Efficient multi-mode communication system

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Abstract: The work aims to outline a system capable of collecting a set of data from the level of each soldier in an intervention group and transmitting it to a collector node that displays them. The collected data is displayed through an app, displaying information about the location where the soldiers have been. The presented experiments show that the proposed solution demonstrates improved features and robustness in the state of the art context.

Keywords: MIoT, Wearable Devices, Sub 1-GHz Communications, RTOS.

1. INTRODUCTION

In this paper, we aim to identify components that allow the creation of a sensory node capable of collecting data, which can then be analyzed and used in tactical situations on the battlefield. A good example is the war on our country's border. Conventional battles are fought in the first days, after which a war of attrition occurs. This war of attrition most often materializes through guerilla wars, where the fighting unit is reduced to a few men and where the better the tactics and positioning of these men in the field, the better the result. Those mentioned above must be closely related to a perfect knowledge of the condition of the soldiers, and at present, this is possible through the use of means of communication, with each of the soldiers confirming his condition.

Our goal is not to replace such a means but to develop a system that allows for the collection of more data and the aggregation at the base station of information about the vital parameters of the soldiers, the parameters of the environment, and some parameters that can be harmful. The ultimate goal is information processing. The more information we have from the field, the greater the chances of success. We start with a minimum set of requirements to be more consistent in identifying critical components inspired by other solutions from literature (Peng et al., 2022; De Castro Leal et al., 2019; Ashour, 2019).

2. RELATED WORK

A number of scientific papers deal with the subject of commercial devices used in the military domain. This paradigm of commercial off-the-shelf devices is discussed in the context of warfare and how it influences classical warfare as we know it (Upadhyay, 2024). The current period, the large flow of commercial devices, hardware solutions that are within everyone's reach, and the very low price of all electronics show us a new area where all these devices can be used. In crisis situations, it must be borne in mind that any method of creating an advantage against the enemy must be exploited. War relies on military devices and solutions, but military countermeasures often make these unavailable. Thus, the identification of alternative solutions, even those that do not meet the standards but solve a tactical need, should be used a lot.

The field of military communications is well-defined; deviation from it is often done only in cases of utmost urgency. The possibility of using commercial solutions, presented as cheap solutions, in the context of specific, situational combat scenarios offers an alternative, yet necessary solution (Mekiker et al., 2023).

Mobile phones have been used extensively in recent wars in the region; one example of their use was in determining troop movements by accessing databases that stored information about the position of soldiers in real-time. The position of artillery guns is information that does not need to be known, and for the enemy, knowing it provides valuable information. VPK's application uses soldiers' phones to capture the sound produced by artillery when they fire and transmit it to a processing system, which then uses at least 3 signals from different phones to be able to triangulate the position of the artillery guns. By emulating dummy cell phones and connecting soldiers to them, the fighters could exploit the vulnerability and determine the positions of larger groups of soldiers. Automatically the mobile phones connect to base stations and make a terminal identification (Horbyk, 2022).

In addition to these mobile phone-based systems, the literature identifies several military solutions based on commercial solutions. A first solution is identified, and a device is proposed to collect data from soldiers. Jain et al. theoretically propose a device capable of acquiring data from temperature, oxygen concentration, and heart rate sensors. In addition to these, a GPS for location identification has been added. Data was read from the sensors one at a time for verification (Jain et al., 2020).

Pauline et al. propose monitoring soldiers' locations using a smart shoe that transmits GPS coordinates via Lora. The received coordinates are then mapped on a map to reveal the soldier's location (Jessica Pauline et al., 2021).

3. PROPOSAL

From a hardware point of view, the device will be divided into four components: the processing, the communication, the signal acquisition, and the power supply part. If, at the functional level, this 4th component did not need to be mentioned, it has a huge role in the hardware proposal. A battery powers the device and power consumption management allows us to achieve a much longer service life. Choosing suitable components for the power supply part considerably improves the consumption, giving the proposed architecture a higher degree of viability.

From the point of view of hardware design, the specialized documentation does not provide us with much information, namely complex schemes that allow the implementation of similar devices. In (Qureshi and Krishnan, 2018) the authors presented both a block diagram and an electrical diagram of a medical device that can acquire a biomedical signal. The blocks give us a general picture of the information reception chain from a PPG (Photoplethysmogram) sensor, divided into three components, a data collection component, a processing component and a visualization component. The authors also come up with a proposal for hardware components, which, from a technological point of view, are outdated, and their performance is limited. Even if the authors invoke an excellent commercial presence of them and a relatively low price for reasons of performance and use, some components cannot be used. The processor used is an ARM processor, but it is used as a development board under the name Raspberry Pi Zero. Typically, the use of an ARM microcontroller can guarantee excellent performance and current consumption. Still, in this case, as a processor running an operating system, the current consumption is too high to use on a wearable device. So, our solution will bring improvements and real contributions also on this topic.

To demonstrate the incompatibility of Raspberry boards or other similar variants, a consumption test is conducted to see the power requirement it needs. A consumption of almost 300 mA in idle mode and in processing mode reaching almost 600 mA does not offer a good start for an easy-to-carry wearable system. The higher consumed power leads to the need to use larger batteries. Moreover, this board cannot enter sleep mode, which would significantly reduce consumption. In the same idea, we have to think that the implementation of a sleep mode method would generate a relatively significant delay from the moment of exiting from sleep to the moment of regular operation, this downtime influencing the response of the device, but also the quality of the data. In (Lacirignola and Pasero, 2017) even if the project's complexity is not so great, their target is to create a device for acquiring ECG signals, the proposed technical solution considers both performance and power consumption. Thus, a low-power microcontroller is proposed, and Bluetooth 4.0, a low-power communication standard, is presented for the communication part.

Our system consists of a series of devices that perform specific functions (Figure 1):

- Collector node—This device is worn by each soldier and acquires data from the integrated biomedical sensors.
- Coordinator/collector node—A device that collects data from the integrated biomedical sensors and aggregates all the data from the mesh level to transmit them to the central station. The data from each collector node contains identifiers to differentiate the collected information.
- Visualization/collector node—A device that collects data from integrated sensors and allows information to be transmitted from the entire network of devices to a smart tab for data visualization.
- Hopping node - This node facilitates the transmission of data to the base, considerably increasing the transmission distance. From the point of view of operation, the hoping point must be a point at a high altitude that facilitates data transmission in the line of sight.

The collector node is the normal-use node whose purpose is to collect data from the human body and transmit it to the coordinator. This node fulfills the function of data acquisition. The chosen processing unit for the collector device is an ARM Cortex M3 microcontroller.

This microcontroller offers a set of features very suitable for our project. It provides us with sufficient processing speed for integrating encryption or processing components, but also very complex power management, allowing configuration for very low energy consumption.

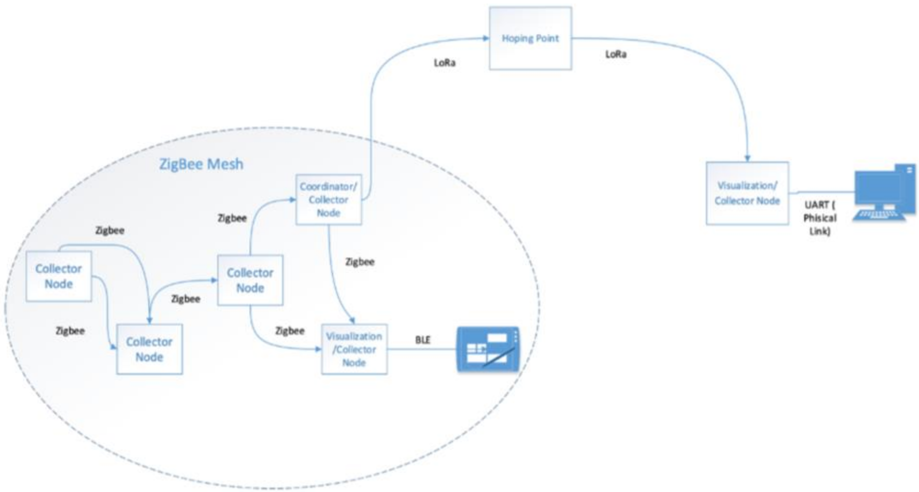


Fig. 1. Proposed protocols.

As it was mentioned above, the collector node is the node whose only function is to collect data from the sensors. We will start from this node to sketch a hardware block architecture.

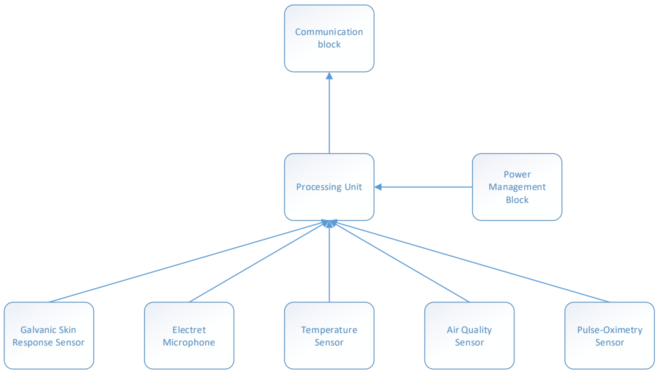


Fig. 2. Hardware architecture of a device.

We aim to create a device that can read several sensors in parallel to have an overview of all the parameters at a particular moment in time. The diagram above (Figure 2) represents the sensors that will be used for the device. Each of these sensors has a way to connect to the microcontroller, these are called serial communication protocols. A communication protocol defines both how the physical connection is made and how the data is transmitted. An example is the SPI (Serial Peripheral Interface) protocol, which uses four wires for communication, and I2C (Inter-Integrated Circuit), which uses two wires for communication. Similar to the two mentioned, the definition of a communication protocol presumes standardization at a global level so that any microcontroller can communicate through the respective protocol.

We previously defined the components of our system at the macro level, having some devices with specific functions that are somewhat similar to each other but differentiated by their position in our architecture.

From the point of view of the communication component, our system will be divided into five categories:

- devices that only use Zigbee communication.
- devices that use Zigbee and Bluetooth communication.
- devices that use ZigBee and LoRa communication.
- devices that only use LoRa communication.
- devices that use LoRa and Bluetooth communication.

4. RESEARCH

To reach the entire system's functionality, we have to go through some stages of individual connection. Respectively, the communication between a collector node and a coordinator node.

For this, we need to identify a series of components that will allow us to achieve the proposed architecture. Previously, we presented the types of processing units we can use. After the analysis, we narrowed the search for microcontrollers, for various reasons: easier interconnection, lower power consumption, etc. We restrict ourselves to those with a data transmission component from this vast segment of microcontrollers. The variants are different and many, depending on the communication protocol.

We mentioned earlier that the objective is to implement a ZigBee-type communication, the latter ensuring efficient short-distance communication, and for long-distance communication we should use the LoRa protocol (Hayati and Suryanegara, 2017). After searching for devices with such capabilities, we identified the development boards from Texas Instruments CC1350. These boards propose a communication in the spectrum of frequencies below 1-GHz, accessible for the public, respectively 868 MHz and 434 MHz. These frequencies are used by most radio communication protocols, being free frequency bands. Data transmission speed and distance depend on modulation and other factors that differ from one protocol to another.

The ISM (industrial, scientific and medical) bands (433/868/915 MHz) have been used for a very long time, and Texas Instruments' proposal does not come as a new concept, namely the use of unknown frequencies. These bands were also used in the past for many radio applications, most of which meant radio communication, different from Wi-Fi and Bluetooth, using frequencies from the ISM bands. So we are now seeing widespread adoption of these frequencies due to the current data context. The application requirement is no longer exclusively for very high transfer speeds. Part of the interest has moved to remote monitoring, with greater distance and lower throughput. This was also allowed due to the significant improvement of communication chips. Through different modulation methods, by increasing the sensitivity of receivers, or through more efficient decoding algorithms, it was possible to transmit a somewhat reduced amount of data at very long distances.

As we mentioned earlier, Texas Instruments proposes this chip, which wants to achieve long transmission distances and very low current consumption. The very low energy consumption brings another significant advantage: the size of the final device.

Throughout this document, the impossibility of knowing in detail the terrain on which an action group carries out its activity was debated. Thus, the capacity of these devices must be analyzed in several circumstances. In an area where there are no buildings, radio devices are much more efficient than in areas where there is a lot of vegetation or buildings. In order to highlight and strengthen the choice of a radio solution, we must see the applicability and the tests carried out with a solution in different scenarios.

In (Wardana et al., 2018), a solution for acquiring signals from different sensors is proposed using sub-1GHz technology. The frequency used is from the ISM band and is 915 MHz. This is chosen for distance considerations, the performance obtained being 43 m in space with buildings, where there is no LoS (Line of Sight) and 280 m when there is LoS. The use of a frequency of 2.4 GHz is inappropriate for such applications. There is another problem in the use of the 2.4 GHz frequency, which exists mainly in the urban environment and is caused by the loading of the spectrum with many signals (Chen et al., 2019).

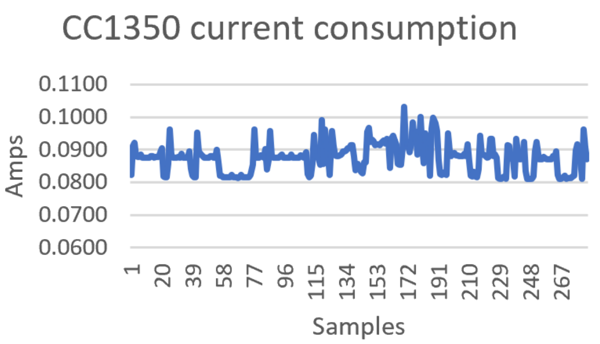
These interferences can cause communication problems for different devices. LoFi is a communication concept that allows using the LoRa protocol in the 2.4 GHz range. LoRa packets are known to be susceptible to wireless network interference. However, at the moment, we have a LoRa communication proposal in the 2.4 GHz range (Semtech, n.d.). In (Chen et al., 2021), the impact of these two types of communication on each other is analyzed. In concurrent use, we see a 2% loss of LoRa packets and a 13% decrease in Wi-Fi throughput. These figures can increase with the loading of the spectrum.

At the same time, we must understand that using sub-1GHz bands can generate differences in speed and distance. This is due, as we mentioned above, to the modulation type, coding and decoding, etc.

The CC1350 module from Texas Instruments is an integrated sub-1GHz radio and Bluetooth Low Energy (BLE) system designed for long-range IoT applications. This module combines a sub-1GHz transceiver with a Cortex-M3 processor, offering high flexibility in wireless system design.

The performance of CC1350 modules in LoS conditions can include a transmission power of up to +14dBm on the sub-1GHz band and a transmission power of up to +8dBm on the BLE band. This allows for a coverage range of up to 10 km on the sub-1GHz band and up to 100 m on the BLE band in ideal LoS conditions.

The first criterion for choosing the platform we will develop is the current consumption at a supply voltage of 5V. We mentioned above that a Raspberry Pi using a 32-bit microcontroller from the ARM family has a current consumption of at least 300 mA. The platform we are using has a consumption during data transmission and reception of 90 mA, which is 70% lower than the Raspberry Pi. It should also be mentioned that the proposed MCU can also operate in sleep mode, which will reduce consumption during this mode by 98% (Graphic 1).



Graphic 1. CC1350 current consumption.

However, in an urban environment, obstacles such as tall buildings and narrow streets create shadowing areas that can decrease wireless signal in certain areas. This can lead to a decrease in coverage range. Phenomena such as absorption, reflection, diffraction, and refraction affect wireless signals, which can decrease system performance.

To accurately determine the signal loss or degradation in an urban environment, conducting real-world tests in the specific environment is recommended. These tests can include evaluating performance based on parameters such as transmission power, receiver sensitivity, obstacle density, and communication technology. By conducting these tests, it will be possible to determine the optimal coverage range for the specific application and adjust the system parameters accordingly to achieve the best performance possible.

It is also worth mentioning that while the physical factors in urban environments can cause a significant signal loss, there are also ways to mitigate these effects. For example, the use of frequency hopping technology, which allows for signal transmission on multiple frequency bands, can help avoid interference and shadowing areas. Additionally, directional antennas or beamforming techniques can also help increase the signal strength in specific areas.

Overall, while the CC1350 module can provide excellent performance in LoS conditions, signal loss or degradation in an urban environment can vary greatly depending on various factors. Considering these factors and conducting real-world tests in the specific environment is essential to determining the optimal coverage range and adjusting the system parameters accordingly.

Changing the current architecture in terms of the types of communication used, i.e. replacing Zigbee for communication between nodes and LoRa for remote communication between collector and hopping point, is a clear improvement, at least from a cost point of view. Using a chip capable of being tuned for both near and far-end communication offers a software design advantage that ultimately results in a lower device cost and a more simplistic architecture. Moreover, using two independent modules is more challenging to implement, having perhaps two different communication protocols. Our system needs to be robust and easy to procure. Lesser components, the more advantageous for our system.

It is essential to consider these factors when designing wireless systems with the CC1350 module in an urban environment. One method of minimizing these effects is through frequency hopping technology, which allows for signal transmission on multiple frequency bands, thereby avoiding interference and shadowing areas.

Conducting tests in real-world conditions to evaluate system performance and determine the optimal coverage range for the specific application is recommended. Testing can include evaluating performance based on parameters such as transmission power, receiver sensitivity, obstacle density, system configuration, and communication technology.

What interests us about the proposed solution, CC1350, is the MCU's processing capacity and what it can offer from the point of view of communication. To cope with various tasks, this SoC includes a 48 MHz ARM Cortex M3 processor, a more powerful microcontroller than 8-bit microcontrollers, for tasks such as signal acquisition, data encoding, or implementation of lightweight encryption algorithms. With these performances, this MCU is a real solution for the device chosen by us.

Another significant advantage we have when using this platform is its RTOS (Real Time Operating System) support. The MCU uses very precise clock sources that allow and support the implementation of a pseudo–operating system because it lacks many functionalities compared to a real operating system. In the same way, we can call it a lightweight operating system. Its purpose is to run on embedded systems and to provide a way to parallelize processes. The RTOS fulfills this task by allowing the developer to implement tasks with different levels of prioritization, depending on their importance.

In order to see how well these radio chips fit in an application of data transmission from sensors, it is necessary to carry out some distance tests. From the speed point of view, the tests that can be performed are with a fixed payload and at a specific time interval. Even if most radio protocols are characterized both in terms of distance and speed, in our case, we are not necessarily interested in high speed. What is of interest to us is that the bandwidth is greater than the amount of data that we want to be able to be transmitted at regular interval.

The frequency offset is a parameter that directly affects the quality of reception, and its influence is greater the lower the transmission band. A larger transmission band allows a larger offset, allowing the receiver to search for the frequency and lock onto it. The narrower the transmission band, the more any offset change affects communication.

The precision of the oscillator gives the frequency offset. The more precise the oscillator, the smaller the frequency error will be. In the case of narrow bands, if the oscillator does not have high precision and the frequency has an offset greater than the bandwidth, there is the possibility of receiving another signal from another band. This is also closely related to the guard band, a free band that allows a receiver not to fit the band of interest perfectly.

The coding scheme presents a series of blocks whose properties can be modified, thus generating changes in the communication parameters. In the figure below, these blocks are represented, this coding chain being standard for radio communications.

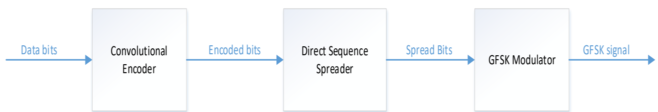


Fig. 3. Coding chain.

A convolutional encoder is a state machine that contains k m-stage shift registers whose purpose is to generate a codeword. It is characterized by three parameters:

- Rate - The rate determines the ratio between the number of input and output bits.
- Length - The length determines the number of levels the convolutional encoder has and in the case of the CC1350 system, for Long Range transmission it is 7. The length is denoted by K.
- Internal coding algorithms—The internal connections inside the encoder give the algorithm, and these can be systematic / non-systematic and recursive or non-recursive. The encoder used is non-systematic and non-recursive.

Direct sequence spreader is a block whose role is to assign for each input bit a sequence of bits at the output. This block can be configured, depending on the length, in 4 ways:

- length 1, logical bit 1 is assigned the sequence "1", and logical bit 0 is assigned "0".
- length 2, logical bit 1 is assigned the sequence "11", and logical bit 0 is assigned "00".
- length 4, logical bit 1 is assigned the sequence "0011", and logical bit 0 is assigned "1100".
- length 8, logical bit 1 is assigned the sequence "00110011", and logical bit 0 is assigned "11001100".

The mapping mode chosen for DSS(Direct Spread Spectrum) automatically affects the data transmission speed. The greater the length of the mapped sequence, the lower the transmission speed.

5. IMPLEMENTATION

According to notes from Texas Instruments, the communication method we will use for data transmission is SimpleLink Long Range Packet Format due to its better performance. The test performed assumes one-way communication between two devices. This test covers two scenarios of our architecture: the communication between a Node collector and a coordinator and the communication between a coordinator and a hoping point. The devices run an RTOS that allows us to execute certain functions in the form of tasks.

The scenario we want to realize is between two CC1350 communication boards. For this scenario, a series of software applications has been installed that allows both the programming of the boards and some radio modifications to them. The data that the two exchange is viewed via a serial program.

In order to achieve communication between the two nodes, Texas Instruments has implemented two firmware to facilitate data transmission by the node and data reception by the collector. For this purpose, a library provided by Texas Instrument was used to abstract the layer that allows access to the commands for radio transmission. The software diagram of the two firmware is shown in Figure 3 and Figure 4. The two diagrams follow each other as it is necessary for the two to synchronize to communicate with each other. Thus, the Node is the one that implements a number of additional functions that allow reading data from GPS, a temperature and humidity sensor, and packages them via a data structure, which is then transmitted to the collector.

Both firmware use RTOS to collect the data and transmit it so the entire code is non-blocking, and as soon as the data is read from the GPS, it is made available to be transmitted to the node. In the case of GPS data readings, two functions have been implemented, which can be enabled or disabled. The first function is stationary deviation rejection, which measures the deviations that the GPS has, and if the soldier is stationary and the GPS transmits coordinates with a small deviation, they are not updated, and the coordinates that were originally acquired are transmitted. When the measurements exceed this deviation, the soldier is considered to be moving, so the data is updated in real-time. This function allowed not populating the map with coordinates that are very close together and then being hard to read. The second function is to store the last set of valid coordinates for cases where the GPS stops collecting valid coordinates and sends coordinates of 0. As soon as the GPS can track it starts retransmitting the coordinates in real-time.

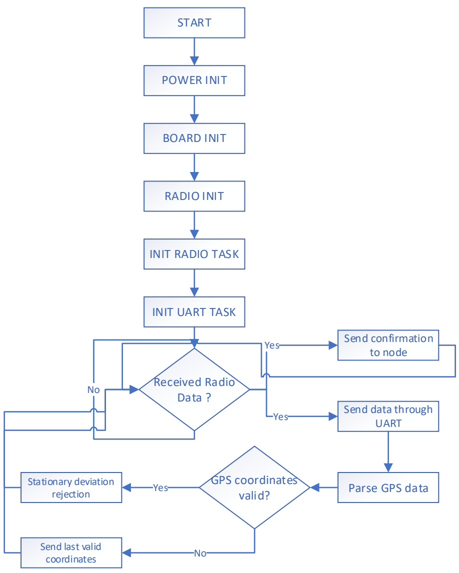


Fig. 4. Collector device software diagram.

In the case of the concentrator node the two tasks of displaying the received information and transmitting the radio packets, allows us to realize a system that does not require synchronizations or times when the device is stuck with reading the sensors and is not able to receive a packet from a node immediately. In this idea the two tasks will have access to the same data set, the radio task will receive the data while the display task sends it for display, and this is accomplished via semaphores. When a data packet is received, in addition to it being made available to the display task via a data structure, an acknowledgement of the data packet is automatically sent.

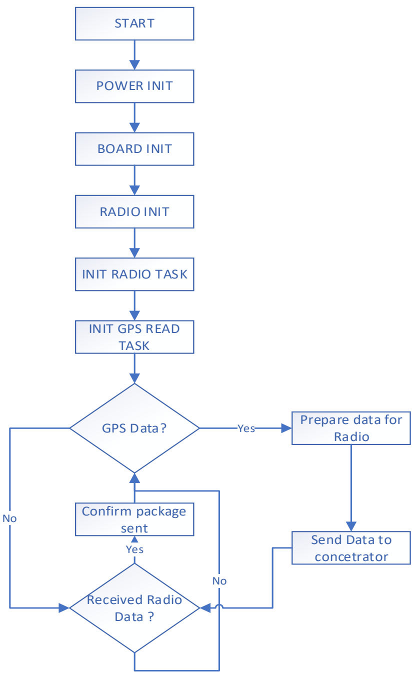


Fig. 5. Node device software diagram.

The node is the one that acquires data from a temperature and humidity sensor and a GPS module via a task named in the figure above GPS data. It runs continuously and checks the availability of new data from the GPS, after it is read, it is in a data structure, and access to it is also done via a semaphore. These semaphores ensure that no operations are performed on the data structure at the same time by two different processes. The semaphores allow access to the data after the whole structure has been written or read. From the data structure, they are prepared to be transmitted as a byte stream, each position in the stream representing a specific piece of information.

The format of the data that is transmitted by the node contains the following information:

- The node id which is unique per device.
- The value read from the ADC for a photoresistor.
- The state of the switch, which will represent the emergency button.
- RSSI (Received Signal Strength Indicator) value for the received packet.
- Temperature.
- Humidity.
- Latitude.
- Longitude.
- Timestamp received from the GPS module.
- Total number of transmitted packets.

The first scenario used two boards and noted the location between the two devices each time. The tests carried out were more laboratory tests, with the two devices being tested at very close distances, a few tens of meters, with the two devices permanently connected to a computer or laptop. Even though the test conditions were excellent, it was realized that it is difficult to note the location of the two nodes, the RSSI, and the transmitted packet number. At the time of testing, we had the ID of the devices, the RSSI, and the transmitted packet number as parameters. The RSSI is a parameter that characterizes the level of the received signal from an antenna to determine its quality. Its values are between 0 and -120 dB, and depending on the system and the modulation or demodulation technology, a lower signal level is proper or not. For example, for a voice signal, a good signal is considered to be a signal higher than -65 dB, whereas for a data signal, a level higher than -85 dB is considered to be a good signal.

Since tracking coordinates and calculating distance was cumbersome and did not allow for distance graphing and performance evaluation, a GPS module was connected to the designated node board. The GPS module is used to obtain latitude, longitude and also exact time. This data is then visualized via a serial application.

While in the first scenario an exchange of data packets between two nodes and a concentrator took place at a distance of a few tens of meters, the second scenario aims at obtaining data between a fixed concentrator point and a moving node, which acquires coordinates (Figure 5).

In the figure below (Figure 6), it can be seen the coordinates obtained through a serial communication program. Using the coordinates of the fixed point and the received coordinates, viewed through the serial application, we tried to determine the distance between the two points. This was quite difficult because the coordinates of the two points had to be copied into an Excel and then fed into an algorithm to determine the distances.

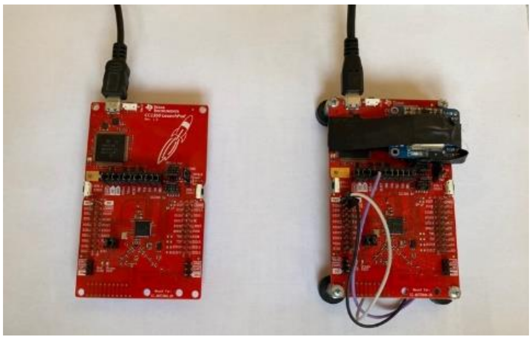
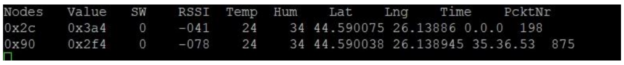


Fig. 6 - Concentrator Node (left) & Collector Node (right).



Nodes	Value	SW	RSSI	Temp	Hum	Lat	Lng	Time	PcktNr
0x2c	0x3a4	0	-041	24	34	44.590075	26.13886	0.0.0	198
0x90	0x2f4	0	-078	24	34	44.590038	26.138945	35.36.53	875

Fig. 7. Received data through a serial console.

As all this work was time-consuming, we decided it was useful to make an application that would take the data from the serial interface, measure the points on a map, and then determine the distance between the fixed and moving points. The data from the serial interface is parsed and the coordinates are stored in a SQLite database. In addition to displaying distances and coordinates in real-time, we can also use the data stored in the database to make graphs. From the tests performed, the application receives coordinates from the moving node and displays the distance between it and the collector device, whose coordinates are entered manually.

The GPS used is a breakout board built around the MTK3339 mode, which is a GPS used very often in commercial devices because of its accuracy but also because of its relatively low consumption, about 20 mA. In the context that according to the graph above mentioned the device without a module attached had a consumption with an average of about 90 mA, the consumption of the GPS will increase this value by about 22%. The accuracy of the GPS is given by the number of satellites it can track; the MTK3339 can track 22 satellites, and, together with the receiver, which has a very high sensitivity of -165 dB, gives a deviation of almost 3 m. We have measured the accuracy of this device with the system we have developed. Figure 8 shows the circle in which these points were confined. Its radius is 4.5 meters.

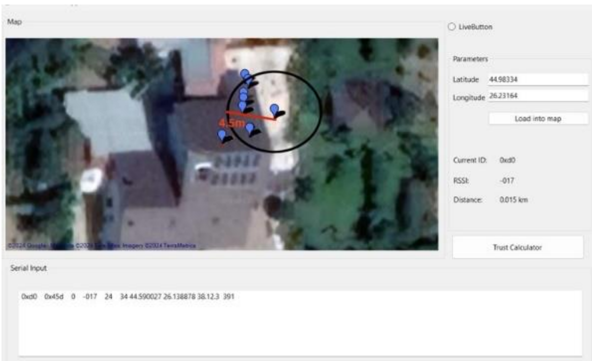


Fig. 8. Gps accuracy.

At the moment no information about the number of satellites to which the GPS is connected is transmitted via the communication protocol between the two devices. The number of satellites ensures a higher positioning accuracy; however, the deviation we obtained is good.

As described above, the topology of the system wants to interconnect several nodes, aggregate them and forward them to a base station. The nodes that are carried by each soldier and contain a suite of sensors collect the data and transmit it to the central node. The data collected by the nodes, as mentioned above, contains medical information, environmental information, and information about the soldier's position and location. To test how these sensors communicate, using the application developed to visualize the communication between a node and a hub, we will map several nodes on the map, each with a different icon. The current view gives us a map of where the soldiers were, not just the point in real time. This is being implemented later thus providing an easier visualization of the data.

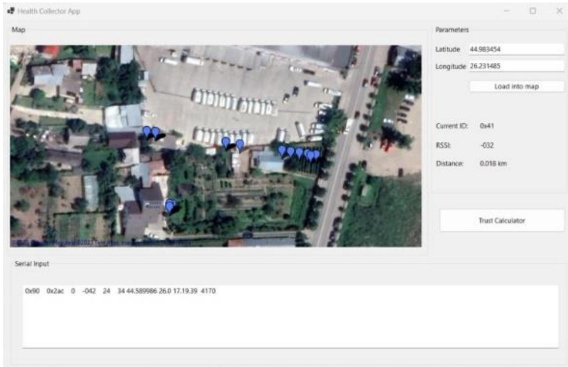


Fig. 9. Coordinates received from 2 nodes.

The points generated in the figure above (Figure 9) represent a series of points received from two nodes by the coordinator and passed to the C# application.

This application will provide the development basis for the application for viewing all the nodes, an application in which we will be able to see each soldier and it will be possible to visualize the vital signals of each individual. At the moment, the application offers a very important and useful functionality, namely the visualization of the coordinates where each device was on the map. As I mentioned previously, visualization and past points help us to determine the quality of the radio signal depending on the distance.

The points displayed in the graphic interface change their color depending on the RSSI, assuming that when we increase the distance, we will have a weaker signal. The way in which the thresholds were chosen is relative to the ability of the receiver to collect the data correctly. This means that as long as the color of the point on the map is not red, the signal can be used to collect information. When the respective point has a red color, this means that the signal has fallen below a certain threshold, which makes it possible for the receiver not to be able to collect information correctly.

Through the application, we currently have the opportunity to see a series of data that we receive from each node. In addition to the coordinates that are visible being mapped on the map, if we hover with the mouse on the screen, we can see data about temperature and humidity collected with the help of the sensor on the board, the scriptic GPS coordinates, but also the RSSI. We can thus track various parameters of the environment through soldiers. In the case of connecting a chemical gas detection sensor, we can see the gas level at various points, using a point where there are no chemical gases to gather the whole team and not expose themselves to those environmental factors. This aspect is also applicable to the use of a radioactivity sensor.

In the end, the application will run as a standalone application on the node represented in Figure 4 as Vizualization/Collector Node. Since the system was designed to be high-performance and allow easy connection methods, we must differentiate the two terminals named the same. We do this because on the Vizualization/Collector Node that a soldier wears, the data on the application will be received via Bluetooth. This node is a node intended for the group commander or group doctor that can view vital signs in real time. The use of wires to receive and view data via UART is not possible in a system dedicated to combat uses. On the other hand, the node that collects the information, located in the base station, can send the data to the application via UART (Universal Asynchronous Receiver-Transmitter).

In addition to tests that allowed us to transmit data from two nodes to a collector node, we also performed distance tests. The scenario involved using a data acquisition node and a collector to see the maximum distance we could achieve without having LoS. The terrain on which it was tested does not have the urban density of a large city with blocks, but is an area of houses in a smaller town. However the signal should suffer modifications by the multitude of obstacles that are present, houses, trees but also other vegetation. I started with distance simulation software that Texas Instruments provide. With the help of Texas Instruments distance calculator, we have configured the table to suit our requirements, and for our target scenario, the distance should reach 500 meters. From the field tests, the distances did not exceed more than 70 meters. In order to have more detailed information on the communication we used a signal reception software that displays the data packets in a way that is easier to troubleshoot. As it can be seen when the distance reached 70 meters, the packets with error started to exceed those that were correctly received.

The difference between the estimated distance and the obtained distance is too big and was initially considered a mistake in configuring the radio parameters. One of the parameters that were reconfigured was the transmit power. This parameter is set by the project config, but it can also be done by configuring at initialization of the radio module. In addition to this parameter, the initial configuration of the radio module was also changed, but the low signal level remained the same. During the tests, a variation of the RSSI was noticed, as the devices were at the same distance but positioned differently. This is due to the PCB antenna. The development boards allow the use of an external antenna via the impedance-matching circuit. Before modifying the antennas, we made power level measurements with a VNA (Vector Network Analyzer), and the results obtained with the PCB antenna are in Figure 10, while the results for the second antenna are in Figure 11.

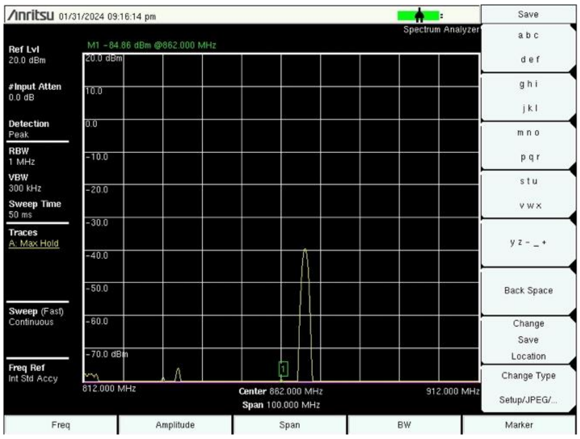


Fig. 10. Measurements with PCB antenna.

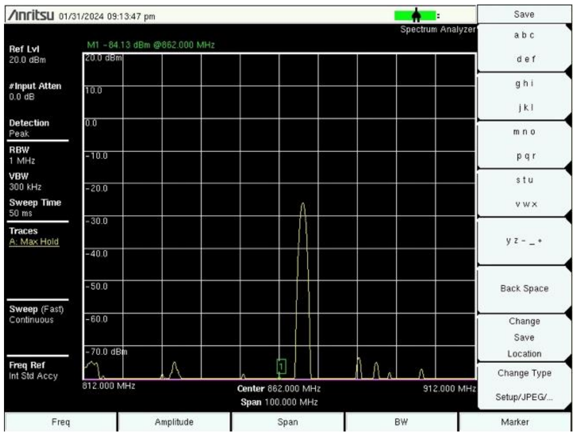


Fig. 11. Measurements with external antenna.

There was a significant difference in signal strength measured in dBm. The first antenna, designated as a PCB antenna, exhibited a reading of -40 dBm, whereas the second antenna, a dipole antenna, displayed a value of -20 dBm.

This dBm disparity translates to a substantial difference in signal power. Because dBm is a logarithmic scale, a 10 dB increase signifies a tenfold growth in signal strength. Consequently, the dipole antenna boasts a signal strength ten times greater than the PCB antenna.

This disparity in signal power translates to real-world performance differences. With its superior strength, the dipole antenna can transmit signals over a considerably larger range and penetrate through more obstacles than the pub antenna.

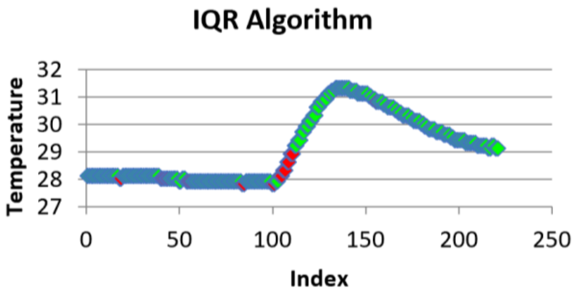
In essence, the -20 dBm reading of the dipole antenna indicates a signal strength ten times stronger than the -40 dBm reading of the pub antenna. This translates to a significantly enhanced ability to transmit and receive signals over longer distances and potentially through interfering environments.

After changing the antennas and measuring them in the laboratory, another series of tests was carried out. The results obtained were very close to those shown in the table from Texas Instruments. The max distance that was obtained was 450 meters, with a stable connection, being able to transmit data continuously.

The device transmits temperature and humidity data in addition to GPS coordinates. Depending on their accuracy, these two parameters can suffer measurement errors, and this is not desirable in the tactical field. Anomaly detection algorithms can be based on statistical, machine learning, or predictive models. Statistical methods are used on microcontrollers with limited processing power and power consumption limitations. The first implementation used was the Interquartile Range (IQR) method (Samara et al., 2022). This algorithm divides a data set into two ranges, calculates the mean value of each range, and then a difference between these two values. Any value that exceeds this value by a certain weight is considered an outlier. An advantage of statistical methods is the use of several algorithms and the comparison of their results. The second algorithm that was implemented was the Z-score, which calculates the standard deviation of the data, and for each value, a Z-score is calculated. If this is outside the range -3 and 3, that value will be considered an outlier (Mahajan et al., 2020; Kathiresan and Karthik, 2021). The last algorithm used that will help us in comparing the data is DBSCAN; compared to the other two, the latter is a more complex algorithm that has the ability to isolate the data into clusters. In our case, it will isolate valid data into a single cluster, and what is outside will be considered an outlier (Cui et al., 2021).

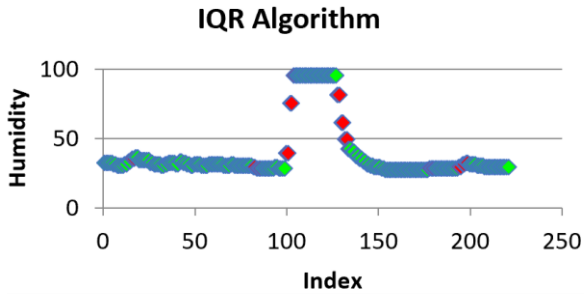
The most important thing for temperature sensors is not to determine outliers but to mitigate the possibility of false positives. The three implemented algorithms behave differently due to variations in values from a temperature sensor. In the graphs shown (Graphic 2 - 7), the values marked as usual are green, and those considered by the algorithms to be anomalies will be red. For each algorithm, graphs will be shown for both temperature and humidity. In the case of temperature, the value was increased by heating the sensor, keeping it near a warmer surface. When the sensor was brought closer to the heated surface, the humidity values were also changed due to the surface moisture.

In the case of the first algorithm, the increase in temperature, even without any outliers, is considered an anomaly for the first values. Once the temperature variation occurs, the algorithm adapts and no longer considers the values abnormal but a normal temperature increase. Certainly, if this algorithm has marked a value as an anomaly at a difference of 0.20 degrees if a substantial sudden variation occurs, it will be considered an anomaly. In the case of the first algorithm, the larger the analysis buffer and the smaller the differences between the values, the algorithm will mark any value that falls outside this range until normalized (Graphic 2).



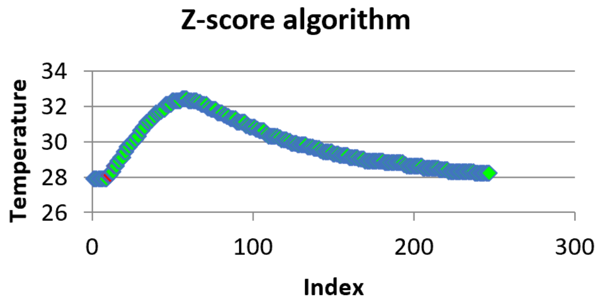
Graphic 2. Temperature IQR chart.

If the increase in temperature was progressive, it was abrupt in the case of humidity. In Graphic 3, the values that are considered anomalies can be observed. For certain reasons, the appearance of such instantaneous changes in values indicates abnormal functioning. However, after collecting several values, they are considered normal values. The more values that are rejected in the incremental increase, the higher the rate of false positives that the algorithm has.

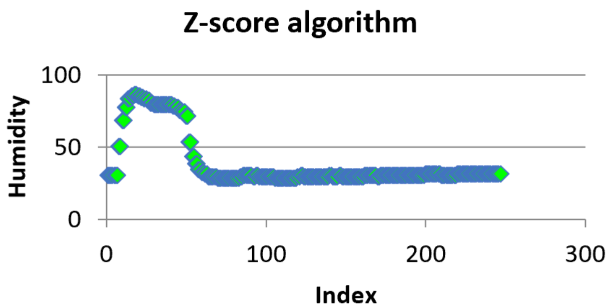


Graphic 3. Humidity IQR chart.

The second algorithm responded much faster to the adaptation to temperature increase, and if, in the case of the first algorithm, there were several consecutive values that were considered abnormal for the second algorithm, the adaptation was made after the first 3 different values (Graphic 4). The reduced number of outliers is also observed in Graphic 5 for the humidity measurements; this algorithm has a much faster response to the variation of values.

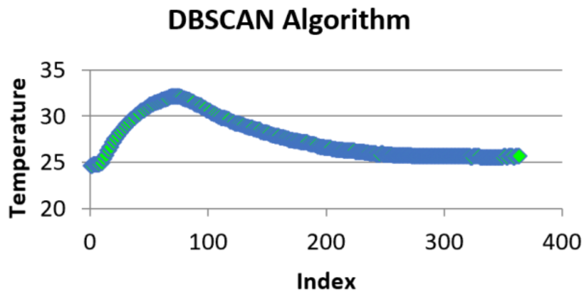


Graphic 4. Temperature Z-score chart.



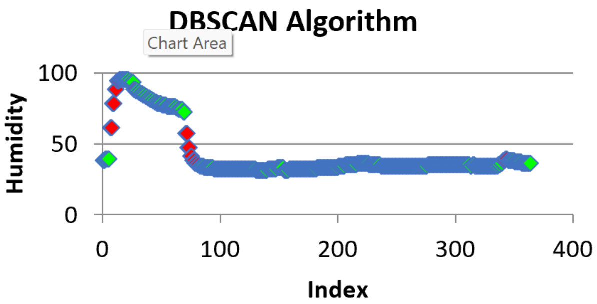
Graphic 5. Humidity Z-score algorithm.

The algorithm with the best response to temperature increase was DBSCAN. It did not flag any values it interpreted as anomalies (Graphic 6). This operation ensures that the correct values are accepted if the algorithm filters the data. As with the other algorithms, instantaneous increases in values with a high weight are considered anomalies. In the tests that were made, the humidity increase was about 130%; for this reason, the algorithms marked some values as outliers until they were able to adapt (Graphic 3, Graphic 5, Graphic 7).



Graphic 6. Temperature DBSCAN chart.

Through the three algorithms, multiple filtering can be done, with the possibility of comparing the outputs from the three algorithms and deciding if a value is normal or anomalous. For the decision function, the weight that the algorithms have in the decision is given, which, in our view, should not be equal. The DBSCAN algorithm, having a higher complexity and being able to detect more accurately, should weigh more in the decision process.



Graphic 7. Humidity DBSCAN chart.

6. CONCLUSIONS

Choosing the proper communication is a vital factor in any system whose purpose is transmitting information. We started from the need for a system that would allow communication between several nodes and support us in developing a system of WBAN (Wireless Body Area Network) nodes. For this, we identified a microcontroller with a radio module, SOC (System On Chip). The microcontroller is a 32-bit Arm Cortex M3, and as mentioned in the documentation on the Texas Instruments website, it is a multiprotocol microcontroller. This means that it provides the user with a radio module whose frequency is 868 MHz, a free frequency, and a Bluetooth Low Energy module. This combination of radio standards offers a wide range of implementations. The radio module operating on the 868 MHz frequency allows data transmission protocols based on this 868 MHz frequency. In the transmission, a spread spectrum type modulation is used, which allows the use of frequencies below 1 GHz to transmit data in urban areas at relatively long distances, 100-200 m, and at speeds of 250 KBps. All these factors make the technology chosen for the implementation of the system suitable and allow the acquisition and collection of data.

The software component was developed using RTOS, a lightweight operating system that allows parallelization of functions within a microcontroller. In this sense, the functions of reading sensors, transmitting information via radio, and processing, work in the form of tasks. For the visualization node, there is another task that transmits data to the graphical interface. The advantage of this system is that depending on the configured priority, if we have a very important task, we can set it as a high priority, and it will have priority during execution. Using the GPS module required the implementation of reading and processing functions, the latter allowing us to obtain coordinates that can be mapped onto the map.

The war in Ukraine shows us what it means to fight a guerrilla war in which coordinating and often locating each soldier in the group individually is impossible. The need for the proposed system is obvious, and if, until the current wars, we have few eloquent examples of what a war to conquer a city entails, we are now faced with a stark reality in which we realize that military technique is the main asset that can change the course of a war. In (Max, n.d.) we find an analysis of the difference that new technology, which Ukraine has benefited from, makes versus old technology, such as that used by Russia. The system we are proposing is not just to give a tactical advantage to a participant in the war but to reduce the number of deaths through rapid medical intervention on the battlefield.

Another element that perhaps changed the fate of warfare was intelligence. Having very good-quality intelligence from the ground and coordinating people is a tremendous tactical advantage. The system that we are proposing aims to allow you to see the movement of your own troops in the field and their physical/psychic condition in real time.

The implementation of anomaly detection algorithms in embedded devices is essential to ensure the accuracy and reliability of the generated data. These algorithms are particularly important for real-time data validation, noise reduction, fault detection, and improved analysis accuracy. In critical applications such as medical devices, accurate anomaly detection can prevent erroneous decisions that could have serious consequences. In addition, these algorithms enable efficient use of limited embedded device resources and contribute to valuable predictive capabilities. For a medical device, implementing outlier detection algorithms offers the advantage of having much higher quality data, i.e., being able to make much better diagnoses or even more informed decisions.

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