**EVALUATION OF RF-BASED INDOOR LOCALIZATION SOLUTIONS FOR THE FUTURE INTERNET**

# D4.1 Report on the definition and setup of the validation scenarios

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**Abstract:**

The EVARILOS project addresses one of the major problems of indoor localization research: The pitfall to reproduce research results in real life scenarios suffering from uncontrolled RF interference and the weakness of numerous published solutions being evaluated under individual, not comparable and not repeatable conditions.

This document is the report of the definition and setup of the validation scenarios in two specific environments: Healthcare and Underground mining. The validation approach closely follows the benchmarking handbook and specifies use cases, environment specifications, measurement point specifications and the processing of the information generated from the benchmarking of different localization solutions. A clear strategy is worked out in a three step validation approach. Finally, metrics and weights are further elaborated.

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# List of Abbreviations

**2D:** Two dimensional space
**3D:** Three dimensional space
**API:** Application Programming Interface
**DECT:** Digital Enhanced Cordless Telecommunications
**GSM:** Global System for Mobile Communications
**GUI:** Graphical User Interface
**LQI:** Link Quality Indication…
**PC:** Personal Computer
**PCB:** Printed Circuit Board
**RFID:** Radio-Frequency IDentification
**RSSI:** Received Signal Strength Indicator
**SMA:** SubMiniature version A connector
**SUT:** System Under Test
**Wi-Fi:** Wireless Fidelity. IEEE 802.11 standards
**WP:** Work Package
**WSN:** Wireless Sensor Networks
**D2.1:** EVARILOS Benchmarking Handbook[1]

[1] http://www.evarilos.eu/deliverables/D2.1_initial_version_of_the_handbook.pdf

# 1 Executive Summary

This document is part of WP4 real environment reports of activities that are being carried out within Tasks 4.1[2] and 4.2[3] corresponding to Healthcare and Underground Mine application domains. It is structured in three main chapters where the first one places inputs and outputs expected from other tasks by establishing relations between them and explains the purpose of this work and the second and third chapters are the ones related to application domains benchmarking scenarios. These scenarios are defined according to D2.1 Initial version of EVARILOS benchmarking handbook and are structured in the following manner:

- First section: What will be tested and where (which use cases, which solutions, which environments)
- Second section: How these tests will be performed (approach, measurements point specs, etc.)
- Third section: Results obtained and how to process them to obtain conclusions

## 1.1 Tasks 4.1 & 4.2 scope

### 1.1.1 Relations with other tasks

The final outcome of Tasks 4.1 and 4.2 is the validation of the benchmarking handbook D2.1 created within Task 2.1[4] by using localization solutions developed in WP3[5] that are intended to enhance robustness in the presence of interferences. These solutions will be tested in a real life environment, evaluating their performance and giving test beds insights on what specific real use cases scenarios match tests being carried out.

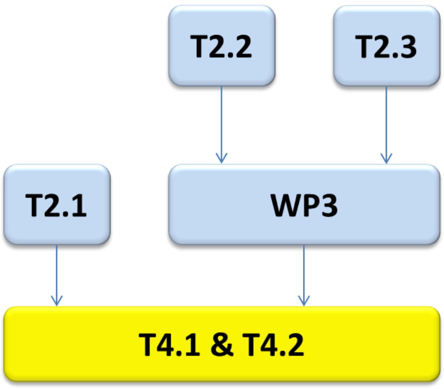


**Figure 1. WP4 Relations with other tasks**

[2] T4.1: Validation in real-life environment: Healthcare
[3] T4.2: Validation in real-life environment: Underground Mining Safety
[4] T2.1: Definition of the scenarios, benchmarks and metrics
[5] WP3: Interference-robust localization

### 1.1.2 Applying the EVARILOS benchmarking handbook

The application of D2.1 is reflected in the description of the scenario where different solutions will be tested plus the methodology to be applied when performing tests. The structure of this document will follow the one defined in D2.1.

Definition of a scenario

A scenario comprises three types of specifications

- Environment specifications
- Measurement point specifications
- List of applicable metrics

Requirements of the scenario description

The scenario should match with one of the defined EVARILOS instantiations

- The environment should be representative for the application domain
- The definition of measurements points should be defined in a way that all classes of use cases are represented
- It should be possible to calculate all possible metrics in an objective manner

Environment specifications

The environment specifications are described in detail in Chapter 3 of the EVARILOS benchmarking handbook. A description is given of typical floor plans and building structures.

List of applicable metrics

At least the metrics defined in Section 4.2.5. of D2.1.

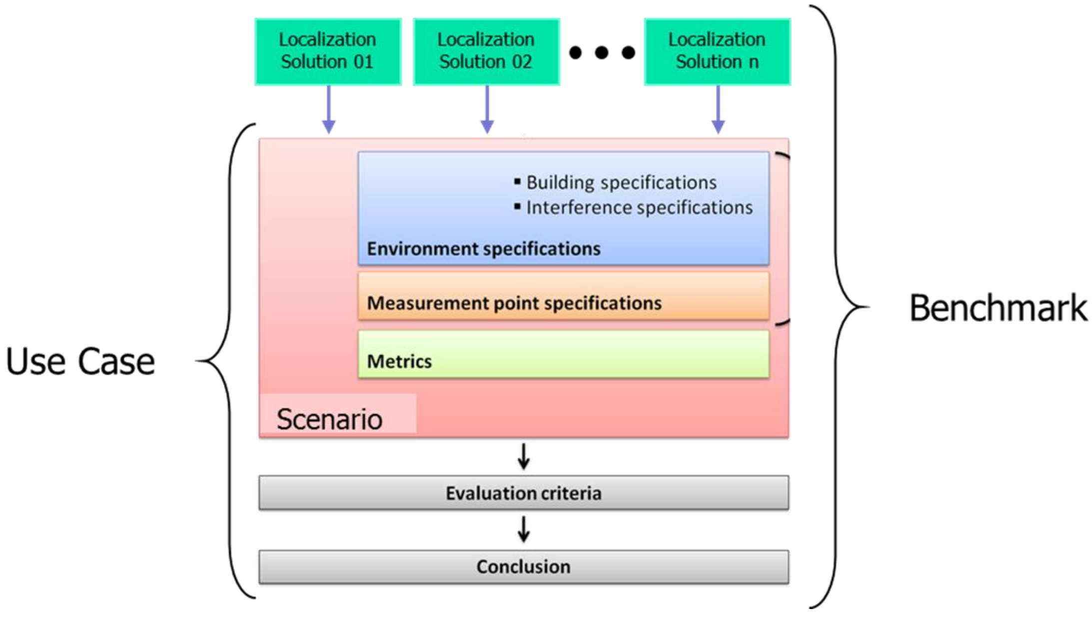


**Figure 2. EVARILOS Benchmarking Approach**

## 1.2 Three step validation approach

The three step validation approach is part of the plan or methodology to define representative scenarios that match real life use cases for benchmarking. Since testing in real environments is not sometimes possible due to companies' constraints, there is the need to simulate these environments in test beds. For this purpose, initial measurements have to be taken in real scenarios in order to provide test beds with propagation and interference related data that allows the characterization of these environments. Basically, this is a generic approach which is valid for both application domains that consists of the following steps:

- Setup and execution of first experiments (onsite)
  - Insight in interference pattern
  - Insight in propagation pattern
- Setup and execution of mockup in representative setting
  - Managing deployment
  - Testing the benchmarking methodology using the suite
  - Comparing different solutions (all)
- Setup and execution in the field (onsite)
  - Only the most suitable candidate will be deployed in the field
  - Confirmation of results

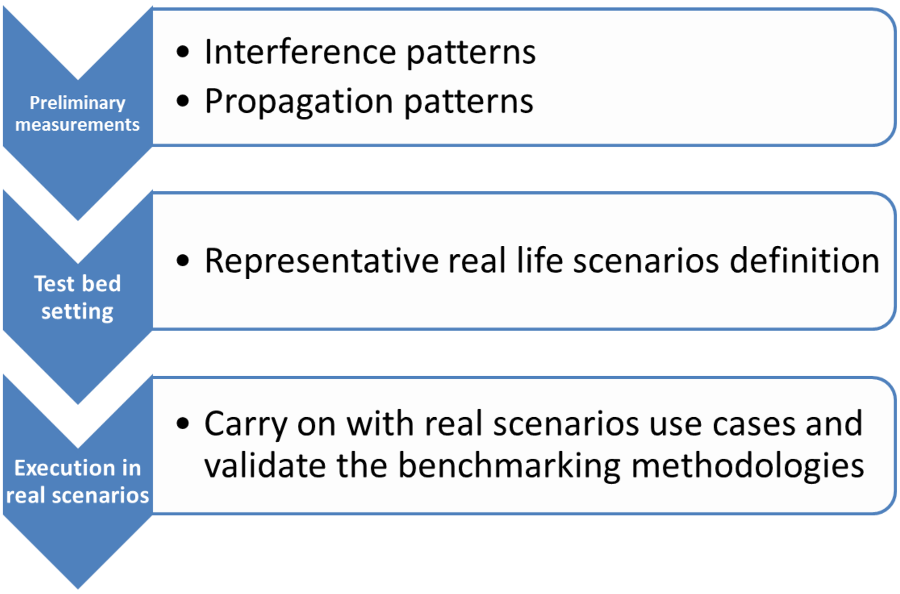


**Figure 3. Three steps validation approach**

## 1.3 Purpose of this Deliverable 4.1

This specific document will set the base for the trials that will be performed in the real life settings. The main goal is the definition of representative scenarios for the test bed by following D2.1. Therefore the main input expected from this deliverable is summarized in the following bullet list:

- Definition of both real settings environments by describing space constraints and interference specifications.
- Provide with realistic scenarios for testing in terms of trials to be performed and technologies used.
- Selection of use cases related metrics. Many metrics that are considered relevant for the measurement of the overall performance of localization solutions will be chosen for each use case.
- Metrics processing for extracting conclusions in order to give feedback to WPs 2 and 3 on benchmarking methodologies and localization solutions performance. WP2 Benchmarking of localization solutions will get feedback on how detailed and useful D2.1 is and WP3 will get input on localization solutions performance in real scenarios.

# 2 Healthcare Application Domain

## 2.1 Validation use case scenarios descriptions

This section describes the use cases on which a scenario will be mapped for the validation in a healthcare setting.

The purpose is to validate

- the benchmarking methodology
- if the results of the mockup can be reproduced in the field
- the metrics and evaluation process

To this end, the methodology of the EVARILOS handbook will be followed. In D2.1 generic application use cases where described. Starting from that list, the most valuable application use cases are selected and a scenario is worked out.

It is important that what is deployed in the validation scenarios matches with the real life use case to achieve a good representation and transferrable results.

### 2.1.1 Selection of use cases and corresponding scenarios

The selection process of the use cases is first of all driven by the application itself. However as the purpose is to evaluate the benchmarking methodology, other criteria were used. The selection criteria are listed below

- Application driven use cases
- How to experiment with those use cases
    - What can be tested in field?
        - What makes sense to test?
- What needs to be measured to enable this use case?
    - What metrics will be used in the scenario?
- Defining representative scenarios for the test bed
    - How to guarantee that they represent a realistic scenario
    - Making sure that what is deployed matches the real life use case (good representation, easy transferable)

#### 2.1.1.1 Application driven use cases

Classification of use cases

From a general description, the use cases can be classified as follows. For each class of use cases, a representative use case and scenario will then be derived. The classification is based on differences between the most important metric.

- Use cases where localization accuracy is crucial
    - Levels of accuracy
        - Room level for standard two or four bed rooms
        - Bed level for larger rooms (e.g. dialysis)
    - Latency is not critical
    - Life time of the tag is important
    - Example: locating patient after alarm call, locating staff, assets

- Use cases related to guidance and tracking
  - Real time localization: should be fast but not critical
  - Example: guidance of a visitor/patient to a given space (room, doctor visit)
- Use cases where an action is automatically triggered in proximity of the user
  - Accuracy: entering a perimeter, zone (a room, or a few meter)
  - Latency is crucial: entering a zone triggers an action
  - Example: wandering, auto log-on
- Use cases where latency is critical and where the user wants to register himself
  - No true localization => Absolute distance for a terminal, close range
  - Latency of about 200ms after the user action
  - Examples are access control and log-on applications.

From the classification above it is clear that all classes of use cases have different requirements in terms of accuracy (room level vs. proximity), latency and other metrics.

Note that the last class cannot be considered as "true" localization. For such use cases RFID solutions are typically selected. They are therefore not considered in this validation process.

<u>Use case 1: Locating a patient after an alarm call</u>

When a patient issues an emergency call, the nurse has to know the location of that patient in order to respond correctly. Depending on the actual position of the patient when he issues the emergency call, the location has to be known in more or less detail.

In case he's inside a patient room, the number of the room is sufficient to identify his location. In case of a multi-bed room, the bed number could be further relevant information, however the notion that the location of the patient is inside a room is sufficient information to act upon the emergency call.

If the alarm is issued in a long corridor however, the notion that he is located inside the corridor is no longer adequate: the location information has to contain more details (e.g. located in corridor one, near room 142). Especially for large hospitals corridors can stretch out quite far, e.g. corridors that are used to interconnect several buildings on a hospital campus.

In a third case, a large public room (like the hospital cafeteria), the location information should indicate a more accurate region of the large room (e.g. a quadrant or a table number in case the tables are numbered).

<u>Use case 2: Guidance of a visitor/patient to a given space for a doctor visit</u>

In a large hospital, it is often not straightforward to find your way to your destination. In such cases a device that guides you there (real time) is very helpful and will increase the efficiency.

When a patient arrives in the hospital to consult a doctor, he will receive a device that knows its actual location and the destination of the doctor's room. An application will tell you (graphically) how to get there. This use case is also referred to as indoor GPS

In contrast to the previous use cases, the real time behaviour is very important, the requirement on latency is still not critical. With respect to location accuracy, point accuracy can be used with a tolerable error of a few meters. With the help of floor plans, false rooms can be avoided.

Use case 3: A patient is wandering, when he/she is approaching the hallway door an alarm should be triggered and the door should be closed in time.

In some conditions, the patient is not allowed to leave a specific zone for his own safety and the safety of others. However, it is not accepted to close doors all the time as in this case the patient would be locked up. Open environments are still preferred in this case. When the patient is detected near the exit of zone, immediate action is required.

It is clear that in such use case, the latency of the system becomes crucial as a critical action will follow (alarm, automatic closing of doors). With respect to accuracy, the level of accuracy should be very precise in proximity of the exit: entering or exiting this perimeter should be detected at all times.

#### 2.1.1.2 How to experiment with those use cases

Scale of the validation

It is important to realize that in a hospital, lives of persons can be at risk. Because our solutions are under validation and are not validated yet, it is not possible to experiment with real patients or nurses. Therefore a kind of role play by members of the consortium or by volunteers (who have no background) can be selected.

A second consequence is that the daily operation of the hospital should not be disturbed. Therefore the validation area (a couple of rooms on a floor) and the validation time (number of days) will be limited.

This motivates our three step validation approach: in a first step, a short measurement campaign will gather the required information to allow to build a representative mockup and to make sure that experiment organized in the test beds are representative as well. The second step will apply the benchmarking handbook (D2.1) and compare the solutions under test. Only the most promising ones will be deployed in the field for final validation.

Another advantage of this approach is that the benchmarking method will already be exercised such that the deployment can go smoothly. Not only the overhead for the hospital will be limited but also realistic measurement data will be obtained for deployment metrics.

Finally, as daily operation continues, no or limited network infrastructure will be available. Only when a separated network for patients is available that could be accessible. However typically this is WiFi based and no Ethernet sockets will be present. Therefore a private network is recommended. Power sockets are normally available in rooms.

Scalability of the solution is obviously important. Therefore it is important to draw correct conclusions. However the impact of scalability can easily be simulated and validated on the mock-up: the effect of the number of users and data traffic can be reproduced. The effect of the environment (propagation) and the interference level is specific and needs validation in the field.

Use case 1: Locating a patient after an alarm call

A person will be given a tag. With this tag, this person will need to walk a specified route. Way points will be selected at which measurements need to be taken.

Two runs are possible: static, the person stays some time at the way point of mobile where the person keeps moving and does not stop. Depending on the solution, this person will need to make clear to the system when he is actually present at the way point.

The person will walk through the corridor and enter every room. In total he will enter 6 rooms, that will be adjacent or opposite to each other.

This test will be repeated for different topologies and environments (see further).

Use case 2: guidance of a visitor/patient to a given space for a doctor visit

A person will be given a tag. The patient will start in a room and will need to go to another room. It will be monitored how fast the location updates occur on a GUI and if the correct trajectory is displayed. This approach avoids having to implement the routing application which is a layer on top of the localization.

Use case 3: A patient is wandering, when he/she is approaching the hallway door an alarm should be triggered and the door should be closed in time.

A person will be given a tag. The patient will start in a room and will walk towards the exit of the hall. A mark at a fixed distance from the exit will define the area or proximity in which the system should respond. The latency from the moment the person crosses the marking will be measured. To split up accuracy from latency, a static measurement can be executed: if it takes a long time before the location appears inside the perimeter, this can be due to latency or due to an inaccurate localization where the system thinks the person in still too far away from the exit.

Discussion on proximity

- Trend of hybridization (multi-modalities)
    - Some commercial solution exploit non RF technologies
    - Infrared, RFID, etc.
- Why RF is still favorable
    - Stick with single technology (cost, size, infrastructure)
    - Study how to accomplish different levels of accuracy in the same premises
        - Increasing number of anchor nodes
        - Increasing number of messages
    - Multimodal solution
        - Over different technologies
        - Over different ranging methods
        - Multimodal solution for interference robustness and accuracy
- Metric for proximity
    - Derived from room level accuracy (no confusion matrix)
    - Room = circle of x meter of anchor
    - Derived from point accuracy (coordinates but needs a too high level of acc.)

### 2.1.2 List of localization solutions

In a first phase, the provided solutions will be limited to the existing list available in the EVARILOS consortium. In summary, the following types of algorithms are available:

- Fingerprinting algorithm based on RSSI measurements
- Weighted RSSI and proximity
- Particle filter based on Time of Flight measurements
- Relative position discovery algorithm

The required hardware to perform the experiments will be determined and delivered by the members of the consortium. Recall (three step validation approach) that all solutions will be compared using the benchmarking topology in a mockup, the best candidates will be evaluated in the field.

### 2.1.3 Description of the environment of the test site

#### 2.1.3.1 Building specifications

As long as no detailed plan is available, no hospital can commit in joining the validation. This plan will only become available after the second phase of our validation process. It is important to exactly know the exact work plan stating the measurements sequence, the required number and position of anchor points, etc. The purpose of the second phase is exactly in specifying all this. However, the selection of the test site should not be important for the validation process. Suppose the results differ too much between different hospitals, this would mean the benchmarking is not representative for the application domain. In D2.1 a number of environment types have been defined. It is clear that the office environment with long corridors and many rooms mimics the best the hospital environment. Both (ply) wooden walls and brick walls exist depending on the hospital (new modern building vs. old buildings)

The environment consists of:

- Patient rooms
- Storage rooms
- Corridors
- Nursing stations
- Large areas: cafeteria, entrance hall
- Stair cases and elevators

Typically there is some symmetry in the floor plan. Mostly rooms are back to back symmetric. However at the opposite side of the corridor this is not always the case as shown in some example topologies.

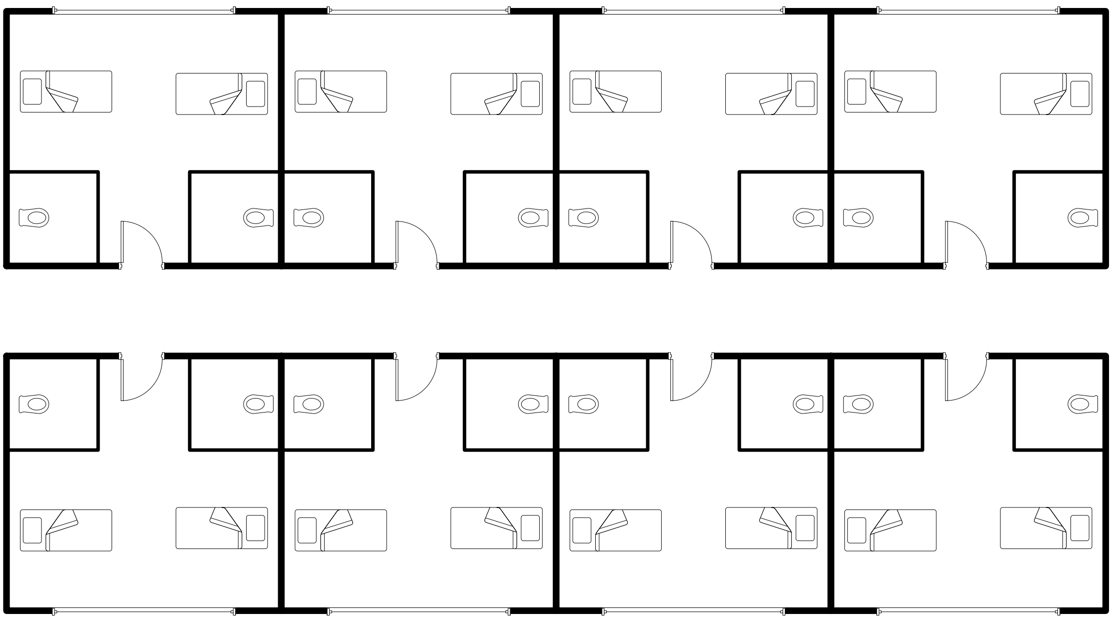

**Figure 4. Building's plan 1: Healthcare**

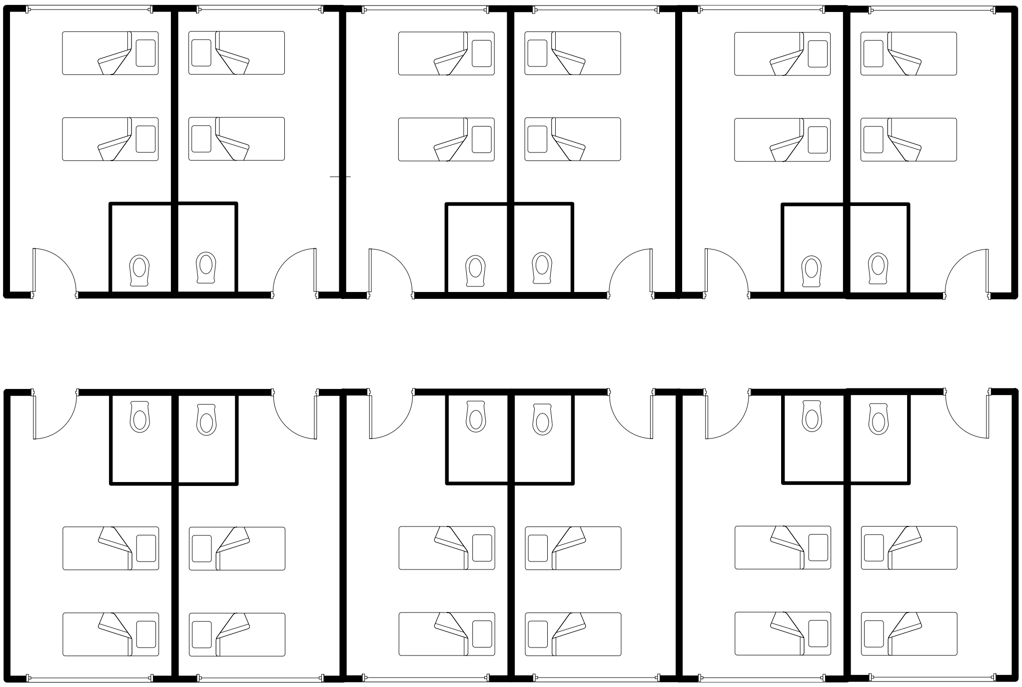

**Figure 5. Building's plan 2: Healthcare**

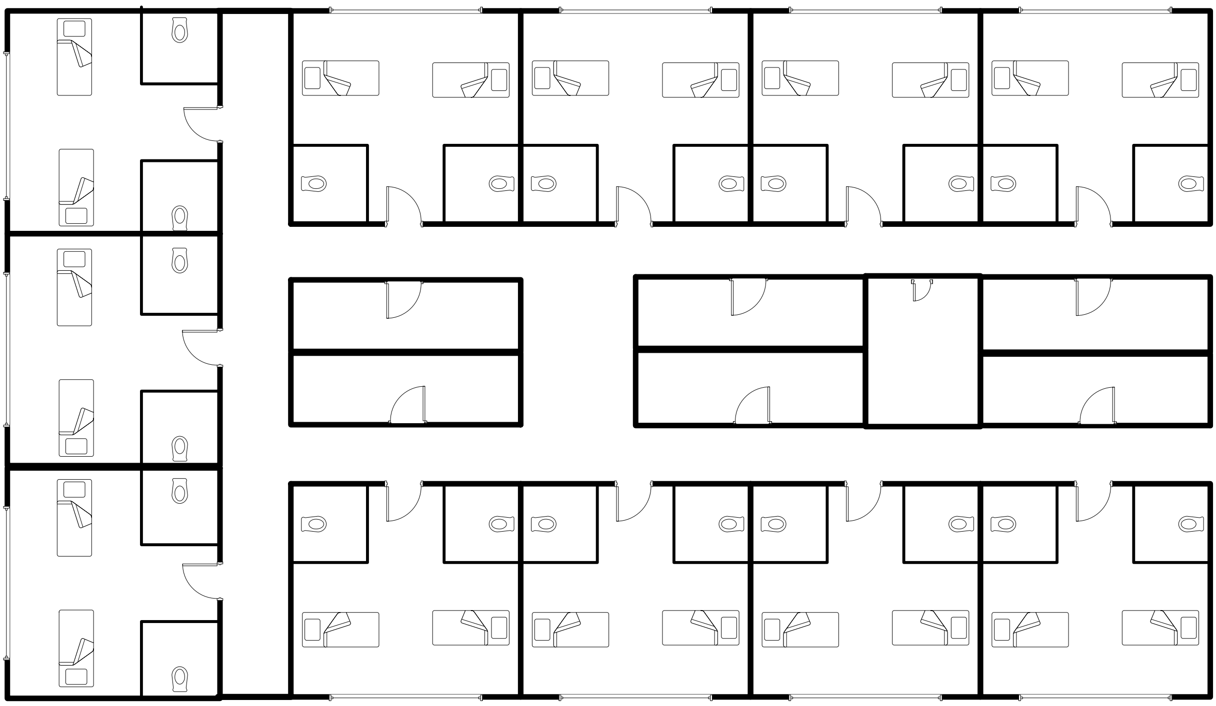

**Figure 6 Building's plan 3: Healthcare**

All kind of structures are possible.

- The walls can be made of plaster or can be concrete walls. Note that combinations are possible and that the exact type is not always known (older buildings)
- The sizes of the room differ (dependent on building and number of beds)
- The entrance of the sanitary cell is located on a different position
- Typically long corridors are present
- Occasionally, the building has a circular or star shape
- Metal objects can be present and can be moved at any time
- The number of people present can be different (can be a lot in case of visitors)

The focus should be on 2D localization. We can assume that the correct floor is known.

#### 2.1.3.2 Interference specifications

The following type of interference is present in the hospital:

- DECT
- 2.4GHz WiFi, (BT)
- GSM
- Medical equipment

To obtain more details about the sources of interference, their traffic and how they influence localization, basic experiments will be organized in the first phase of the validation process in order to have more details and insight.

## 2.2 Methodology of the validation process

### 2.2.1 Validation approach

The field tests in the hospital will follow the generic validation approach as pointed out in Section 1.2. This approach consists of three steps. At the proposal phase, a two-step approach was mentioned to make sure the deployment phase was mastered before entering the field. These two steps become now step 2 and step 3 of the generic validation approach. In this section each step is explained in more detail.

<u>Step 1: Setup and execution of first measurement onsite</u>

In order to make the field tests practically manageable, a lot of effort will be put in creating a mockup in a representative setting before actually going to the field. To make this mockup representative, it is crucial to do a good characterization of the real situation up front. This way we can feel confident that the results in the mockup and also the results from the test bed are representative for the actual application domain. This characterization is exactly the purpose of step 1.

On short term first experiments in a hospital are planned with the following goals:

- To retrieve insight in the propagation characteristics
    - Experiments will be organized to estimate the path loss, transmission range and throughput or several technologies
- To retrieve insight in the interference level onsite

- Experiments will be organized to scan the environment over different frequency bands

Note that none of these experiments target to do any localization meaning that the experiments are executable with a minimum of infrastructure or hardware.

Step 2: Setup and execution of mockup in representative setting

The purpose of this step is to validate in a near-life-like environment. A mockup will be created that matches as good as possible with the real life environment. This will be achieved by using the results of the first step. From these results, the actual place, environment and the correct interference source will be installed.

The mockup should fulfill the following conditions:

- Physically equivalent: practical elements of the setup (physical installation time, configuration, information needed in advance, replacement time, financial cost) should match with the real setting.
- Focus on non-technical metrics
- Goal to be sure that deployment in real setting is first time right (limited testing time) and that the deployment is fully under control (comparable to a skilled installer)

Questions that should be answered in the step are:

- Physical distribution of the static nodes in the deployment. How many are strictly necessary? (SUT dependent)
- Number and type of mobile nodes for the tests
- Wireless sensors firmware. Who will provide the firmware and how should we install this in each node?
- Algorithms. Are they going to be locally installed in a PC or in a remote server? Must the deployment be accessible from the Internet?
- How to do the data storage?
- Are tests going to be continuous or iterative?

On top of measuring and validating deployment metrics, the benchmarking will be tested thoroughly applying the benchmarking suite. Goals are:

- Evaluation of the suite when deployed outside the test bed
- Validation of the calculation of the metrics
- Experimenting how to enter different scenarios (defining weights, etc.)
- Validating the scoring system

To support this, localization solutions will be fully deployed and by using the results of the benchmarking. In this phase, also the performance metrics listed in D2.1 will be calculated and evaluated. It should be possible to select the most suitable candidate solution for each scenario in a healthcare setting. These solutions will be transferred to step 3.

Step 3: Setup and execution in the field onsite

In this step, the benchmarking methodology will be validated in a real hospital for a limited subset of localization solutions which have been selected in step 2. In Chapter 3, three use cases where selected. For each of those use cases, the scenarios will be further detailed based on solutions under tests. Note that multiple scenarios will be created per application use case depending on:

- Different environments (different sections of the hospital)

- Different levels of applied interference
- Different deployment per solution

The goal is to confirm the results obtained in the mockup (step 2). Achieving the same results means not only that the benchmarking methodology works but more importantly that the results can be ported from test beds, to mockups into the field. This makes up front comparison for localization solutions possible before actual deployment or purchase motivating the added value of this approach.

### 2.2.2 Validation plan and measurement point specification

This section will describe

- The purpose of the different types individual measurement points
- The number and order of measurement points, defining a route
- How long to measure at each point

The answer of these questions is specific per scenario per use case.

#### 2.2.2.1 Types of individual measurement points

Different types are defined because of the different way the end-user is interacting with it or the way it allows a specific use case. To categorize the measurement points the classification used in Section 2.1.1.1.

- Use cases with primary metric space accuracy (location on request)
- Use cases related to guidance and tracking: real time localization based on point accuracy and space accuracy
- Use cases where an action automatically is triggered in the proximity of the user. Primary metrics in this case are point or space accuracy but tailored for proximity and the specific trade-off with latency.
- Use cases where the latency is critical and where the user wants to register himself to the system. Primary metric is accuracy.

Based on this classification, the following types of measurement point are defined:

- Measurement points in room or corridor with the objective to validate the accuracy. Some points will be defined on a normal route the end-user is meant to follow. Other measurement points will be defined to validate room level accuracy meaning that the measurement point will be located about 10cm away from the wall. During the field tests, way points will be defined and indicated on the floor serving as ground truth. A person/asset carrying the mobile node should follow the indicated route.
- Measurement points near a terminal where the user is interacting with. Note that in some situation no dedicated access point will be available while otherwise a dedicated access point near that terminal can be installed. The measurement points will be chosen such that the user is approaching the terminal. The evaluation of latency vs. accuracy will be very important.
- Measurement points at a terminal position. In this case an access point needs to be located next to that measurement point as this comes down to proximity measurements and we can assume that the SUT has no 3D accuracy of about 10cm.

Finally it is important to take into account the dynamic nature of the healthcare setting. Patient and nurses are typically walking. Especially for wandering detection (patient that is leaving a zone); you cannot assume the target is placed stationary for a period of time.

#### 2.2.2.2 Defining a route

In the previous section, different types of measurements points were defined. Depending on the use case, the sequence and the measurement time per point will differ. Per scenario per use case, a route will be defined. A route will uniquely define the measurement flow. For each SUT, this route will be repeated. A detailed description will be required in the work plan which will be presented to the hospital that will join the field tests. Because the exact description is site dependent, only some generic examples are given.

- The height of the measurement is about 1m (height of wristband)
- Default, every meter a measurement point should be defined
- When entering/leaving a room, the grid should be reduced to about 10 cm in order to know when a new location is given by the SUT
- Inside a room, a sub route should be defined next to the four walls, at 10 cm from the wall at the grid of 1m. The corner points should be included
- When the route goes to a terminal or exit door, which are typical “proximity” points, the grid should be reduced to 10 cm. The route should follow the normal way to this user interaction point. For each proximity point, a distance will be defined for entering the perimeter.

The number of measurements at each point is dependent of the SUT. It is up to the SUT to guarantee that not only stationary situations are possible which would exclude e.g. patient tracking. The number of measurements will have an impact on the metrics, as they will impact for example latency and power consumption.

Three speeds are considered, resulting in a new set of scenarios

- Stationary: 0 km/u
- Walking: 4km/u
- Running: 10km/u

### 2.2.3 Work plan

A detailed work plan is required to present to the hospital. It consists of a detailed description of the measurement campaign based on the outcome of step 2 of our validation approach.

It will describe how the three use cases will be validated on the specific site. For each use case a list of scenarios will be described. Each scenario will comprise

- Description of the measurement points
- Description of the route
- Description of the instances (different speed, test for repeatability)
- Description of the SUT
    - In this section all questions posed in Section 2.2.1 (step 2) should be answered based on the results from the mock-up e.g. number of anchors
- Description of the required infrastructure and central equipment
- Description of how the measurements are processed

Based on the above description, a detailed planning and time line will be prepared and agreed with the hospital.

It is important to also clearly motivate in the beginning of the document what is the added value for the hospital.

As a preparation, a formalized specification is given for each of the three use cases.

| Use case name | **Locating a patient after an alarm call** |
|---|---|
| Brief description | Patient triggers an alarm call. At that moment, the exact room number needs to be sent to nurses. In case of multiple bed rooms, the exact bed should be specified. |
| Flow of events | A patient moves freely inside the hospital: its own room, the corridor, the cafeteria, etc. At random times, the location will be requested. During the validation, this will be tested on each point on the route specified for the scenario. |
| Basic flow | The position is calculated and fed to the benchmarking suite. This position should be linked to the ground truth. |
| Alternative flow | N/A |
| Special requirements | The SUT should be able to run independent from the hospital infrastructure. Only some power sockets are available. An own private network will be required. The algorithm and benchmarking suite should run on a local pc, unless a connection can be foreseen to the cloud.<br><br>The SUT should not disturb the normal wireless network operation of the hospital. The normal interference present in the hospital will be used. No additional interference will be generated.<br><br>A GUI should be available to select the scenario, visualize all calculated metrics, and select (weights) metrics. Accuracy should always be visible at run time (error shown). |
| Preconditions | Detailed work plan mapped on the test site. The scenarios should be preconfigured to immediately start the measurements. |
| Post conditions | Possible to take several measurements in several positions. Easily switch between stationary and mobile measurements |
| Extension points | N/A |

**Table 1. Use case 1: Locating patient after an alarm call**

| Use case name | **Guidance of a visitor/patient to a given space for a doctor visit** |
|---|---|
| Brief description | Patient of room A (can be the entrance for non-hospitalization) has an appointment with a doctor in room B. The patient will be guided using a mobile device to that room. |
| Flow of events | A patient follows a predefined route from room A to room B. His location will be tracked. Real time localization should occur. |
| Basic flow | The position is calculated and fed to the benchmarking suite. This position should be linked to the ground truth. The latency between location updates will be monitored as these are dynamic measurements. |
| Alternative flow | N/A |
| Special requirements | The SUT should be able to run independent from the hospital infrastructure. Only some power sockets are available. An own private network will be required. The algorithm and benchmarking suite should run on a local pc, unless a connection can be foreseen to the cloud. |

| | |
|---|---|
| | The SUT should not disturb the normal wireless network operation of the hospital. The normal interference present in the hospital will be used. No additional interference will be generated.<br><br>A GUI should be available to select the scenario, visualize all calculated metrics, and select (weights) metrics. Accuracy should always be visible at run time (error shown).<br><br>In this specific case, a basic floor plan of the test site could be important to monitor the real time tracking |
| Preconditions | Detailed work plan mapped on the test site. The scenarios should be preconfigured to immediately start the measurements. |
| Post conditions | Possible to take several measurements in several positions. Easily switch between stationary and mobile measurements |
| Extension points | N/A |

**Table 2. Use Case 2: Guidance of a visitor/patient to a given space for a doctor visit**

| Use case name | **A patient is wandering, when he/she is approaching the hallway door an alarm should be triggered and the door should be closed in time.** |
|---|---|
| Brief description | The test site will be split up in two zones. One where the patient is allowed, one where the patient is not allowed. The boundary will be specified by the exit door of the corridor. |
| Flow of events | A route will be indicated on the floor with a dense measurement grid. For this “proximity” use case, specific measures can be taken to locally enhance the location accuracy. A perimeter around the boundary will be specified e.g. one meter. When the patient enters/leaves this perimeter, an alarm should be triggered. The error from the boundary will be monitored and the latency. Location accuracy will be expressed in the following metrics: point accuracy and location accuracy. |
| Basic flow | In the basic setup, the higher accuracy will be achieved by increasing the number of anchor nodes. (special anchor might be required) |
| Alternative flow | The higher accuracy will be achieved by increasing the number of anchor nodes by increasing the duty cycle of the device.<br><br>The higher accuracy will be achieved by a multimodal solution where several localization technologies are combined. |
| Special requirements | The SUT should be able to run independent from the hospital infrastructure. Only some power sockets are available. An own private network will be required. The algorithm and benchmarking suite should run on a local pc, unless a connection can be foreseen to the cloud.<br><br>The SUT should not disturb the normal wireless network operation of the hospital. The normal interference present in the hospital will be used. No additional interference will be generated.<br><br>A GUI should be available to select the scenario, visualize all calculated metrics, and select (weights) metrics. Accuracy should always be visible at run time (error shown). |

| | |
|---|---|
| Preconditions | Detailed work plan mapped on the test site. The scenarios should be preconfigured to immediately start the measurements. |
| Post conditions | Possible to take several measurements in several positions. Easily switch between stationary and mobile measurements |
| Extension points | N/A |

**Table 3. Use case 3: Patient wandering**

## 2.3 Evaluation process

### 2.3.1 Metrics and weights

#### 2.3.1.1 Generic metrics

Depending on the application use case, different criteria for the evaluation of the performance of the localization hold. Therefore the selection of critical metrics is done per group of use case as prepared in D2.1.

Next to performance metrics also deployment metrics (or an indication of the overall system cost) are very important in the decision process of a company whether to invest in the system of a given performance. For these metrics, no distinction is made for the different use cases as the amount of investment is dependent on the business model of each individual company.

Critical performance metrics

| Use case | Metric | Score |
|---|---|---|
| **Localized nurse call** | Space accuracy (critical) | Very high |
| | Latency (fast but less than scenarios below) | Moderate |
| | Scalability (solution should work with multiple people in one room e.g. visitors in a room) | Moderate to high |
| **Wandering** | Point accuracy (how far away from the point where you want the action to happen) | High |
| | Latency (alarm should be triggered fast enough) | High |
| | Mobility (patient possibly running away) | Moderate to high |
| **Access control** | Point accuracy | High |
| | Latency (door should open if want to enter) | Very high |
| **Auto log-on** | Point accuracy and room accuracy (log on is active is a perimeter around the device or is active when a nurse is in the room | Very high |
| | Latency | |
| | Triggered entering the room | Moderate |
| | Triggered in a smaller perimeter e.g. 1m | High |
| **Assets** | Room level accuracy (less critical than in case of an alarm of a patient) | Moderate |
| | Energy efficiency: you don't want to replace tags on assets regularly | High |

| | | |
|---|---|---|
| **Track and trace** | Room level accuracy | Moderate to high |
| | Mobility (people are walking around) | High |
| | Energy efficiency | High |
| | Scalability | Moderate |

**Table 4. Use Cases and Metrics**

Note: metrics of robustness (interference, environment) are difficult to assess as it will have an impact on the basic performance metrics. We want some kind of guarantee that e.g. when interference occurs, the system will still work. The amount of interference should be representative for the use case.

<u>Critical deployment metrics</u>

In order of priority (1=highest):

1. Physical installation and configuration: basically everything that requires manpower
2. Maintenance (especially for battery replacement in person tags)
3. Hardware

#### 2.3.1.2 Use case specific metrics and quantification

The table above gives us a general feeling of which metrics are relevant. In this section, the use cases will be mapped on this table. Secondly, it is important to quantify the metrics. Per use case a weight needs to be selected to give more or less relevance to a specific metric. This will lead to an overall score. Below a first estimate will be given. In step 2 of the validation process (mockup), it will also be verified whether those weights have been correctly determined by studying the ranking coming out of the benchmark.

1. Metrics for “Locating a patient after an alarm call” => *Localized nurse call*
2. Guidance of a visitor/patient to a given space for a doctor visit => *Tracking*
3. A patient is wandering, when he/she is approaching the hallway door an alarm should be triggered and the door should be closed in time => *Wandering*

| Metric | Localized nurse call | Tracking | Wandering |
|---|---|---|---|
| Point accuracy | 0 | 0 | 0.2 |
| | | 0.2 | 0 |
| Space accuracy | 0.3 | 0.2 | 0 |
| | | 0 | 0.2 |
| Latency | 0.05 | 0.1 | 0.2 |
| Energy efficiency | 0.2 | 0.2 | 0.1 |
| Repeatability | 0.05 | 0.05 | 0.05 |
| Interference robustness | 0.05 | 0.05 | 0.05 |

| | | | |
|---|---|---|---|
| Environment robustness | 0.1 | 0.1 | 0.05 |
| Mobility | 0 | 0.1 | 0.15 |
| Scalability | 0.1 | 0.05 | 0.1 |
| Set-up overhead | 0.1 | 0.1 | 0.05 |
| Technology | 0 | 0 | 0 |
| Financial cost | 0.05 | 0.05 | 0.05 |

**Table 5. Metrics Weights for Healthcare**

Note that for the for the use case of wandering, the cost metrics are less important as this use case is valid on a few dedicated points in the hospital where the first two use cases require coverage over the entire site.

For some use case, step 2 in our validation process will indicate which of the accuracy metrics are most relevant.

### 2.3.2 Mapping functions

Each metric will be converted into a score from 0 to 10 where the highest score corresponds to the best result. To this end, mapping functions will be used to uniquely translate the metric (measured in an absolute unit) into this score. The mapping function is a monotonous but parameterized function. The kind of function will only depend on the metric but will be independent of the use case. The parameters in the mapping function however are use case dependent as e.g. an error of 1m can be ok in one use case but only average in another.

The overall benchmarking score will be computed form a weighted sum of the individual scores per metric. These weights will determine the relative importance of each metric depending on the use case as discussed in the previous section.

Below mapping functions per metric are discussed. The parameters present in the equations are quantified in Table 7.

**<u>Point accuracy</u>**

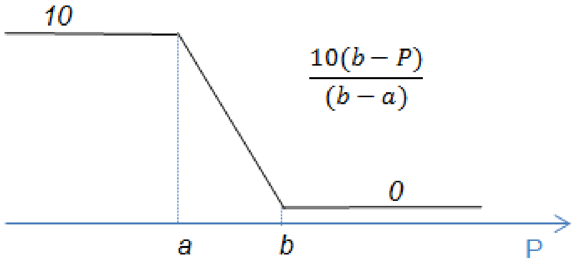


**Figure 7: A linear parameterized mapping function converting physical units to scores (0-10).**

Define two parameters:

*a: maximum allowed error without performance degradation yielding a perfect score of 10*
*b: error for which the results becomes useless yielding a score of 0*

**Space accuracy**

The room confusion matrix will be used to compute the score. This room confusion matrix lead to a success rate (see D2.1). From this success rate a score is computed as defined by the following mapping function. Note that the definition of success rate is updated and depends on the number of rooms you are mistaken.

*10 ( 1 – 1x (#errors in adjacent rooms)/(#total number of measurements) – 2x(#errors two rooms off)/(#total number of measurements) – 3x (…) )*

**Latency**

During the measurements, the mobile node will update its position according to a measurement plan. Each time the mobile node is given a new location is given, the time will be measured unit this new position if found by the system under test. This will lead to an average time.

Another measurement will measure latency as the computation time between a message sent by the mobile node to update its position and when the algorithm has finished computing the location triggered by the new message.

The first measurement will take into account the duty cycle of the system. Systems that transmit more often will have lower latency but increased power consumption. The second measurement gives an estimate of the computational complexity of the algorithm.

As mapping function, the same type of function as for point accuracy can be used where the parameters a and b have the following meaning:

*a: maximum allowed latency without performance degradation yielding a perfect score of 10*
*b: latency for which the results becomes useless yielding a score of 0*

**Energy efficiency**

In this case only the situation where the system is up and running is considered.

From the description of the SUT, a power calculation can be made if the following numbers are known or can be measured.

- Length of a transmission
- Power consumption in Tx mode
- Length of a transmission depending on the message length, data rate and duty cycle
- Power consumption in Rx mode
- Time in Rx mode
- Power consumption in sleep mode
- Time in sleep mode

Next the energy consumption will be translated into total life time of a mobile node. If a tag lives longer than x months, a score of 10 is given. The score is linearly reduced by each month the life time of the system is lower.

**Derived metrics: repeatability, interference robustness, environment robustness, mobility, scalability**

According to D2.1[6], those metrics are derived metrics as they study the degradation of the primary metric caused by e.g. interference or the number of mobile nodes. The measurement method will result in a relative number. This percentage can be straightforward converted into a score between 0 and 10 by dividing the percentage by 10.

**Set up overhead**

For all deployment metrics such as physical installation and configuration, two measurement techniques will be combined resulting in two scores. The total score for set up overhead will simply be the average. The total time will be measured as well as a questionnaire will be answered.

D2.1 gives insight why this approach is followed. E.g. configuration involves many aspects that all require some time. However in some cases spending time on a particular aspect is no issue, in some cases, it can be really important.

The total installation time will converted to the number of men hours. The more men hours a physical installation demands, the lower the score becomes. The number of men hours will be translated into a score between 0 and 10. During the second step of the validation approach, insight will be obtained how to define the absolute scoring system. Note that the time will be relative to the area of the site where localization is performed.

For the questionnaire, a number of relevant questions will be posed. The relevance of these questions is use case dependent and therefore, the questions need weighing.

| Question | Score (1-10) | Importance (%) |
|---|---|---|
| Does it require fingerprinting or not? | YES: 0<br>NO: 10 | 100 |
| How long does it take to get the system up and running? | < 1 minute per room: 10<br>> 10 minutes per room: 0 | 20 |
| Do you need to enter coordinates? | YES: 0<br>NO: 10 | 50 |
| How are these nodes mounted on the ceiling? | | 30 |
| How are the central components installed? | | 20 |
| What are the locations of the anchor points? | Nurse call node: 10<br>Additional: 5<br>Ceiling: 2 | 60 |
| Can you place your anchor points anywhere? | YES: 10<br>NO: 0 | 80 |

**Table 6. Questionnaire measuring set-up overhead**

[6] http://www.evarilos.eu/deliverables/D2.1_initial_version_of_the_handbook.pdf

**Technology type**

For the healthcare application domain, the kind of technology is not important in a first phase. Whether a dedicated tag is required or a smartphone can be reused will have impact on the financial part of the solution. E.g. performing localization with a smartphone is only beneficial in case it is used by other applications e.g. receiving alarm calls. Also the specific business model of the company will have impact.

**Hardware cost**

The hardware cost is an absolute number. This cost will be converted to a cost per room, per area, per site or per gate depending on the application domain and use case. Based on the maximum cost of a SUT and the minimum SUT (determining the parameter a and b of the function), a linear mapping function will be obtained for scoring between 0 and 10.

**Parameters of the mapping function per use case**

| Metric | Localized nurse call | Tracking | Wandering |
|---|---|---|---|
| Point accuracy | A=1m<br>B=3m | A=1m<br>B=3m | A=0.5m<br>B=2m |
| Space accuracy | Above 3: always 0 | Above 3: always 0 | N/A |
| Latency | A=1s<br>B=5s | A=0.5s<br>B=3s | A=0.5s<br>B=2s |
| Energy efficiency | X=1 year | X=2 months | X=2 years |
| Repeatability | % | % | % |
| Interference robustness | % | % | % |
| Environment robustness | % | % | % |
| Mobility | % | % | % |
| Scalability | % | % | % |
| Set-up overhead | Time in men hours per area | Time in men hours per area | Time in men hours per number of gates |

| | | | |
|---|---|---|---|
| Technology | N/A | N/A | N/A |
| Financial cost | Hardware cost per room | Hardware cost per floor | Hardware cost per gate |

**Table 7. Parameters for the mapping functions**

### 2.3.3 Measurement processing

Further development of the benchmarking suite will give insight of

- how data is collected from the anchor point
- how data is stored and which servers are required
- how the API looks like

Next it will describe the user interface which is currently under development for defining the scenario specific metrics and weights. More details will be available in D2.5 (work in progress).

Finally, the SUTs will be ranked and tell the user the best solution for the specific use case.

In our validation process, these results will be carefully analyzed and compared with the result of the mockup.

# 3 Underground Mine Application Domain

## 3.1 Validation use case scenarios descriptions

This section describes the use cases on which a scenario will be mapped for the validation in an underground mine setting.

### 3.1.1 Selection of use cases and corresponding scenarios

Two use cases have been defined in D2.1 according to a previous analysis on application specific requirements. These tests comprehend personnel and machinery localization with four trials that are useful for evaluating metrics that are relevant for the system under test.

Some of these tests represent real life situations where the system should prove to be stable and provide accurate data within some predefined ranges. The main criteria for the selection of these use cases lies in the provision of data that enables the application provider to establish metrics and get conclusions of the system deployed over performance indicators such as energy efficiency, deployment time/cost, latency, accuracy, etc.

The following trials have been selected from the generic use cases:

1. Personnel tracking: Personnel are tracked and traced from the entrance to their destination.
2. Machinery tracking: Machinery is tracked and traced from the entrance to their destination
3. Air quality monitoring and personnel location: An alarm is triggered when certain levels of toxic gases are reached. Personnel are evacuated and traced.
4. Air quality monitoring and machinery location: An alarm is triggered when certain levels of toxic gases are reached and machinery is approaching that area.

#### 3.1.1.1 Application driven use cases

The following tests are derived straight from use cases defined above:

- A single worker/machine will be indicated to go through a predefined route marked in the mine's ground and stop in specific spots where measurements will be compared with the actual position.
- A single worker/machine will be indicated to go through a predefined route marked on the mine's ground without stopping so the route shown in the application can be compared with the actual marked one.
- Many workers will be measured and identified according position. No route will be indicated so the main result expected is location matched with ID.
- An emergency rehearsal will be done in order to prove system's accuracy and response:
    - In the personnel case, many workers will be sent an alarm through the mine's system when they reach a certain predefined area and all will be evacuated. The system should show all workers' positions and let the operator know when all workers have been evacuated
    - In the machinery case, a single worker will be evacuated and two cases will be defined with different alarm levels (high/low risks). When the machine reaches a certain area, the worker will be sent a low risk alarm and the application will show how much time the evacuation lasts. In the other case the worker will be notified with a high risk alarm and indicated to leave with a higher speed.

### 3.1.2 List of localization solutions

In a first phase, the provided solutions will be limited to the existing list available in the EVARILOS consortium. In summary, the following types of algorithms are available:

- Fingerprinting algorithm based on RSSI measurements
- Weighted RSSI and proximity
- Particle filter based on Time of Flight measurements
- Relative position discovery algorithm

Recall (three step validation approach) that all solutions will be compared using the benchmarking topology in a mockup, the best candidates will be evaluated in the field.

### 3.1.3 Description of the environment of the test site

#### 3.1.3.1 Building specifications

Location

The site selected for testing is called "*El Brillador".* It is a copper mine located 20 km north of La Serena, Chile, 600 m above sea level, in the "*Cerro Brillador*". It has underground and surface work, including the first 5,000 m of tunnels, shafts, chimneys, etc.

**Figure 8. Mine location: Coordinates: -29.814715585983162,-71.19436740875244**

Test site Plans

Tests in the mine will be performed near the entrance. A 100 portion of a straight tunnel was selected for the initial measurements. The following figure shows the site's plan and the test site inside the red area.

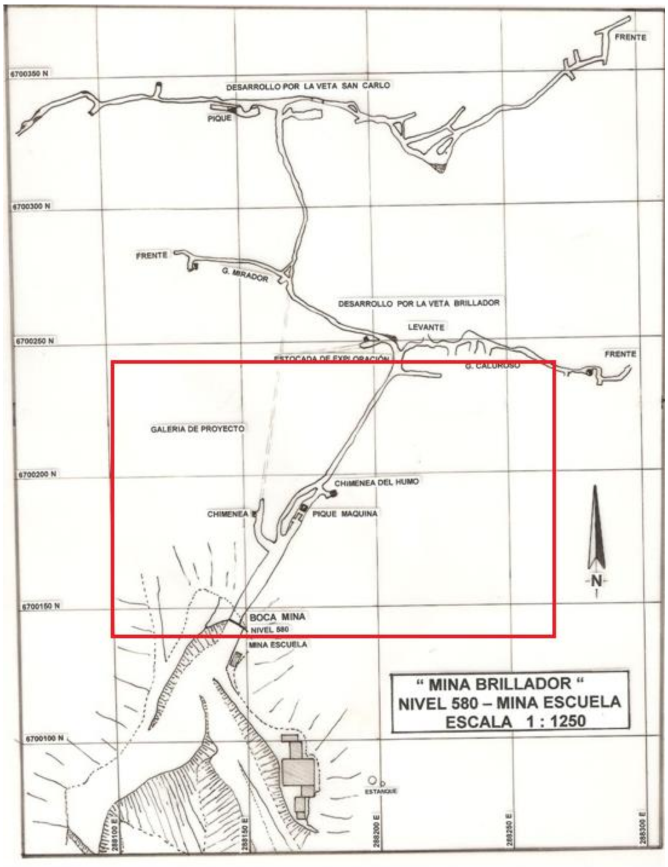


**Figure 9. Mine's plans and test site marked red**

<u>Open Space classification</u>

| | Medium |
|---|---|
| PARAMETER | |
| Number of rooms | 1 |
| Minimum area (m2) | 100 |
| Maximum area (m2) | 2000 |

**Table 8. Space specification**

#### 3.1.3.2 Interference specifications

| Type of interference source | |
|---|---|
| **Microwave** | NO |
| **Wi-Fi** | YES |
| **DECT** | YES |
| **Bluetooth** | NO |
| **3G** | YES |
| **Zigbee** | NO |

**Table 9. Interference specifications. Sources**

Interference sources parameters will be specified once initial measurements are planned. Some of the sources number will be variable and some could not be present at the time when performing tests. These parameters include number of sources, power, waveform, traffic model, etc. Moreover, it will also be necessary to include environmental parameters that affect wave propagation.

## 3.2 Methodology of the validation process

### 3.2.1 Validation approach

One of the objectives of this project is to study the impact of RF interference occurring in localization applications using wireless sensing systems for tracking (people, objects, etc.) and then improve the state of the art in terms of the robustness of tracking solutions.

As part of the activities undertaken in the project, an implementation of wireless sensing systems in real scenarios shall be done, and in this particular case in a mining tunnel, so to validate the effectiveness of proposed communications systems through different metrics that account for the robustness and efficiency of the systems.

The validation of localization solutions will be carried out by varying technologies and settings. Therefore, different tests from 1 to n will be applied to each localization solution.

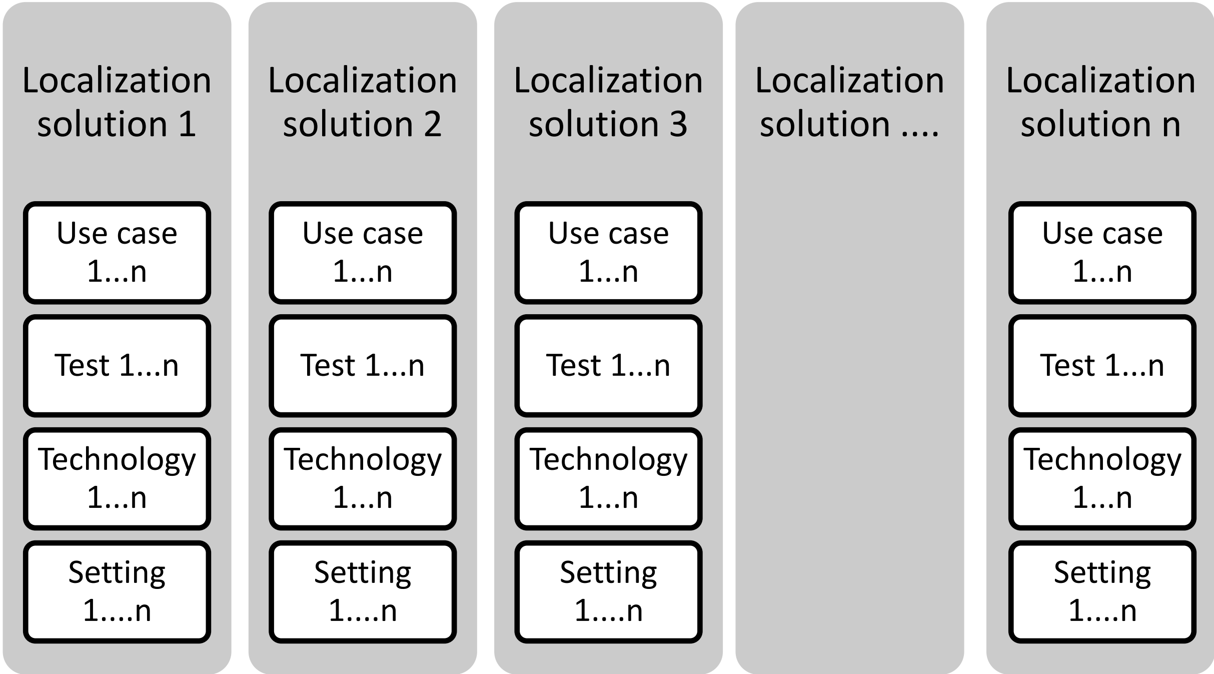


**Figure 10. Tests validation approach**

#### 3.2.1.1 Technologies description

The system will consist of a fixed infrastructure of devices placed on the walls of the underground mine in positions to be determined but in no case exceeding the size of a tunnel 100 meters long. These must have connection to the grid and will be responsible for locating objects and people inside the tunnel. Furthermore, mobile devices will be provided which must be carried by people or equipment in order to be located as accurately as possible.

The rationale for the selection of the different nodes is strictly related with their features. The most important deployment and performance related parameters for the different settings are transmission capabilities, energy efficiency, costs and deployment easiness.

As for data, it will be sent stored and analyzed in a local PC or laptop where the testing software application will be running interacting with different localization solutions.

**Static and mobile nodes description**

**Static**

<u>CM3300</u>

The CM3300 mote is IEEE 802.15.4 compliant wireless sensor node based on the original open-source "TelosB" platform design developed and published by the University of California, Berkeley ("UC Berkeley"). The mote has the following general characteristics:

- IEEE 802.15.4 WSN platform
- TI MSP430 Processor, CC2420 RF with additional power amplifier & LNA
- TinyOS 2.x & ContikiOS Compatible
- User & Reset Buttons
- 3xLeds
- 2xAA Battery Holder
- SMA Antenna
- 51-pin connector
- DC Input
- Included DC Power Supply

The CM3300 has a Molex® connector compatible with WSN Interface boards. The 51-pin connector also adds a lot of versatility to this product as it is attachable to all the WSN Sensor family of sensor boards, and the SMA design greatly increases coverage area through the use of a more powerful antenna. The CM3300 has an additional power amplifier and LNA in the radio chip to further increase transmission power. Due to this increased radio power, the CM3300 has a DC input as it is normally used as repeater or root node in normal network topologies, rather than with batteries.

**Figure 11. CM3300**

CM4000

The CM4000 mote is IEEE 802.15.4 compliant wireless sensor node based on the original open-source "TelosB" platform design developed and published by the University of California, Berkeley (“UC Berkeley”). The mote has the following general characteristics:

- IEEE 802.15.4 WSN platform
- TI MSP430 Processor, CC2420 RF
- TinyOS 2.x & ContikiOS Compatible
- User & Reset Buttons
- 3xLeds
- 2xAA Battery Holder
- PCB Antenna
- 51-pin connector

The reduced size format of this mote makes it especially suitable for compact designs, as it does not have USB interface or SMA antenna. The 51-pin connector adds a lot of versatility to this product as it is compatible with all the WSN Sensor family of sensor boards.

**Figure 12. CM4000**

CM3000

The CM3000 mote is IEEE 802.15.4 compliant wireless sensor node based on the original open-source "TelosB" platform design developed and published by the University of California, Berkeley (“UC Berkeley”). The mote has the following general characteristics:

- IEEE 802.15.4 WSN platform
- TI MSP430 Processor, CC2420 RF
- TinyOS 2.x & ContikiOS Compatible
- User & Reset Buttons
- 3xLeds
- 2xAA Battery Holder
- SMA Antenna
- 51-pin connector

The CM3000 presents a compact design in which the traditional USB connector has been replaced with a Molex® connector compatible with WSN Interface boards. The 51-pin connector also adds a lot of versatility to this product as it is attachable to all the WSN Sensor family of sensor boards, and the SMA design greatly increases coverage area through the use of a more powerful antenna.

**Figure 13. CM3000**

XM1000

The XM1000 is the new generation of mote modules, based on "TelosB" technical specifications, with upgraded 116Kb-EEPROM and 8Kb-RAM and integrated Temperature, Humidity and Light sensors.

- IEEE 802.15.4 WSN mote fully compatible with TelosB platform
- TI MSP430F2618 Microcontroller, CC2420 RF
- TinyOS 2.x & ContikiOS Compatible
- Temperature, Humidity, Light sensors
- User & Reset Buttons
- 3xLeds
- USB Interface
- 2xAA Batteries included

**Figure 14. XM1000**

**Mobile**

CM5000

The CM5000 mote is IEEE 802.15.4 compliant wireless sensor node based on the original open-source "TelosB" platform design developed and published by the University of California, Berkeley ("UC Berkeley"). The mote has the following general characteristics:

- IEEE 802.15.4 WSN platform
- TI MSP430 Processor, CC2420 RF
- TinyOS 2.x & ContikiOS Compatible
- Temperature, Humidity, Light sensors
- User & Reset Buttons
- 3xLeds
- USB Interface
- 2xAA Battery Holder

This product is especially suitable not only as cots environmental wireless sensor node, but also as a very useful research platform for developers, as it includes in the same hardware module all the needed functionalities: sensor readings, processor power and wireless communication potential.

**Figure 15. CM5000**

**Sensor Board**

The AR1000 is an attachable sensor board that is compatible with all the CMXXXX series of WSN Motes that have the 51-pin connector. It includes the following sensors:

- CO
- CO2
- Dust

AR1000's main field of application is environment monitoring, as it can give real time information on the dust concentration and gases concentration due to CO level as well as CO2. The AR1000 can be useful in environment monitoring applications, where the air quality and the pollutants concentration have to be analysed.

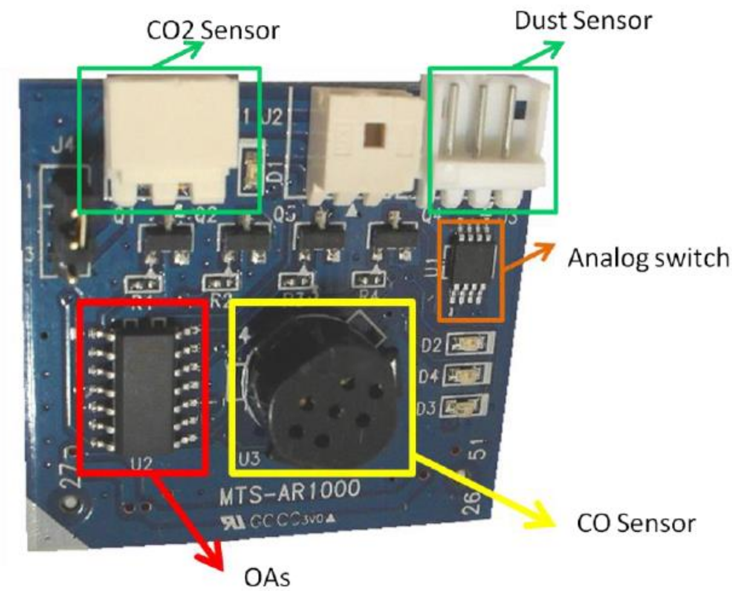


**Figure 16. AR1000 Sensor Board**

**Features**

| | Antenna(PCB, external) | Static(S)/Mobile (M) | Consumption | Deployment easiness. Difficult(D)/Medium(M)/Easy(E)* | Cost (€) |
|---|---|---|---|---|---|
| **CM5000** | PCB | M | ~25mA | E | 77 |
| **CM30** | External | S | ~25mA | E | 71 |

| | | | | | |
|---|---|---|---|---|---|
| **00** | 5dBi Dipole Antenna | | | | |
| **CM3300** | External 5 dBi Dipole Antenna | S | ~120mA | M | 95 |
| **CM4000** | PCB | S | ~25mA | E | 71 |
| **XM1000** | PCB | S | ~25mA | D | 85 |

**Table 10. Nodes features. Technology Underground Mine**

***Deployment easiness is evaluated according to installation possibilities regarding ON/OFF switch availability in nodes and battery or DC power dependent**

### Software application

### Initial measurements

The software application for the initial measurements will be the Trident application that allows the configuration of an experiment as a series of tests, each characterized by a set of parameters.[7]

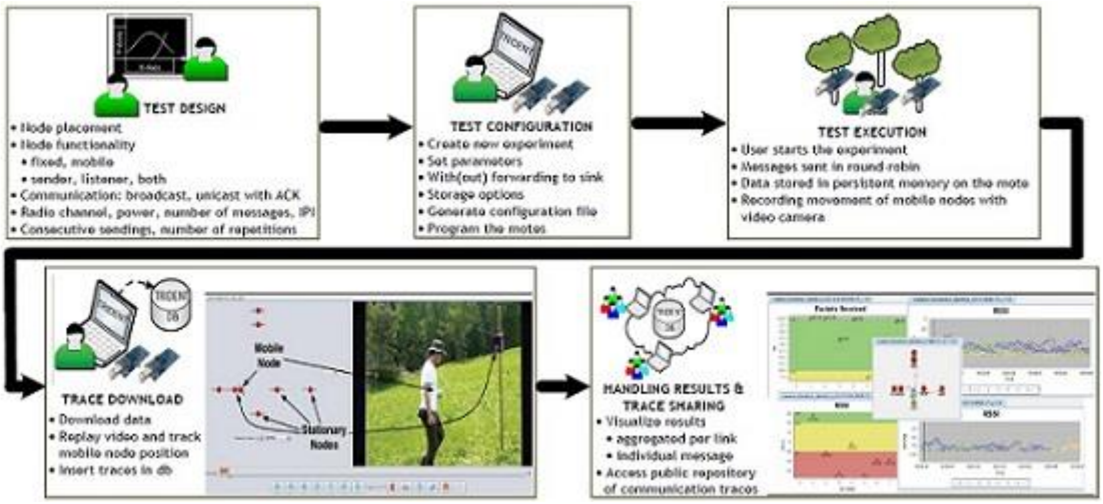


**Figure 17. Trident Software for testing**

### Application specific tests

The software application will be physically installed in a PC locally for the operator. This application will be similar than Trident but will show the operator a picture of the environment, its dimensions and moving objects will be displayed as moving dots on top of the tunnel. Thus, it will also show dots' actual position and will provide means to identify objects and define goals and areas for performing tests.

[7] http://wirelesstrident.sourceforge.net/index.html

The most important aspect of the testing application is the implementation of localization solutions. Whether they are locally implemented or accessed through web services can have a considerable impact on latency metrics. In case they are deployed over web services we should consider we should have Internet access on site and of course latency they would introduce.

| Technology | Total Latency | Total Packets | Total data transferred in bytes |
|---|---|---|---|
| WS | 0.11s | 16 | 3338 |
| CORBA | 0.48s | 8 | 1111 |
| CORBA & name server | 0.86s | 24 | 3340 |
| Java RMI | 0.32s | 48 | 7670 |

**Figure 18. Distributed systems technologies comparison. Web Services latency[8]**

Another major aspect for the implementation of the application is the API specification for obtaining localization information from the different solutions. These libraries or web services specifications will be defined in D2.5.

### 3.2.2 Validation plan and measurement point specification

**Initial Measurements**

The initial measurements will be performed in order to obtain interference and propagation patterns inside the mine so this scenario can be reproduced in test beds and localization solutions be selected for this application. The proposed setting for the preliminary tests is defined in the following figure. Test design tables established will serve to define how measurements will be taken and stored during preliminary measurements.

The initial test figure shows the setting for the initial deployment in the mine. There are two pictures in the figure. The first one provides a longitudinal view of the tunnel where the blue circles represent wireless nodes. As it can be seen the test site is a 100 meters straight tunnel and 5 meters width. The second one represents a section of the tunnel which is 3 meters high and of course, as indicated in the first figure, it has a 5 meters width. Nodes will be places 10 meters from each other along the tunnel and 2 meters above the floor as the second picture shows. They will also be faced in parallel 5 meters from each other.

[8] http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.69.2475&rep=rep1&type=pdf

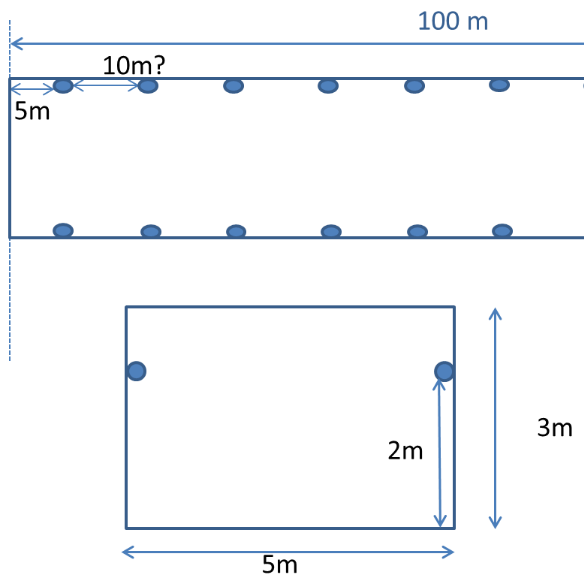


**Figure 19. Initial test setting**

<u>Measurements</u>

For the propagation measurements, the test setting will be similar to what is expected in the real scenario and measurements will gather data on RSSI, PRR (Packet Reception Rate), and LQI, for different settings of TX-power.

For the interference measurements, there will be a similar setup and also other equipment that generates the interference (802.15.4, 802.11, or other). Measurements will gather the same parameters than in the propagation test (RSSI, PRR, LQI). The interferers should transmit either a continuous carrier wave, or a continuous stream of random symbols.

<u>Technology</u>

| Technology | Max no. | Battery | DC input | OS | Antenna | Fixed/Mobile |
|---|---|---|---|---|---|---|
| **CM5000** | 20 | Yes | No | TinyOS | PCB | Fixed |
| **CM5000-SMA** | 20 | Yes | No | TinyOS | Omni 5dBi | Fixed |

**Table 11. Nodes for initial tests**

<u>Test design options</u>

| **Nodes functionality (fixed/mobile, sender/listener/both)** | Brief description |
|---|---|
| **Communication (broadcast, unicast with ACK)** | Choose a communication mode |
| **Radio channel** | Choose channel. Not to interfere with Wi-Fi channel in the mine in |

| | |
|---|---|
| | case a temporary network is operative. |
| **Number of messages** | Establish number of messages |
| **Consecutive sendings** | Enter a representative number |
| **Number of repetitions** | Enter a representative number |
| **Radio Tx Power** | Enter a value for CC2420 radio transceiver |

**Table 12. Initial test design options**

Test configuration parameters (according to Trident testing software)

| **Forward message to sink** | Choose option: Yes/No |
|---|---|
| **Messages** | Format |
| **Interference parameters** | Which parameters should be recorded |
| **Propagation parameters** | Which parameters should be recorded |

**Table 13. Initial tests config. parameters**

### Use Cases & Measurement Points Specifications

The following tests have been extracted from use cases selected in D2.1.

| **Use case name** | **Object tracking. Single spots measurements** |
|---|---|
| **Brief description** | This use case is one simple localization situation where an object/person is located inside the mine in different positions. |
| **Flow of events** | While the object is positioned in a certain point in the tunnel, the security operator queries for its position with the user interface. This experiment is repeated several times for a single spot and then switched to other positions within a predefined area in the tunnel. |
| **Basic flow** | The position where the object is encountered is shown in the user interface and the operator confirms the measurement. |
| **Alternative flow** | The object's position does not appear in the user interface or it is outside the graphs boundaries. The error is too high and therefore the operator discards the measurement.<br>The position shown is close to the actual one. The operator confirms the measurement and registers the error |
| **Special requirements** | Security requirements compliant with underground mine standards for accessing the mine should be met. Therefore, required equipment and clothes will be necessary.<br>Installations should also be compliant with security standards. Cables and electronics housing will have to be compatible with standards.<br>The user interface should be able to show the tunnel graph, a grid where several sections can be selected and classified, provide the possibility to start measurements, reset all parameters, confirm |

| | |
|---|---|
| | measurements and also show parameters values as room accuracy and latency. |
| **Preconditions** | -- |
| **Post conditions** | The system should be ready to take several measurements in several positions. This use case represents only one case of several measurements therefore the system should record all values and restart measurements for a different position. |
| Extension points | -- |

**Table 14. Use Case: Object tracking. Single spots measurements**

| **Point** | **Location Description** |
|---|---|
| **1** | Object location is 50 meters from the entrance of the test site, approx. 2.5 meters from each of both walls |
| **2** | Object location is 100 meters from the test area entrance 1m next to the wall |
| **3** | Object location is at the entrance of the test area 2.5 meters from both walls |

**Table 15. Measurement point specs. Object tracking. Single spots measurements**

| **Use case name** | **Object tracking. Path measurement** |
|---|---|
| **Brief description** | This use case represents an object tracking situation where the object follows a trace inside the mine and the route is shown to the operator. |
| **Flow of events** | While the object follows a trace, the user interface records a position every second and shows the trace to the operator. |
| **Basic flow** | The track the object follows is marked in the user interface. After finishing the operator should record all measurements and pictures showing the trace marked in the user interface |
| **Alternative flow** | The object's position does not appear in the user interface or it is outside the graphs boundaries. The error is too high and therefore the operator discards the measurement.<br>The track follows a different way or direction. The measurement is discarded.<br>The position shown is close to the actual one. The operator confirms the measurement and registers the error |
| **Special requirements** | Security requirements compliant with underground mine standards for accessing the mine should be met. Therefore, required equipment and clothes will be necessary.<br>Installations should also be compliant with security standards. Cables and electronics housing will have to be compatible with standards.<br>The user interface should be able to show the tunnel graph, a grid where several sections can be selected and classified, provide the possibility to start measurements, reset all parameters, confirm |

| | |
|---|---|
| | measurements and also show parameters values as room accuracy and latency.<br><br>The path will be shown as a printed trace in order to compare with the ground truth that will be shown in the same map but with a different color. |
| **Preconditions** | Start and end points should be marked in the tunnel along with a trace going from the start point to the end point. This trace should include cross areas localization and also go close to the walls and through the middle of the tunnel. |
| **Post conditions** | The system should be ready to take several measurements in several positions. This use case represents only one case of several measurements therefore the system should record all values and restart measurements for a different measurement. |
| **Extension points** | -- |

**Table 16. Use Case: Object tracking. Path measurement**

| Point | Location Description |
|---|---|
| **1** | 100 meters trail 1 meter away from the wall from the entrances to the end of the test site |
| **2** | 100 meters trail in the middle of the tunnel from the entrances to the end of the test site |
| **3** | 50 meters going from one wall to another turning every 10 meters. Then 50 meters next to the wall (1 meter) |

**Table 17. Measurement point specs. Object tracking. Path measurement**

| Use case name | Object tracking plus identification |
|---|---|
| **Brief description** | This use case represents an object tracking situation where several objects follows a trace inside the mine and the route plus their correspondent IDs are shown to the operator. |
| **Flow of events** | While many object are positioned at certain points in the tunnel, the security operator queries for their position and corresponding ID with the user interface. This experiment is repeated several times for single spots and then switched to other positions within a predefined area in the tunnel. |
| **Basic flow** | The position where objects are encountered are shown in the user interface and the operator confirms the measurement. |
| **Alternative flow** | Objects' positions do not appear in the user interface or are outside the graphs boundaries. The error is too high and therefore the operator discards the measurement.<br><br>The track follows a different way or direction. The measurement is discarded.<br><br>The position shown is close to the actual one. The operator confirms the measurement and registers the error |

| | |
|---|---|
| **Special requirements** | Security requirements compliant with underground mine standards for accessing the mine should be met. Therefore, required equipment and clothes will be necessary.<br><br>Installations should also be compliant with security standards. Cables and electronics housing will have to be compatible with standards.<br><br>The user interface should be able to show the tunnel graph, a grid where several sections can be selected and classified, provide the possibility to start measurements, reset all parameters, confirm measurements and also show parameters values as room accuracy and latency. |
| **Preconditions** | Start and end points should be marked in the tunnel along with a trace going from the start point to the end point. This trace should include cross areas localization and also go close to the walls and through the middle of the tunnel. |
| **Post conditions** | The system should be ready to take several measurements in several positions. This use case represents only one case of several measurements therefore the system should record all values and restart measurements for a different measurement. |
| **Extension points** | Emergency situation with several objects |

**Table 18. Use Case: Object tracking plus identification**

| Point | Location Description |
|---|---|
| **1** | 5 objects are positioned all together 1 meter from each other 20 meters from the entrance and 2 meters from one of the walls |
| **2** | 5 objects are positioned in the nearest 50 meters areas from the entrance, 10 meters from each other forming a triangle facing the entrance |
| **3** | 5 objects are positioned in a line within the farthest 50 meters area from the entrance. They run towards the entrance and before entering the nearest 50 meters area two of them stop and the rest split and follow single paths independently. One path in the middle 2.5 meters from the walls, and the rest 1 meter from the wall. |

**Table 19. Measurement point specs. Object tracking plus identification**

| Use case name | Object tracking. Emergency situation |
|---|---|
| **Brief description** | This use case represents an emergency situation where an object moves at different speeds |
| **Flow of events** | The object is standing at a certain position in the mine, then it is directed towards the exit at high speed (approx. 20 km/h) |
| **Basic flow** | The operator queries for the object's path towards the exit. |

| | |
|---|---|
| **Alternative flow** | The object's position does not appear in the user interface or it is outside the graphs boundaries. The error is too high and therefore the operator discards the measurement.<br>The track follows a different way or direction. The measurement is discarded.<br>The position shown is close to the actual one. The operator confirms the measurement and registers the error |
| **Special requirements** | Security requirements compliant with underground mine standards for accessing the mine should be met. Therefore, required equipment and clothes will be necessary.<br>Installations should also be compliant with security standards. Cables and electronics housing will have to be compatible with standards.<br>The user interface should be able to show the tunnel graph, a grid where several sections can be selected and classified, provide the possibility to start measurements, reset all parameters, confirm measurements and also show parameters values as room accuracy and latency. |
| **Preconditions** | Start and end points should be marked in the tunnel along with a trace going from the start point to the end point. This trace should include cross areas localization and also go close to the walls and through the middle of the tunnel. |
| **Post conditions** | The system should be ready to take several measurements in several positions. This use case represents only one case of several measurements therefore the system should record all values and restart measurements for a different measurement. |
| **Extension points** | -- |

**Table 20. Use case: Object tracking. Emergency situation**

| Point | Location Description |
|---|---|
| **1** | The object is positioned in a line within the farthest 50 meters area from the entrance and runs towards it. The object follows a path marked between approx. 2.5 meters from both walls in the middle of the tunnel |
| **2** | The object is positioned in a line within the farthest 100 meters area from the entrance and runs towards it. The object follows a path marked approx. 1 meter from the wall. |
| **3** | The object is positioned in a line within the farthest 100 meters area from the entrance and runs towards it. The object follows a path marked approx. 1 meter from the wall. In the first 50 meters and then 50 meters going from one wall to another turning every 10 meters. |

**Table 21. Measurement point specs. Object tracking. Emergency situation**

### 3.2.3 Work plan

An overview of the whole plan is shown above in the form of tasks sequence. These dates were established for all the process until the end of the project. However, a specific plan will be established with the mine operator for those tests that will be carried out in the mine. These plans will be published in the next deliverable and will be made during tasks 1 and 2.

Plan overview

**Task 1 - Getting Data from the tunnel.**

Collection of information on rock composition, size of the mine and any other material (e.g., graphic) to allow tracking algorithms to calibrate

Duration: September 1 to October 31, 2013

**Task 2 - Design and implementation of the system**

Based on the data obtained in Task 1, the system will be designed and proceed to installation.

Duration: November 1 to November 30, 2013

**Task 3 - Monitoring system operation and maintenance.**

Begin with monitoring and maintenance tasks. Here's where trials will begin including initial measurements.

Duration: December 1, 2013 - May 31, 2014

**Task 4 - Getting results of the demonstration**

The results are analyzed in terms of location accuracy but also in terms of battery life and usability of the system.

Duration: 1 June to 30 June 2014.

## 3.3 Evaluation process

### 3.3.1 Metrics and weights

The following figure shows metrics selected from D2.1. These metrics must be extrapolated to the tests defined in the measurements point specification Section 3.2.2.

Performance metrics

| USE CASE | METRIC | SCORE |
|---|---|---|
| 1. Personnel location and $CO_2$, humidity and temperature measurements. | • Room accuracy (must be possible to know in which area of the shaft)<br>• Latency (can be critical to address alarm in time)<br>• Energy Efficiency of Mobile Nodes (not feasible to replace personnel batteries frequently)<br>• Energy Efficiency of Infrastructure Nodes (ideally, infrastructure nodes will be powered from the lighting system)<br>• Interference Robustness (Copper mine likely to produce interference)<br>• Environment Robustness (ideally, test in different humidity conditions)<br>• Mobility (the miners will normally move at reduced speed throughout the mine)<br>• Scalability (10 000 employees in the mine means that the system must scale consistently) | • High<br>• Very high<br>• High<br>• Low<br>• High<br>• Moderate<br>• Low<br>• High |
| 2. Machinery location | • Room accuracy (knowing which shaft is normally enough)<br>• Latency (unlikely that alarm will trigger a machine location sequence)<br>• Energy Efficiency of Mobile Nodes (possibility of powering mobile nodes from the machine will be explored)<br>• Energy Efficiency of Infrastructure Nodes (ideally, infrastructure nodes will be powered from the lighting system)<br>• Interference Robustness (Copper mine likely to produce interference)<br>• Environment Robustness (ideally, test in different humidity conditions)<br>• Mobility (the machines will normally move at reduced speed throughout the mine)<br>• Scalability (10 000 employees in the mine means that the system must scale consistently) | • Moderate<br>• Low<br>• Moderate<br>• Low<br>• High<br>• Moderate<br>• Low<br>• High |

**Figure 20. Metrics defined in the EVARILOS Benchmarking Handbook (D2.1)**

Deployment metrics

| METRIC | SCORE |
|---|---|
| 1. Maintenance: understood mainly as battery replacement in mobile nodes. Due to the amount of personnel and machinery in the mine, replacement of the batteries should be as spaced in time as technically possible. | |
| 2. Physical installation and configuration: installation of the infrastructure within the mine cannot result in too much manpower drawn away from their main work in the mine. | |

**Figure 21. Metrics from D2.1**

Metrics weights according tests defined and metrics weights factor

For defining a final score for these metrics it is necessary to establish a weight factor given the importance in tests carried out which are strictly related to the application in each specific domain. The criteria for the importance assignment were defined in D2.1 according to application requirements. In this case, the most important metrics are room accuracy and latency which are critical for any emergency situation and of course deployment and robustness metrics which have a direct influence in system's performance.

Weight Factors

These factors are numeric values corresponding to weights significance in use cases.

| **Factor** | **Value** |
|---|---|
| Very High | 0.3 |
| High | 0.2 |
| Moderate | 0.15 |
| Low | 0.1 |
| Very Low | 0.05 |

**Table 22. Weight Factors**

Classification of use cases and weights

A preliminary classification of desirable metrics and their importance in use cases is shown in the table below.

| **Use Case Reference** | **Test name** | **Metric** | **Weights** |
|---|---|---|---|
| **(1)(2)** | Object tracking. Single spots measurements | Room accuracy | High |
| | | Latency | Very high |
| | | Environment robustness | Moderate |
| **(1)(2)** | Object tracking. Path measurement | Room accuracy | High |
| | | Latency | Very High |
| | | Energy Efficiency of Mobile/Infrastructure nodes | Low |
| | | Mobility | Low |
| **(1)** | Object tracking plus identification | Room accuracy | High |
| | | Latency | Very High |
| | | Energy Efficiency of Mobile/Infrastructure nodes | Low |
| | | Interference robustness | High |
| | | Scalability | High |
| **(1)(2)** | Object tracking. Emergency situation | Mobility | Low |

| | | | |
|---|---|---|---|
| | | Latency | Very high |
| | | Interference robustness | High |
| | | Room accuracy | High |
| **(1)(2)** | All | Maintenance | High |
| **(1)(2)** | All | Physical installation and configuration | High |

**Table 23. Metrics weight and use cases. Underground Mine**

(1) Personnel location and CO2, humidity and temperature measurements

(2) Machinery location

Metrics

Finally, metrics' scores taken in each use case will be multiplied by the correspondent weight to finally get a feeling of how the system performs. Metrics' scores will be calculated using the mapping function defined in Section 2.3.2 on page 22.

| Metric | Object tracking. Single spots measurements | Object tracking. Path measurement | Object tracking plus identification | Object tracking. Emergency situation |
|---|---|---|---|---|
| Point accuracy | 0 | 0 | 0 | 0 |
| Space accuracy | 0.2 | 0.2 | 0.2 | 0.2 |
| Latency | 0.3 | 0.3 | 0.3 | 0.3 |
| Energy efficiency | 0 | 0.1 | 0.15 | 0.05 |
| Repeatability | 0 | 0 | 0 | 0 |
| Interference robustness | 0 | 0 | 0.2 | 0.2 |
| Environment robustness | 0 | 0 | 0 | 0 |
| Mobility | 0 | 0.1 | 0 | 0.1 |
| Scalability | 0 | 0 | 0.2 | 0 |

| | | | | |
|---|---|---|---|---|
| Set-up overhead | 0.2 | 0.2 | 0.2 | 0.2 |
| Technology | 0.2 | 0.2 | 0.2 | 0.2 |
| Financial cost | 0.2 | 0.2 | 0.2 | 0.2 |

**Table 24. Metrics and Numeric Weights for Each Use Case**

### 3.3.2 Measurement processing

Further development of the benchmarking suite will give insight of

- how data is collected from the anchor point
- how data is stored and which servers are required
- how the API looks like

Next it will describe the user interface which is currently under development for defining the scenario specific metrics and weights. More details will be available in D2.5[9].

Finally, the SUTs will be ranked and tell the user the best solution for the specific use case.

In our validation process, these results will be carefully analyzed and compared with the result of the mockup.

[9] http://www.evarilos.eu/deliverables.php

# 4 Conclusion

In this document, a generic three phase validation approach has been applied for Healthcare and Underground Mine application domains. This is part of the methodology to define representative scenarios that match real life use cases for benchmarking. As a result, we have created a detailed validation approach and action plan towards real life validation and deployment out of the benchmark approach.

The next step will be the implementation of the whole plan and reporting each step and continuously report feedback for WP3 and WP2. On short term the focus lies on the first on-site experiments corresponding to the first step of our validation approach. The following deliverable D4.2 will report on the measurements, their specifications and methodology employed. Furthermore, it will also report about the second stage of operations in both application domains in consecutive iterations.

As previously described, this document followed D2.1 structure. It has served well as a guide to describe the scenario, validation approach and methodology although some remarks can be extracted from this experience:

1. Specifications and guidelines about tests are necessary:
    a. how data is stored and which servers are required
    b. how the API looks like
2. For real-life validation, a detailed work plan is required. To obtain those details, a realistic emulation of the test is required which is covered by the proposed three step validation approach.
3. There should be a standard way to define use cases and also related trials as defined in tables in both application domains.
4. The quantification of metrics and mapping functions is an iterative process. Based on first experiments, it will be verified that they indeed are representative for the specific use case.