the wearable device. The wearable device if it needs to calculate its location and turns out to be outside a safe area or can transmit to less than three reception stations will go into an emergency where it will change the data transmission frequency or transmission power so that it can transmit even in a bigger range. The management subsystem is responsible for detecting situations in the system. In case a wearable device is lost, it should call the rescue team and transfer information about the last location of the device and its possible location.
- Emergency Alerts: The wearable device will support an emergency alert function with the press of a panic button. With the appropriate sensors it will be able to inform rescuers about the physical condition of the missing so that, in conjunction with positioning, they can make the right decisions about the rescue strategy.

WESAR WEARABLE ARCHITECTURE

This section describes in detail all the parameters related to the hardware architecture of the wearable device, which is the basic unit of the WeSAR system. The module used should, in addition to being able to interface via Bluetooth, also provide the ability to add various peripherals for additional programming. It is noted that the choice of all peripherals is very important as the device is oriented to be "wearable", so there is a limitation in size, and it will also be battery-powered, so there is a limit on power consumption.
Today wearable devices come in a variety of shapes and forms, including smartwatches, smart glasses, heads-up displays (HUDs), acting like monitoring devices, health monitors, portable scanners and navigation devices, smart tags, and so on. Currently, most devices are worn on the wrist and the solutions available today can be grouped as follows:

- Monitoring activity during training: these devices come in different sizes and shapes. They do not have advanced features and user interface. As they usually do not have their own screen, all measurements are transmitted via BLE to a mobile phone for visual representation and optimized through dashboards.
- Smartwatches: these devices can be connected to a mobile phone and send alerts to missed calls or messages.
- Sport watches: ideal for users who love sports such as running, cycling, swimming, or hiking which are equipped with sensors for fitness monitoring such as Heart Rate Monitoring (HRM) as well as GPS.

Wearable systems usually consist of the following main components:

- MC Microcontroller Unit (MCU): The choice of the main processor is related to the type and complexity of the device. Modern MCUs integrate most functions into one chip. This is an important one that reduces overall size and minimizes the cost of external wiring.
- Wireless connectivity: This is important for wearable devices as they need to interact with one or more other devices or even to connect in central GWs. Depending on the type and features offered, different wireless protocols such as Wi-Fi and BLE may need to be supported.
- Sensors: Can include various sensors such as accelerometers to monitor movement in any direction, gyroscopes for orientation and rotation, and biosensors for monitoring biometric data (e.g. HRM module).
- Other peripherals: GPS function for outdoor activities and sports. NFC capability for mobile payments. Vibrator / buzzer for alerts. microphone for voice commands etc.
- User Interface: Consists of LCD screens, touchpads and mechanical buttons.

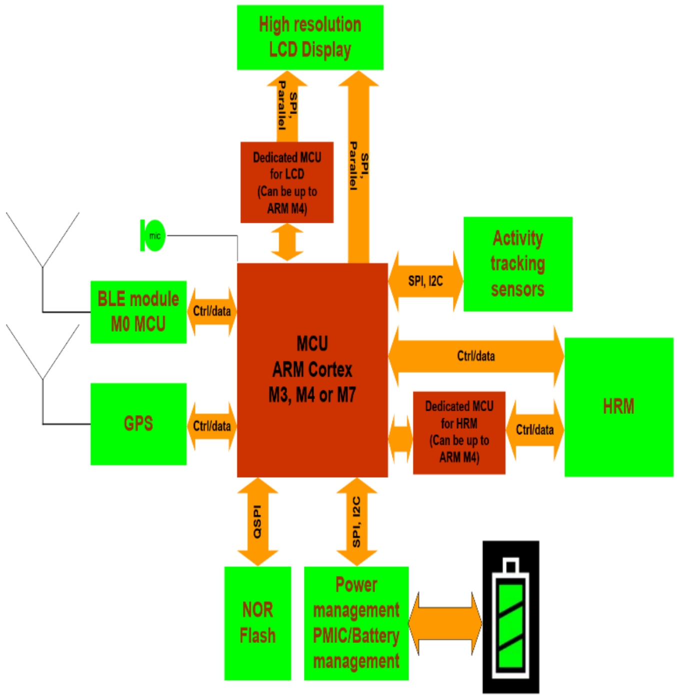

Figure 3. Block diagram of a high-end wearable system.

The block diagram of a high-end wearable system is shown in the figure above. Typically, this includes:

- Microprocessor Main Unit: ARM Cortex M3 / M4 or M7 class.
- High capacity memory for storing data from sensors, GPS, etc. (or NOR Flash for data storage).
- Multiple microprocessor units (can reach ARM Cortex M7 class) to support display functions, HRM data processing, GPS functions, etc.
- Various sensors, such as environmental or activity monitoring sensors.
- Advanced power management unit and battery charging units.
- BLE for data transmission and cloud connectivity.
- High-resolution TFT or OLED display that can be operated either directly from the main microprocessor (via parallel or serial memory) or from a separate display subsystem.
- High capacity battery, typically 250 mAh or greater.

In general, ARM microprocessor technology in high-end wearable systems provides powerful processing power. It also incorporates a large memory to support complex monitoring and sorting functions. By adopting architectures that include parallel microprocessors that handle the various subsystems, high-end devices can use additional microprocessors to process sensor or GPS data, freeing the master microprocessor. These systems also incorporate sophisticated user interfaces as they can operate autonomously without having to connect to a smartphone or tablet.

The firmware that the module will run will consist of:

- The central task, which will be responsible for communicating with the base stations, sending signals to determine location, caching, managing the real-time clock and the mechanism to control the accuracy of operation. It will also control both the display and the touch function. Finally, it will communicate with the second task that handles the sensors.

- The task responsible for the management of the sensors, and in particular the aggregation of all measured sizes and the power to the mechanism that extracts the most high-level data (heart rate, calories counting, sleep quality, etc.).

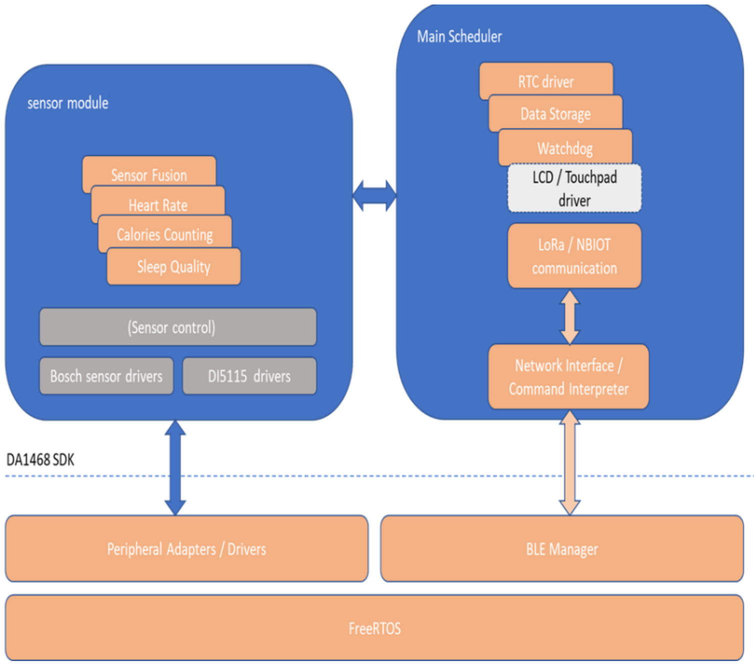

Figure 4. The firmware architecture of the WeSAR wearable.

The interface / command interpreter network is the entity that is essentially responsible for communicating with the receiving device to the receiving station and interprets messages coming through NB-IoT interface and sends it back to the receiving station.
WeSAR wearable consists of the following modules

1. **External Memory Flash:** The function of this memory is to execute code directly, using the internal cache, or just to keep a copy of the Random Access Memory (RAM) contents during boot.
2. **Clocks:** Even in use for the Extended / Deep Sleep mode.
3. **GPIO Interface:** Due to the use of peripheral systems for measuring different sizes (temperature, humidity, cardiac function coke) as well as driving systems such as the external display, there is a need for general purpose pins (GPIOs). For this reason, a peripheral is intended to extend these in / out ports.
4. **Battery:** The battery used must be a rechargeable Li-Po battery. These batteries are the most popular mobile batteries today. Laptops are now mainly used for small LiPolymer cells or LiCoin rechargeable cells. From lithium-ion batteries to coin batteries and from battery life to size and application, there are many choices from which battery technology best suits the needs of any application. Also the battery must be fitted with a circuit protection module (PCM). This generally gives the battery protection against overcharging, short circuits have a current limiter, and provides voltage / current balancing in each cell. All the above are important for the battery to have maximum performance and the longest possible life.
5. **Gyroscope, accelerometer and Magnetometer and Temperature sensors:** The above sensors provide high precision temperature measurement, humidity, location detection, and movement tracking while operating at low energy consumption. The connection interface of these sensors is

called a “cascade”, which minimizes the number of GPIOs needed and further requirements of the main processor.

6. **RTC (Real Time Clock):** This module is intended to provide real-time clock functions in the absence of battery. Its main feature is having very low power consumption, and many functions including battery backup, programmable meters, and timer and watchdog alarms. It connects to the microprocessor via an Inter-Integrated Circuit (I2C) bus.
7. **Antenna:** Used for covering the NB-IoT band providing high efficiency in a very small form factor.
8. **Cardiac Monitoring Unit:** Traditionally, heart rate monitoring equipment (pulse meters) included chest straps that were somehow connected to an external device, such as a mobile phone via BLE. These solutions have some obvious disadvantages, such as the fact that these straps are often not so comfortable to wear. the accuracy of the method.
9. **GPS Unit:** The system will provide GPS support if the other positioning methods provided do not work well. Alternatively, due to the extra cost and impact on battery life, GPS may only be available in certain cases in specific versions of the hardware. The GPS will communicate with the main processor via the Universal Asynchronous Receiver Transmitter (UART) bus.

ALGORITHMS FOR OPTIMIZATION OF ENERGY CONSUMPTION

Energy consumption in IoT applications is a very crucial factor that must be taken into consideration when designing such systems. In the project’s framework, energy consumption is quite important, as for example when the user is in a state of emergency the battery should be alive as long as possible, so the authorities have more time to act, to locate and rescue the user. Furthermore, extending battery life is a convenience, especially considering the fact that the WeSAR system is intended to be used for children or for people suffering from autism or dementia, so longer battery life makes the life of the parents or of the people that are responsible caring about them too. The energy saving research has taken place having in mind the available hardware and modules.

One of the ways to achieve energy efficiency in battery constrained IoT devices is to introduce on the devices and the system a state logic. Particularly, to reduce energy consumption in applications where there are battery-operated devices, the concept of operating modes has been introduced. Depending on the technology, some situations are defined where the device has the least consumption while in other situations depending on the function that needs to be performed the energy consumption is highest. In sleep situations the current should be as low as possible. This approach is introduced and implemented in the case of the WeSAR system, too. Furthermore, more approaches that authors followed are: a) Energy consumption and sensor management b) Energy consumption and frequency of transitions c) Energy consumption and data transmission.

In this case authors have defined the user’s states in which they can be. These states are the following:

1. Low risk, e.g. the user is sleeping, or the wearable is charging, not used.
2. Normally, there is no danger.
3. High risk, e.g. child at the boundaries of the controlled area, some biometric sensors show high other non-hazardous signals.
4. In an emergency, the user is at risk either because of their location or because they were activated by an external user e.g. by pressing a panic button.

The following figure shows the transition of the user’s states.

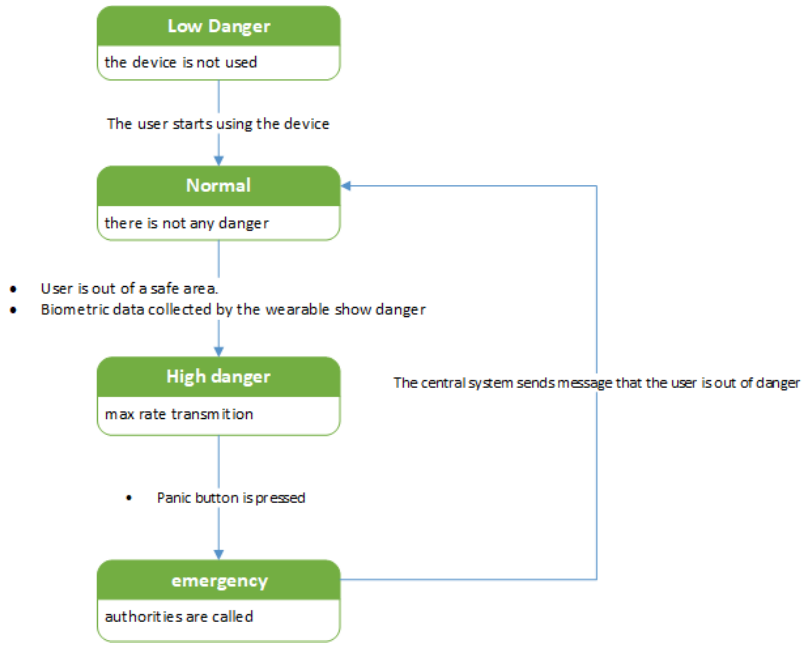

Figure 5. The supposed transition of the user's states

Table 1 shows the energy consumption over the various states. Taking all the above into consideration, authors try to map the user's state to the device's states in order to understand the energy impact on it. So, we introduce the following device's states.

- Off: in this state the device is switched off.
- Hibernate: in this state, only the accelerometer is switched on, because it is an essential sensor so as to transit to other states.
- Idle/normal: in this state the sensors are taking measurements and transmit these measurements through NB-IoT to the cloud.
- Emergency: in this state all the sensors are switched off, except of the sensors that are crucial for the detection of the user, in order to expand the battery's life.

Figure 6 shows the way of the transition between the device's states. Off status is ignored in the figure of the transitions from one state to another. Beginning with the hibernate state, the transition to idle / normal from hibernate state is: every x seconds switches from hibernate mode to idle normal to read sensor measurements and then switches back to hibernate mode. Each y time unit switches from hibernate mode to idle / normal and in addition to reading sensor measurements and then it is also sent to the base station. After sending the data, the device / wearable waits for any messages from the cloud and then returns to hibernate mode. The only sensor authors assume that is working in hibernate mode is the accelerometer. When the accelerometer detects a dangerous movement, it goes into idle / normal mode and reads the sensor values and sends them to the base station using available communication technology in our case NB-IoT. After sending the data the mobile device waits for any messages from the cloud and then switches to hibernate mode.

A key factor in energy consumption is the rate at which the sensors collect data and send it. Therefore, it is important that there is a difference in the rate at which data will be sent depending on the situation of the user and the mobile device itself. Determining which of the sensors will remain active as well as the interval for which they will remain active will be determined by the related algorithm running in the cloud and notifying the wearable device with an appropriate message. Another parameter in the management of the sensors is the existing energy level. Thus, the sensors should remain off for a longer period of time. Even the previous statement should be dynamic, because when the user is in an emergency the hardware modules that are relevant for the localization mush remain switched on, otherwise it will be infeasible for the authorities to rescue the user.

Table 1. Energy consumption over the states

Factor	State		
Sensor management	Sensors are switched off	Some sensors are switched off	All sensors are switched on
Frequency of state transition	Low	Medium	Large
Data transmission	Sleep	Radio on	Transmission
Transmission parameters	Low power	Medium power	Large power
Energy Consumption	Low >>>>>>>>>>>>>>>>>>>>>>Medium>>>>>>>>>>>High>>>>>>>>>>		

Among other things, the following parameters will be taken into account: When switching from normal / idle to emergency mode, data transmission rate increases, as it is vital for finding the user, resulting in reduced battery life. 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 is optimized according to the existing conditions. For example, if the battery is below a value e.g. At 30 percent in normal / idle mode, the rate would be lower than if it were at 90 percent battery level. This extends to the emergency mode where the data rate is set according to the battery level. When the battery is low, the transmission frequency should be lower.

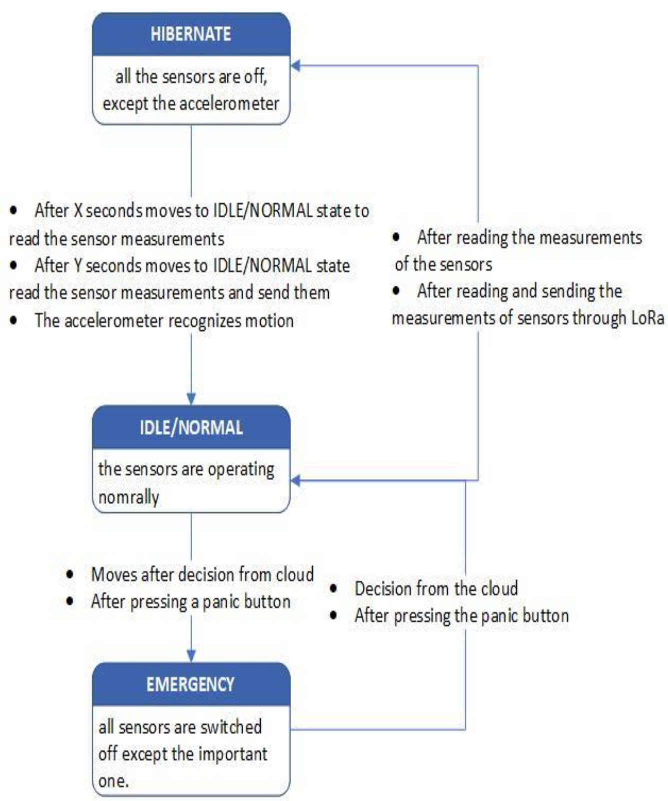

Figure 6. Transition of the states

Another important factor affecting energy consumption is data transmission. Generally speaking, when the communication modules are inactive (or in hibernate mode) the power consumption is minimal, but when receiving data, the power consumption of the device is increased, and maximized when sending data. As described above, authors should always take into account the different modules of the device. In a general case of our system, authors can consider three ways of transmission a)BLE (in case the mobile device is paired with the mobile) b)LoRa, c)NB-IoT.

In the first case of using BLE, the power consumption is less than the three cases because the device is paired with the cell phone, and the cell phone is in charge of communicating with the receiving station, so this is the device that consumes more energy. If the wearable device is not paired with the smartphone, the available communication protocols (LoRa / NB-IoT) should be used. Each of the two protocols has a number of parameters that affect communication according to existing conditions such as the distance of the device to the receiving station. So overall, the mechanism determines the parameters of transmission (power of transmission of the data packets) in order to achieve better energy consumption. More specifically, in NB-IoT authors need to deal with NB-IoT UE duty cycle state as explained in the following figure (Sultania, A.K. et al. (2019)). Some of the parameters affecting energy consumption in a NB-IoT network are transmission power, Uplink (UL) data rate, Downlink (DL) data rate, extended Discontinuous Reception (eDRX) duration, and when Power Saving Mode (PSM) is used or not. Accordingly, authors did in the case of LoRaWAN protocol, with its own different duty cycle and its own parameters, such as Spreading Factors (SF), center frequency, etc.

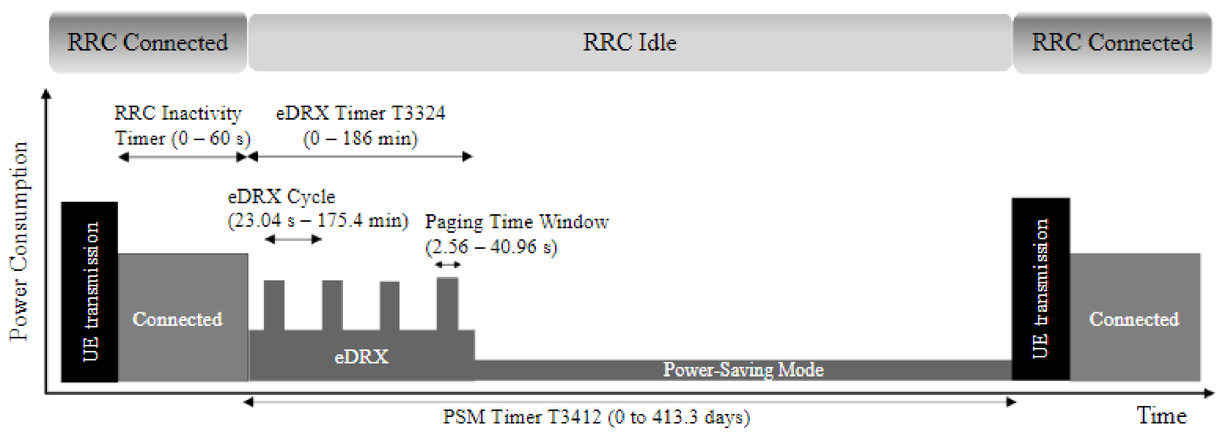

Figure 7. Overview of the NB-IoT UE Duty cycle states

ALGORITHMS FOR LOCATION DETECTION

This section introduces our study on location estimation through the trilateration algorithm. Authors described a solution that is based on IoT devices and the deployment of various NB-IoT gateways to provide localization of vulnerable people use cases. Through the estimation of the NB-IoT channel and using trilateration, the localization of the person can be obtained within a 40-60 m range. The main advantage of this current solution is that it is low cost as the modules cost a few dollars and as a mechanism can give better results even indoors.

Our approach is based on the usage of the RSSI by various gateways (see figure 8). In this study authors focus on the RSSI meaning value for the distance estimation. Authors consider that the above solution could be a research study for indoor areas such as shopping malls, universities campus, or even playgrounds where authors could locate people wearing just a wearable device as a tag.

All established GWs inside a NB-IoT enabled topology can receive a packet from an end-node IoT device and forward it to the network server. This leads the network server to have multiple copies of the same package. To resolve issues of multiple copies of the same data packet only an updated version of the data packet is being forwarded to the application service through filtering. A JSON file containing all the data and various details about the data channels and GWs is being created for testing purposes. This file contains all the appropriate information related to the GW position and configuration settings so as to be used subsequently from the geolocation algorithm. The algorithm for location detect has the limitation that in any position inside an area the client must have connectivity to a minimum of three GWs so that can benefit from trilateration. Installation and configuration of Gateways can vary depending on the need in the area and the limitations that may exist. The setup of the NB-IoT GWs has to be done into consideration of factors like the size of the area that want to cover, the number of devices that can be tracked, and any buildings that may be in front.

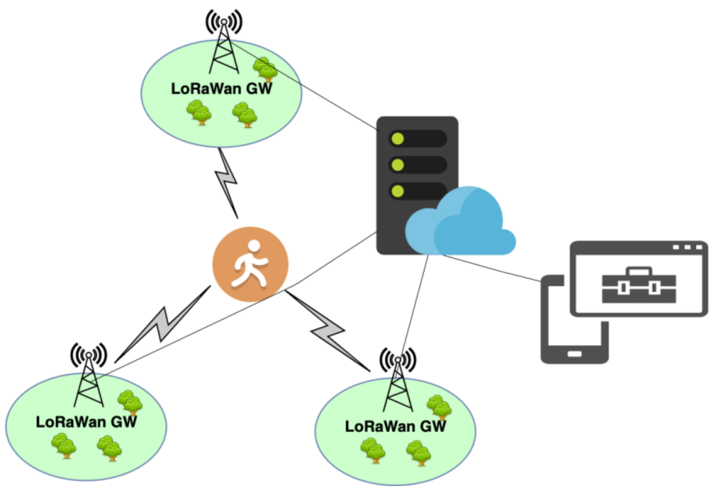

Figure 8. The architecture of location detection.

The network server as described above includes the data in a generated JSON file with various details about the configuration of the GWs where the packet got through.

Example of the metadata format in JSON

```
{
    "modulation": NB-IoT,
    "coding_rate": "4/5",
    "frequency": 868.3,
    "gateways": [
      {
      "channel": 1,
      "id": eui-fipy2,
      "latitude": 33.216720
```

"longitude": 22.651546,

"rssi": -110,

"snr": 10

"time": "2019-11-05T16:31:24"

},...

}

The above file is being used as input to the Geolocation algorithm. The NB-IoT architecture provides complete information about the GWs that received the packet sent by the wearable device and the strength of the signal (RSSI) with which it was received and appends this data to the generated JSON file. Using the above information, authors can apply the algorithm which makes use of trilateration. The same logic is also used by traditional GPS. With three NB-IoT GWs, the true location can be retrieved as the connected point where all three circles intersect. The GWs that receive the data packet from the wearable device act like the satellite on the GPS, and the RSSI value for each GW perceived by the client is used to determine an estimation of the distance. The received RSSI values from the three GWs are used for the estimation of the distance. This process is already known in the literature through various models. So, it can simply be defined by the mathematical formula below:

$$P_r(d) = \frac{P_t}{d^n}, \quad (1)$$

where n is the called distance-power gradient in [2,6].

$$d = 10^{\frac{RSSI}{10*n}}, \quad (2)$$

Supposing the use of the RSSI value from three different NB-IoT GWs, g1, g2, g3 that are located at coordinates of type (x, y). If authors indicate the computed distances as d1, d2, d3, will have the following equations:

$$\begin{aligned} \left(x-x_{g1}\right)^2+\left(y-y_{g1}\right)^2 &= d_1^{\,2} \\ \left(x-x_{g2}\right)^2+\left(y-y_{g2}\right)^2 &= d_2^{\,2}, \\ \left(x-x_{g3}\right)^2+\left(y-y_{g3}\right)^2 &= d_3^{\,2} \end{aligned} \quad (3)$$

After expanding the squares and subtracting the equations:

$$\begin{aligned} Ax+By &= C \\ Dx+Ey &= F \end{aligned}, \quad (4)$$

which give us:

$$x = \frac{CE - FB}{E - BD}, \quad y = \frac{CD - AE}{BD - AE} \tag{5}$$

where $A = (-2x_{g1} + 2x_{g2})$ $B = (-2y_{g1} + 2y_{g2})$, $C = d_1^{\ 2} - d_2^{\ 2} - x_{g1}^2 + x_{g2}^2 - y_{g1}^{\ 2} + y_{g2}^{\ 2}$, $D = (-2x_{g2} + 2x_{g3})$, $E = (-2y_{g2} + 2y_{g3})$, and $F = d_2^{\ 2} - d_3^{\ 2} - x_{g2}^2 + x_{g3}^2 - y_{g2}^2 + y_{g3}^2$. This is clearly a 2D plane.

Python Algorithm Implementation

```
#Trilateration formulas to return intersection point of three circles

def trackIoTWearable(x1,y1,r1,x2,y2,r2,x3,y3,r3):

  A = 2*x2 - 2*x1

  B = 2*y2 - 2*y1

  C = r1**2 - r2**2 - x1**2 + x2**2 - y1**2 + y2**2

  D = 2*x3 - 2*x2

  E = 2*y3 - 2*y2

  F = r2**2 - r3**2 - x2**2 + x3**2 - y2**2 + y3**2

  x = (C*E - F*B) / (E*A - B*D)

  y = (C*D - A*F) / (B*D - A*E)

  return x,y

#Generate and represent data to be used by the trilateration algorithm

  x1 = randint(-150,-80)

  y1 = randint(-150,150)

  x2 = randint(80,150)

  y2 = randint(20,150)

  x3 = randint(80,150)

  y3 = randint(-150,-20)

  x  = randint(-60,60)
```

```
  y  = randint(-60,60)

  r1 = ((x-x1)**2 + (y-y1)**2)**0.5

  r2 = ((x-x2)**2 + (y-y2)**2)**0.5

  r3 = ((x-x3)**2 + (y-y3)**2)**0.5

x,y = trackIoTWearable(x1,y1,r1,x2,y2,r2,x3,y3,r3)


#Output IoT location - coordinates

  print(x,y)
```

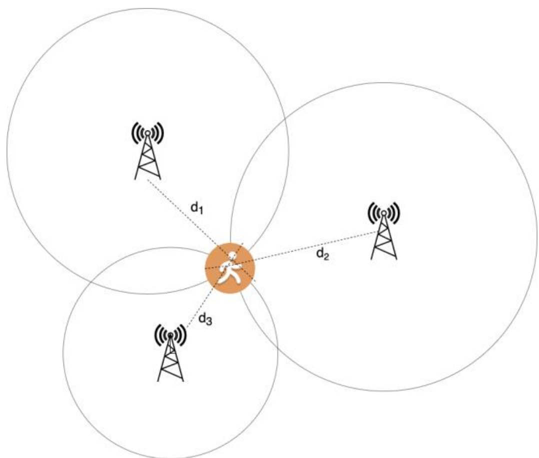

Figure 9. Graphical representation of the trilateration algorithm.

The cumulative distribution as metric describes the chance that a given variable will fall between or within a specific range. Using Equation 2, authors have $n = \frac{|RSSI|}{10 * \log_{10}(d)}$ with n = 3.9, d = 150m and |RSSI| = 82. This value may be different in other cases where the topology is different and RSSI signal is varied. Values of n at interval [4,6] seem to be ideal in our scenario using 3 GWs for trilateration. Fig. 4 shows the distribution on the obtained position estimation; authors could place the IoT module in a circle where the distances from the NB-IoT GWs are in the middle of a circle. Using Geometric dilution of precision (GDOP), authors can describe the error caused by the relative position of the devices; Basically, the more signals a NB-IoT receiver can “see” (spread apart versus close together), the more precise it can be. From another point of view if the GWs are spread apart in the locations, then authors could have a better GDOP.

FUTURE RESEARCH DIRECTIONS

IoT has been increasingly introduced in our everyday life, so its impact on our lives will be greater and greater. So, LPWAN technologies are expected to gain more popularity, thus NB-IoT is expected to be introduced to more and more applications. Especially with the advent of 5G, NB-IoT will be a key player in the LPWAN market. As described in WeSAR authors focused on energy efficiency and positioning. So, authors consider researching on these important topics. Machine learning (ML) can be a great tool for dealing with these limitations. Machine learning can help increase the accuracy of localization and it can be introduced in the proposed system. There is research about integrating ML techniques in localization algorithms for NB-IoT networks. Berruet, B. et al. (2018) have studied and proposed a fingerprinting algorithm for localization in indoor condition for IoT, using WiFi wireless technology. Such an approach can be used for the WeSAR system, too for future work. Pan, G. et al. (2020) have tested a scenario in which positioning from the Observed Time Difference of Arrival (OTDOA) in NB-IoT network has been improved. This improvement is achieved with the use of deep learning techniques. Their results showed tremendous improvement in accuracy. Despite the fact that in our current equipment authors cannot use Time Difference of Arrival, they implement a similar approach with the use of RSSI data. Also, it would be helpful to embed ML for energy consumption, not only for the IoT devices but also for the network in general. In other words, ML can help in reducing the congestion in NB-IoT networks, techniques such as Multi-Armed-Bandit algorithms, etc. For example, Chen L. et al. (2018) have implemented an adaptive mechanism, using reinforcement learning. Their solution is specialized for NB-IoT networks. Finally, energy harvesting techniques should be investigated as a possible solution. However, as mentioned by Haridas A. et al. (2018) there are a number of challenges that need to be addressed, due to the need of a small volume of the devices. This problem is more serious in the case of WeSAR, as the wearables are meant to be as light as possible.

CONCLUSION

In this chapter, the project WeSAR was presented and described, a project that aims to provide to some groups of people with specific needs an important solution. With the use of LPWAN technology such as NB-IoT, authors are able to provide search and rescue solutions for individuals, especially those belonging to groups of people who are more possible to get lost. The central part of the system is a modular “wearable” device, while in the framework of the implementation of this system authors have seriously taken into consideration the aspects of energy efficiency in order to provide better battery life. Better battery life means more convenience for the users and in many cases can be a lifesaver. The approach authors followed is based on the notion of statuses. Apart from energy efficiency, another aspect that has been taken into account is the research on the localization algorithms using NB-IoT, as it is a key factor in the overall system. NB-IoT has gained popularity and other LPWAN technologies as well, so in the future authors expect to see such technologies in more and more applications.

ACKNOWLEDGMENT

The authors acknowledge that the starting point and the drive of this paper have been generated in the context of the project “WeSAR (Wearable based Search And Rescue system)”. In this framework, we would like to thank all the project partners and employees of Econais AE, Yodiwo AE, and CTI (Computer Technology Institute & Press “Diophantus”) for their personal copy information and experience on this project. 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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KEY TERMS AND DEFINITIONS

Autism spectrum disorder: Autism spectrum disorder is a developmental disorder that affects communication and behavior. Although autism can be diagnosed at any age, it is said to be a “developmental disorder” because symptoms generally appear in the first two years of life.

Dementia: Dementia is a broad category of brain diseases that cause a long-term and often gradual decrease in the ability to think and remember that is severe enough to affect daily functioning.

IoT: The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.

Low Power Wide Area Network: A low-power wide-area network (LPWAN) or low-power wide-area (LPWA) network or low-power network (LPN) is a type of wireless telecommunication wide area network designed to allow long-range communications at a low bit rate among things (connected objects), such as sensors operated on a battery.

NB-IoT: Narrowband Internet of Things (NB-IoT) is a Low Power Wide Area Network (LPWAN) radio technology standard developed by 3GPP to enable a wide range of cellular devices and services.

RSSI: In telecommunications, received signal strength indicator (RSSI) is a measurement of the power present in a received radio signal

Search and Rescue: Search and rescue (SAR) is the search for and provision of aid to people who are in distress or imminent danger.

Triangulation: In trigonometry and geometry, triangulation is the process of determining the location of a point by forming triangles to it from known points.

Trilateration: It is the process of localization of a point by forming circles to it from known points.

Wearable Devices: Wearable Devices are smart electronic devices (electronic devices with micro-controllers) that can be incorporated into clothing or worn on the body as implants or accessories.

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