SAFETY 4.0: AN EXAMPLE OF APPLICATION AND PERFORMANCE EVALUATION OF WIRELESS TECHNOLOGY TO HIGH-RISK WORK ACTIVITIES MONITORING

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Abstract

Thel objective of the project is to experiment with beacon technology and Bluetooth 4.0 in the field of applications to support worker safety in the workplace by a continue monitoring. In this area, most of the applications focused on RfiD technology while our interest turned to the use of Bluetooth technology, which, being available on most SmartPhones, allowed the latter to be used as local data collection systems, with benefits of stability, cost reduction and ease of use.

INTRODUCTION

The new solution is able to guarantee strong interoperability between the world of sensors potentially present in work environments with worker safety detection and control systems. In particular, 3 types of sensors were considered: a) sensors applied to PPE, b) sensors for monitoring environmental parameters, c) sensors for monitoring the medical parameters of operators. This was the main point on which attention was focused, as well as the need to use one of the most widespread tools today with multiple potentials such as the Smartphone. The Smartphone becomes, so to speak, the easy and intuitive "intelligent control unit" (easily available on the market) which informs of the possible risks associated with carrying out one's work task, also filling the role of help in cases of difficulty.

Purpose of the solution

In the workplace, there are processes that are inherently dangerous for which the only defense in terms of safety is to stop them in a preventive manner if certain conditions occur. The use of Intelligent PPE, i.e. PPE equipped with special sensors, allows the possibility of accidents and their severity to be significantly reduced. The SAFETY 4.0 solution allows continuous monitoring of the use of intelligent PPE by staff in the workplace and preventative management of risky behaviour. The intelligence of PPE is given to them through their integration with Bluetooth sensors. After a configuration in which each worker is associated with the right task and the PPE required for that task, the solution automatically assigns to the worker the obligations and PPE required by the law, creating a direct connection between the worker and the fulfillment, so as to make immediate supervision of compliance with safety regulations.

MATERIALS AND MODELS

Method of use of the solution

The monitoring of workers takes place by implementing checks relating to the provision of appropriate PPE devices, as established by the Human Resources module, using Bluetooth beacons, combined with an IoT (Internet of Things) infrastructure. The use of the type of technology will depend on the application context. Appropriate readers arranged in proximity, or "long range", quickly identify all the elements both at the entrance and during the activities carried out in the various company areas, verifying the congruity with respect to what was pre-determined and declared during the configuration phase of the system. The workplaces in which staff work can be divided into zones with different degrees of risk, and checks can be carried out on the time spent on each employee or guest in the different risk areas. This occurs through a system of positioning "long range" readers near the boundaries of the identified logical areas, so as to record the passages of the workers and allow a remote operator to check on his monitor not only the number of workers in a specific moment present within a work area with elements of risk, but also the duration of stay in the individual areas. Pre-established levels of permanence can be associated with these areas, so as to have the appropriate alarm notifications, also from the software system. Finally, a detection and alarm action can be activated in the event of approaching areas or machinery judged to be highly dangerous without the use of appropriate PPE. The "long range" reading systems positioned at appropriate distances allow the sending and local activation of timely alarm signals or, following additional integration activities, the immediate stopping of the functionality of the machinery). The devices used to monitor workers can be very varied: HELMETS, GLOVES, SHOES, PROTECTIVE MASKS, etc.

Instruments and libraries

To carry out the tests carried out both indoors and outdoors, a Samsung Galaxy S20 running the Android 10 version was used, equipped with a Broadcom BCM4773 Bluetooth chipset. For their creation, a special application was also implemented with the help of the Android Studio 1.4 IDE designed to carry out the following operations:

- scanning of visible beacons:
- acquisition of the necessary information
- print to a.txt file

In order to operate on beacons, two libraries were used: the native one of the Jaalee beacon in use, plus a second one, which uses the AltBeacon protocol. In general, the methodology studied for evaluating the performance of beacon sensors can also be used for other brands of beacons, although the evaluation parameters could be influenced by the specific engineering of the various beacons.

RESULTS AND DUSCUSSION

Technological infrastructure of the solution

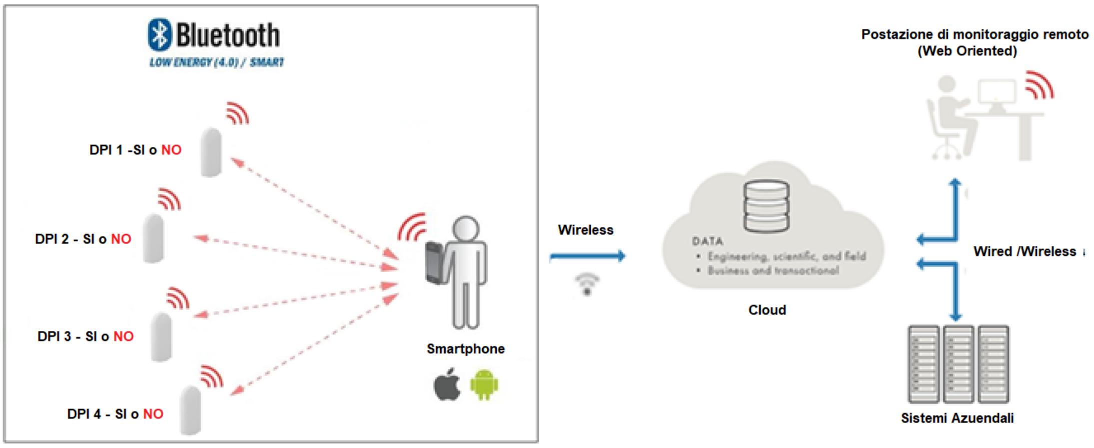

Figure 1 – description of the solution architecture

Latest generation technologies are used, widely spread but at a low cost, which involve the use of smartphones in an Android/IOS environment for the interaction between the user's Intelligent PPE and the technological safety monitoring and management system. Sensors already available on the Smartphone {GPS, accelerometer, Bluetooth} are also used. Based on the experience acquired, it was decided that the project was designed to operate not only with PPE equipped with beacons (Bluetooth sensors) but also with sensors for detecting environmental parameters and with wearable sensors to monitor the physical and vital parameters of the operators. This allows the solution to be used in a wide range of application areas.

Monitoring mode

In figure abbiamo sintetizzato le modalità di funzinamento del sistema durante il monitoraggio ed indossando i DPI intelligenti su scarpe ed elmetto

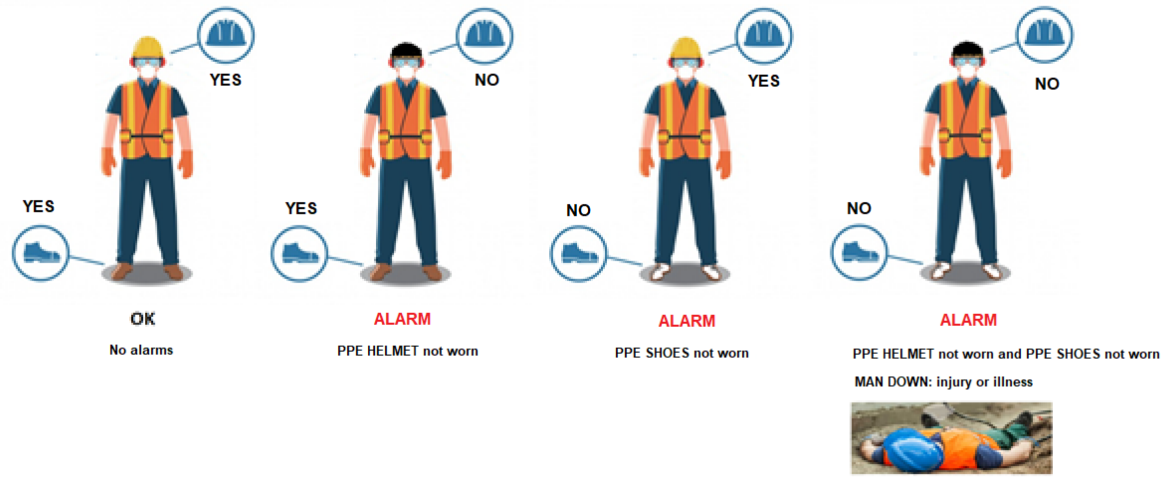

Figure 2 – Different monitoring mode

Real-time or near-real time monitoring of the correct methods of carrying out the activity by the workers, identifying some anomalies that can compromise the worker's activity:

- Identification of the position in which each worker carries out his activity
- Correct use of all PPE equipped with Beacons required for the job
- Monitoring of environmental parameters (gas leak, smoke, oxygen level, etc.)
- Management of the different types of alarm

- Rapid identification of anomalies due to illness or accident at work (man down)

Functionality of the Safety 4.0 APP

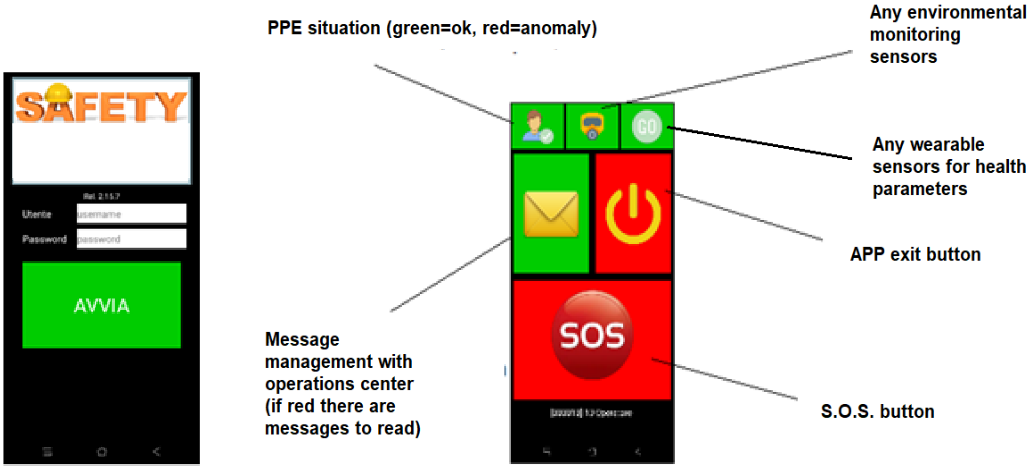

Figure 3 - Access interfaces to Safety 4.0 APP features

a. Check for anomalies in the use of PPE (if green ok, if red anomaly). In the event of an anomaly, an audible alarm is activated by the APP using the phone speaker and at the same time the flashing of the APP joke is also activated.

b. Verification of environmental conditions (presence of gas, temperature, vibrations, noise, etc.). Also in this case, in the event of an anomaly in the parameters detected which may represent a danger for the worker, an audible alarm is activated on the APP accompanied by the screen flashing and an automatic message reporting the type of anomaly detected so that the operator can. At the same time, an alarm message is sent to the control unit relating to the specific sensor so that the type of danger to which the worker is subjected can be established.

c. Reception of messages from the control panel for communications relating to anomalies in the use of PPE detected through alarms to the control panel or other communications on the service (green there are no messages, red there are messages to read).

d. Emergency button, which the worker can activate in case of illness or emergency. By pressing the SOS button an immediate alarm is activated on the monitoring station so that the necessary intervention operations can be activated). Since an illness or an accident may not allow the worker to have the time or strength to press the emergency SOS button, using the cell phone's accelerometer, the man down function has been provided which is automatically activated when no movements are detected from the sensors for a time configurable by the Monitoring Operations Center. Following an SOS or automatic MAN DOWN alarm signal, since these signals involve the activation of rapid intervention procedures, the operator is asked to respectively confirm the state of emergency in the case of an SOS or to move the mobile device in the event of a MAN DOWN alarm. If the worker does not respond, the state of emergency continues and interventions are put in place to protect his health. However, if the worker reports that it was an error, or moves the device (Smartphone), the workers at the control and monitoring center can cancel the emergency state.

e. With the GO button, functions related to the use of Wearable can be managed to detect the operator's vital parameters (heart rate, blood pressure, heart rate). The anomalies can depend both on the type of work carried out and on the general health conditions of the worker. Anomalies cause local audible alarms and flashing of the APP screen, but also the sending of an alarm message to the control unit with the code relating to the anomaly (for example excessive heartbeat).

Functionality of the Safety 4.0 CONTROL CENTER

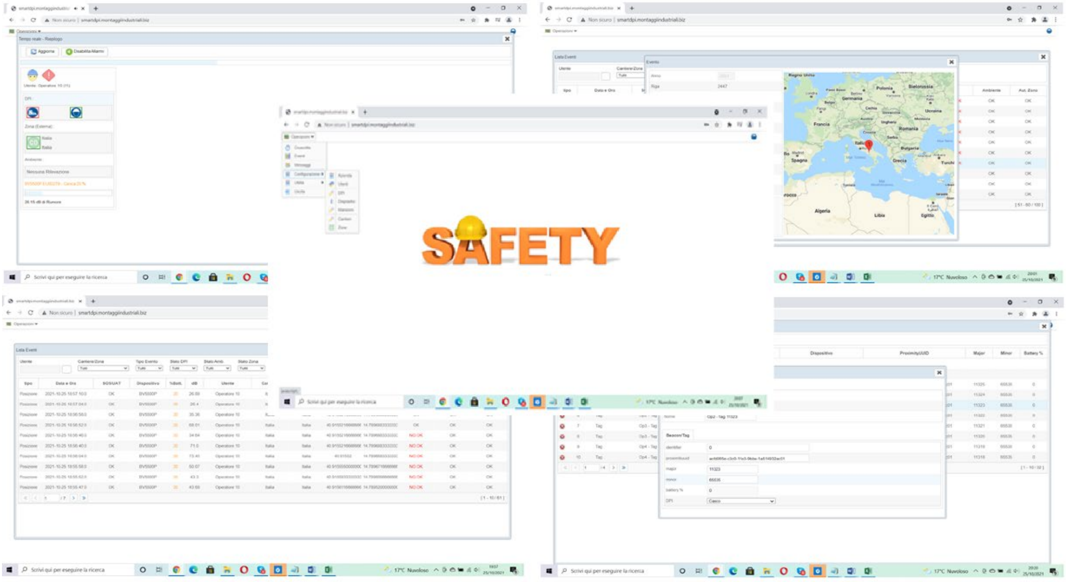

Figure 4 - access interfaces to the functions of the Safety 4.0 monitoring operations centre

The operations center software is a web application designed for multi-channel use (responsive interfaces). There are two levels of professional figures:

a. System administrators (can configure users, DPI, devices, solution operating parameters, etc.)
b. Supervisors (users of the control panel for control and supervision purposes)

Through the operations center software it is possible to manage all the components of the IoT-Cloud infrastructure and have data analytics functions. The software effectively implements a governance system for the innovative IoT security infrastructure, which allows a series of functions of which we provide a (non-exhaustive) summary below:

a. Real-time monitoring dashboard of the correct use of PPE by operators, with the management of alarms caused by the removal or non-use of the same.
b. Configuration menu of the operating parameters of the solution (Configuration of the construction sites where operators and Smart PPE are assigned to them. Association of PPE to each operator based on the tasks, inactivity time for activation of the "man down" alarm, Management of the list of PPE required for the various tasks, Configuration and consultation of PPE, Configuration and consultation of sensors measuring environmental parameters, Configuration of sensors measuring vital parameters relating to the health of the operators, Configuration and consultation of access zones and access restrictions for operators with inadequate tasks, Configuration and consultation of the list of operators, Configuration and consultation of the areas in which the user can access, Configuration and consultation of company data, Configuration of the operating parameters of the solution, etc..),
c. Event consultation dashboard (numerous filters available).
d. Consultation and modification of operators' tasks.
e. Consultation of the operator's location (geo-localization).
f. Management of alarms for incorrect use/removal/absence of PPE required by the job.
g. Management of SOS received for man down (SOS automatically generated due to inactivity). This report is also generated if the operator voluntarily removes and puts down PPE.
h. Management of SOSs received from an explicit request from the operator via the SOS button on the APP.
i. Access to message management to/from operators.
j. Menù utilità (Dashboard degli utenti collegati, Download della APP per installazione su atri dispositivi, Big data Analytics, ecc…).

Performances relating to broadcast performances

Two key parameters of beacons are the transmission frequency or scan interval denoted by (Ts) and the duty cycle denoted by (fD). It should be noted that it is normally possible to set its activity period in an application that uses beacons, thus allowing the determination of the moments in which the beacon can send signals to the smartphones used for reception. The first parameter (Ts) indicates precisely this aspect. The second (fD) expresses the relationship between the scanning period and the transmission frequency or how long the scanning is actually active. If set correctly, these two parameters give greater autonomy to the device or rather ensure that the daily consumption is a maximum of 30%. If, on the contrary, there was a need for continuous scans, it would be necessary to set the scanning interval to around 5 seconds to avoid excessive consumption [14].

Application contraindications

There are also some issues to take into consideration when using beacons. One, for example, concerns the format in which the data is sent. In fact, for Apple devices this format cannot be set. The only way to change it is to implement your own Bluetooth data format which for example allows you to add and record some functions such as the temperature sensor. Another problem to consider carefully concerns how the waves propagate and above all which materials contain the strength of the signal. Normally the Bluetooth signal propagates 2.4 GHz, but the human body or walls tend to attenuate the transmission strength. In general all wireless LAN devices, cordless phones or a microwave oven could disturb the Bluetooth connection. Apple has carried out a study [23] explaining which materials absorb or refract the signal best.

Table 1 - The materials that are able to absorb the waves propagated by the beacons are listed in order of interference

Type of material	Potential interference
Wood	Low
Synthetic materials	Low
Glass	Low
Water	Medium
Bricks	Medium
Marble	Medium
Mortar	High
Concrete	High
Bulletproof glass	High
Metal	Very high

The result of this experiment shows that the material that attenuates the signal the most is metal. If we considered water as an example, at a distance of 0.10 meters between a beacon and a smartphone and we placed a layer of water between them at a distance of 0.04 m, the calculated distance which depends on the RSSI is 0.49 m. If instead you inserted a hand between the two devices, the distance would be 1.50 m.

Remove any obstacles or change your position to allow proper communication. The interference problems illustrated do not affect the proper functioning of the SAFETY 4.0 solution as the distance between the Smartphone worn by the workers and attached to the belt of the workers' trousers and the beacons positioned on the PPE (helmet, shoes, gloves, uniform, glasses, etc..) is of the order of 0.5-1.2 m depending on the height of the operator and there is no interposition between them.

However, some communication interference problems can be hypothesized in the case of use of sensors for monitoring environmental parameters. The problem is solved by placing a transmission control unit (Smartphone) near the environmental monitoring sensor, ensuring that there is no obstacle in the middle of their communication range.

Test Sperimentali sui beacon

Testing what they are able to offer represents the next step to confer authority and guarantee their performance. Below we will show some data obtained from experiments that describe their behavior under normal circumstances. First of all, the data that establishes how the RSSI varies in relation to the real distance will be presented. Subsequently, the data will be shown that compare the real distance with that proposed by the AltBeacon library to understand how much it differs and finally, in this regard, the miss rate will be calculated, which means the number of packets that do not arrive. at destination.

Test 1: Variation of RSSI as a function of distance

The RSSI (Receive Signal Strength Indicator) is a parameter used in telecommunications, and generally measures the strength of a signal. As part of the research activity, the parameter is mainly used by the controller to measure the strength of the signal received from the beacon. The unit of measurement used for RSSI is dBm, i.e. ten times the logarithm of the ratio between the power (P) measured at the end of reception and the reference power (Pref). The final receiving power is inversely proportional to the square of the distance. So RSSI could potentially be used as an indicator of how far away the transponder is from the controller, which receives the return signal. When the beacon's return signal is received by several controllers, its position can be judged with reasonable accuracy.

The RSSI parameter can be used to:

- **Evaluate the distance** between the transponder and the controller.
- **Identify the direction** a beacon is moving.
- **Use filters** to optimize the detection area.
- **Locate tags**.

With the first experiment, therefore, we were interested in analyzing the variation in RSSI as a function of the variation in distance both in a closed environment and in an open space. In both circumstances, n values were taken at each movement to better manage the oscillatory trend of the RSSI; the arithmetic mean is subsequently calculated:

$$\frac{\sum_{n=0}^{Number\_of\_trials} . RSSI}{number\_of\_trials}$$

In this experiment *number_of_trials* is set to 20 in consideration of the number of measurements performed. As regards the indoor space, the data obtained and the related graph are as follows:

Table 2 - Indoor data first experiment

Distance (m)	Average RSSI (dB)
2	-76
4	-91
6	-91
8	-89
10	-93
12	-96
14	-89
16	-96
18	-96
20	-94

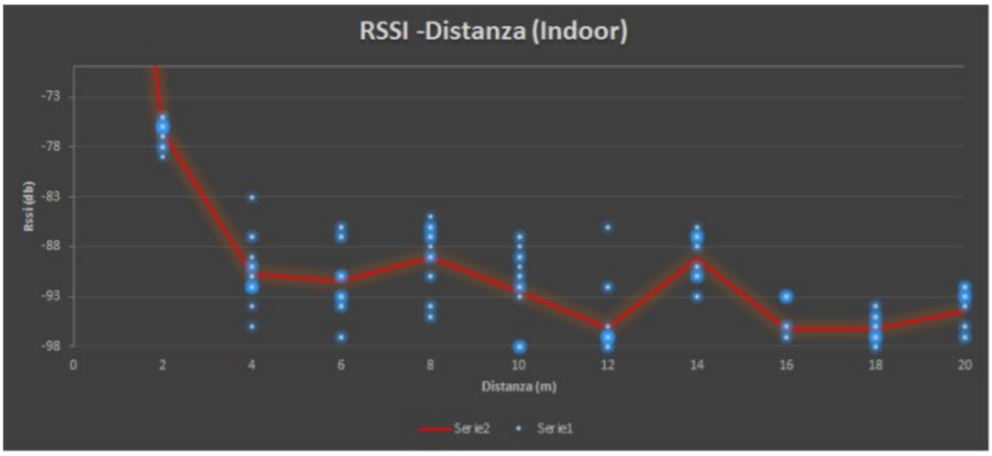

Figure 5 - Graph showing RSSI value as a function of distance for indoor scenarios

For outdoor spaces the data and graphs associated with it are as in following table:

Table 3 - First experiment outdoor data

Distance (m)	Average RSSI (dB)
2	-90.3
4	-91
6	-91
8	-91
10	-91
12	-91
14	-91
16	-91
18	-91
20	-91

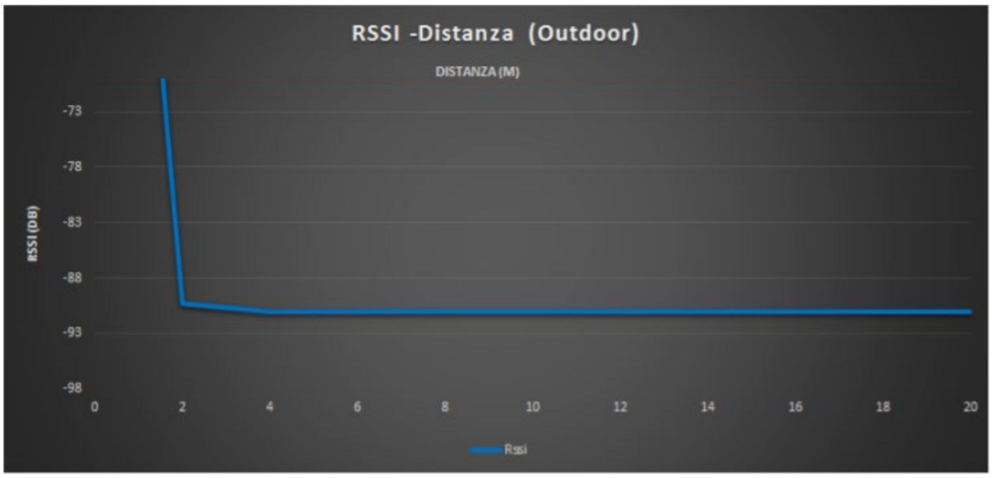

Figure 6 - Graph showing RSSI value as a function of distance for open spaces

In both circumstances, the observation period for each distance was 2 minutes. The two graphs are clearly different from each other. This may depend, in the case of outdoor scenarios, on the dispersion of the signal which already takes place at two meters and remains weak and constant throughout the rest of the experiment; a situation that does not arise for indoor scenarios where, going into detail, the trend appears to be oscillatory and shows peaks, especially between 12 and 14 metres.

Test 2: Error analysis

In the second experiment the AltBeacon library was used which allows the scanning of all types of Beacons regardless of who the producer is, simply by setting a parser. Since it is a different library than the native one, it seemed appropriate to carry out the previous experiment to verify whether the library affected the RSSI signal in some way. After which the distances were compared: the one proposed by the library and the one calculated experimentally and to conclude the error was calculated, i.e. how much the two distances differ, according to the following formula:

$$\frac{|\, \mathrm{d_{real}} - \mathrm{d_{library}}|}{\mathrm{d_{real}}}$$

It should be specified that this distance used in this second test is defined on the basis of the following calculation

$$\mathrm{d} = A\left(1 + \frac{r}{t}\right)^{B+C}$$

Where:

- R = RSSI
- t = RSSI reference 1 meter away
- A, B, C = costants

The following data contains the experiments carried out according to the pre-established objectives

Table 4 - Data relating to the distance error

Distance (m)	Indicated distance (m)	RSSI (dB)	Distance error (m)	Error (%)
1	6.61	-78	5.61	561
2	6.97	-80	2.49	249
3	7.59	-88	1.53	153
4	7.85	-83	0.96	96
5	8.2	-94	0.64	64
6	9.57	-91	0.60	60
7	11.6	-97	0.67	67

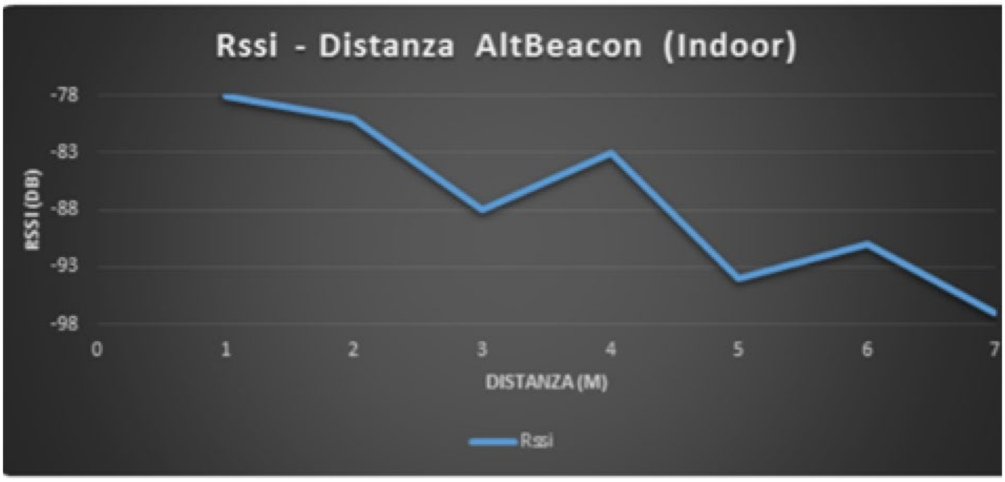

Figure 7 - Distance variation as RSSI varies with the Altbeacon format

At first glance, from the trend of the graph, the RSSI signal does not seem to differ too much from the signal examined in the previous test. What stands out is the proposed distance. In a closed environment, although you are a few meters away from the beacon, a distance is set that is significantly greater than the real one, which seems to grow proportionally as the real distance increases.

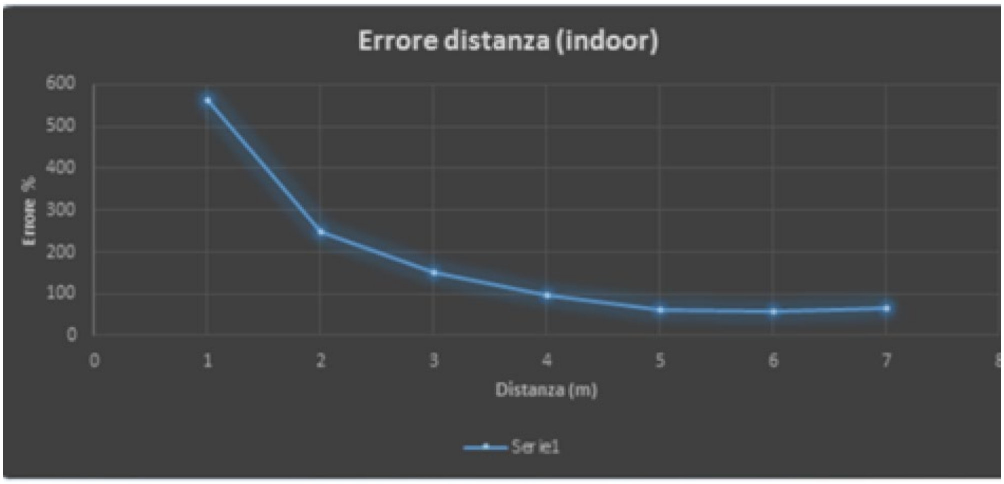

Figure 8 - Variation of the error as the distance varies

The error graph shows how in general the error is high, but tends to get smaller as you move further away as is to be expected. For outdoor experiments, the data is as follows:

Table 5 - Data relating to the error of outdoor distances

Distance (m)	Indicated distance (m)	RSSI (dB)	Distance error (m)	Error (%)
1	6.02	-96	5.02	502
2	9.46	-97	3.73	373
3	10.4	-95	2.47	247
4	10.22	-100	1.56	156
8	10.22	-100	0.28	28
12	30.67	-98	1.56	156

16	30.67	-98	0.92	92
20	30.67	-98	0.53	53

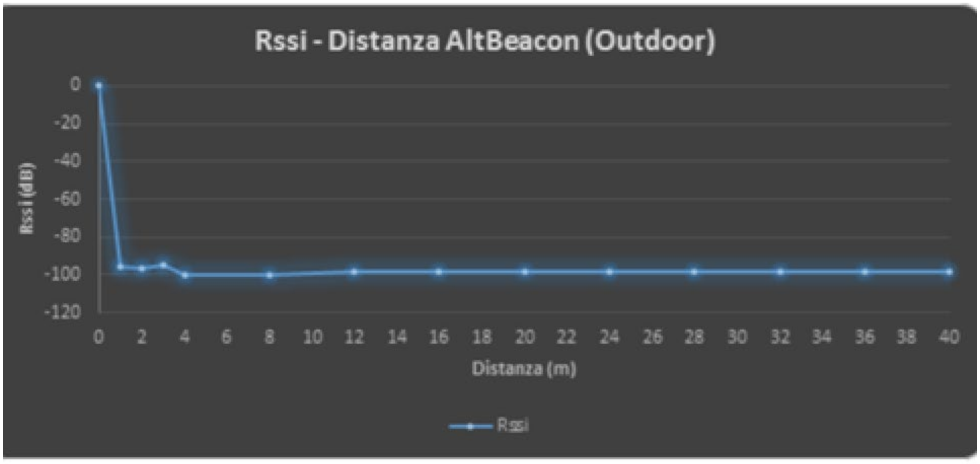

Figure 9 - Distance variation as RSSI varies with the outdoor Altbeacon format

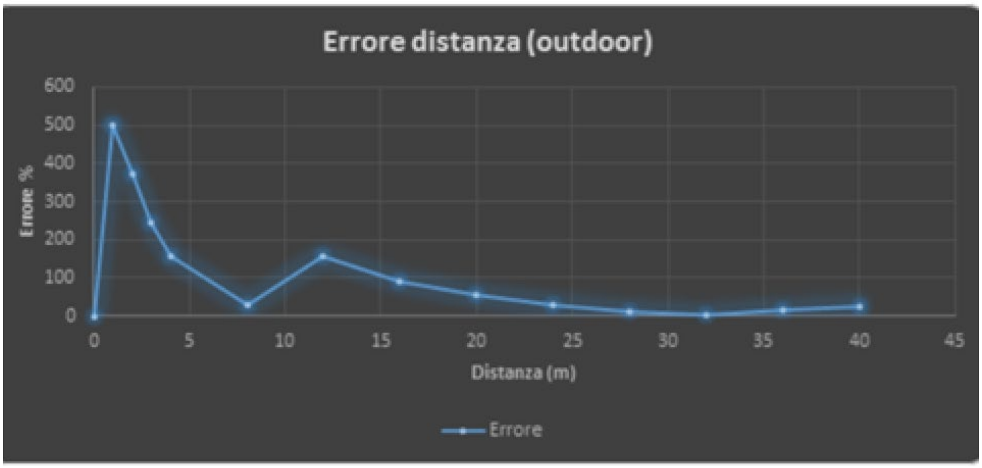

Figure 10 - Variation of the error as the outdoor distance varies

The situation outside is the same: overall the same condition as in the first experiment applies, i.e. that the signal decreases considerably after a few meters (again due to the issue of the lack of propagation by the walls). The error, however, is high between 0 and 5 meters and then gradually decreases. From this second test it turns out that the RSSI signals of the two libraries are similar but that the distance calculation differs greatly from the actual one both in closed and open environments, although this difference tends to narrow over long distances. From further studies it emerged that the accuracy of the calculation improves when there is a greater distribution of beacons within two meters but at the same time there is a smaller distribution for distances greater than 9 meters considering the recommended settings of Ts and fD [14] .

Test 3: Study of the variation of the Miss Rate

The last experiment instead tries to explain if and how the Packet Delivery Ratio is influenced in the emission of packets: the sum of the packets received, divided by those sent. The calculation was carried out on the basis of the Duty cycle seen previously. To obtain reliable results, the device's default value was taken as the transmission frequency: 1s; the same for the scanning period, which, as mentioned, is generally set to 5 seconds. So the objective of the experiment was to verify how the Packet Delivery Ratio varies in a 2-minute analysis at each move. For this reason, using the application designed for the occasion, we acted as follows:

- whenever a signal was detected, a ListView on the device updated the number of Items;
- the results were printed to a.txt file.

In the end, considering that the set duty cycle was 1 s, 120 packets should have been received at each distance, but in reality the number of packets turned out to be inversely proportional to the distance, so the greater the distance, the fewer packets. were received. Taking into consideration the miss rate obtained from the following percentage difference:

MissRate = (100 – PacketDeliveryRatio)%

we notice how at increasing distances, the lost packets increase.

Table 6 - The table shows how the number of lost packets increases with increasing distances

Distance (m)	Packets sent (1s)	Packets received	Packet Delivery Ratio	Packet Delivery Ratio (%)	Miss Rate (%)
2	120	92	0,77	76.67	23.33
4	120	91	0,76	75.83	24.17
6	120	85	0,71	70.83	29.17
8	120	84	0,70	70.00	30.00

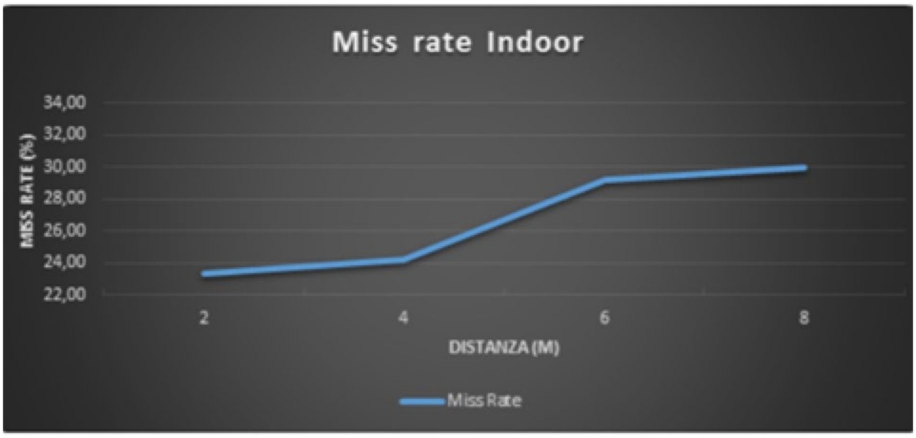

Figure 11 - The graph shows the number of packets lost as the distance varies

As regards outdoor scenarios, it is expected, also considering the results seen previously, that the Miss Rate should be greater for the same distances depending on the dispersion of the signal:

Table 7 - The table shows how the number of packets lost for outdoor spaces increases with increasing distances

Distance (m)	Packets sent (1s)	Packets received	Packet Delivery Ratio	Packet Delivery Ratio (%)	Miss Rate (%)
2	120	101	0,84	84.17	15.83
4	120	86	0,72	71.67	28.33
6	120	77	0,64	64.17	35.33
8	120	54	0,45	45.00	55.00

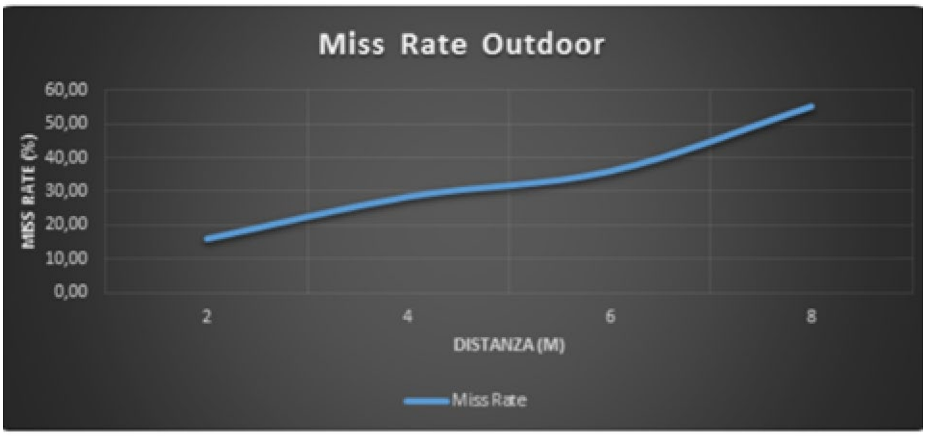

Figure 12 - The graph shows the number of packets lost as the distance varies for outdoor spaces

To give an answer in reference to this last experiment, a similar study [14] helps us where the variation of the miss rate is shown for increasing distances up to 5 meters. In that case up to two meters the miss rate settles at ≈ 15%, while from two meters upwards it is ≈ 27%. In this case, however, the average indoor miss rate is different: ≈ 23% up to 4 meters, ≈ 29%, from four meters upwards. As regards the outdoor miss rate, considering the same distances, up to 4 meters it is even lower than the indoor one ≈ 22%, after the four medium distances it increases dramatically: ≈ 45%. The discrepancy between the results of the two experiments may be due to a series of factors such as the device used (in our case Samsung Galaxy S20) and beacon used (EstimoteTM Beacon vs. Jaalee). Nonetheless, they have the following response in common: the value of the miss rate is independent of the scanning interval Ts, but dependent on the fD. The same study also delves into the miss rate of multiple beacons and shows how the highest values of lost packets occur between a number of beacons between 1, 5, 9 metres.

CONCLUSIONS

The initial objective of the project was to experiment with beacon technology and Bluetooth 4.0 in the field of applications to support worker safety in the workplace. In this area, most of the applications focused on RfiD technology while our interest turned to the use of Bluetooth technology, which, being available on most SmartPhones, allowed the latter to be used as local data collection systems. , with benefits of stability, cost reduction and ease of use. During the research activity, two macro topics were addressed, tested and discussed. The first concerns workplace safety issues and the implementation of a solution based on:

- Use of low energy consumption beacon sensors (rechargeable or with replaceable battery),
- an IoT-Cloud Infrastructure for collecting data from PPE equipped with beacons to verify their presence or absence within a certain radius during risky work activities; the presence of PPE and their movement allows you to establish its use,
- a set of sensors for monitoring environmental parameters that can be risky for the health and safety of operators,
- a set of parameters for monitoring some medical parameters
- an APP for Smartphone with functions as a data collection system from various sensors (DPI, environmental parameters, medical parameters) and manages the sending of such data to the Cloud together with GPS data
- A control center where settings and configurations of the monitoring solution are possible, as well as georeferenced consultation and interpretation of the parameters of the various monitoring systems. The control unit also allows the reconstruction of the history of all the monitoring events that detected an anomaly, but also of those that were successful.

The second macro topic analyzed the performance of Bluetooth 4.0 technology in the context of security to identify any limitations of use or factors to keep under control for its correct use. Some tests relating to the performance that beacons are able to offer were carried out and analysed.

The application obtained as a summary of the topics covered works well; all the objectives set at the beginning of the research activity have been achieved. It was also possible to define "best practices" for an effective implementation of the technology in possible application contexts. The idea is to continue investing in this application, trying to improve it more and more as Bluetooth technology evolves. To achieve this aim, the objective is to add more and more functionality and make it more usable.

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