# A Sensor Network for the Indoor Localization

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## ABSTRACT

In a context of the evolution of localization based on the technological progress and the implementation of GNSS such as GPS or the European Galileo project to used in outdoor environment allowing accuracy of a few meters, but for an indoor environment, the signal is deteriorated due to the obstacles, so other techniques are used. This paper provides an overview of the indoor localization techniques. After presenting all the existing location technologies, I am going to introduce a new design based on the fusion of data from different sources.

**Keywords**— Indoor localization; fusion data; optimization algorithm; GNSS; RF localization

## 1.INTRODUCTION

Today, the need to obtain a position more precise within a short time at any point, is forcing us to use navigation systems efficient. They are constantly evolving to enhance the integrity, accuracy and availability for civil and military applications. Based on technological advances, many mobile applications have been developed and allow the delivery of personalized content depending on the geographic position of the user.

When we have to locate an object in outdoor environments, GNSS satellite systems (GPS, Galileo, ...) are used and provide a good accuracy, but we must be in an open environment where there is a line of sight with the satellites (at least four satellites), while in indoor environments (inside buildings), this constraint is no longer respected, which explains the deterioration of accuracy due to the signal degradation by the obstacles met in their paths. (TABLE I.).

**Table 1. Attenuation of Radio Signal (L1=1500mhz) after Passing through Different Materials used in Construction[1]**

| Material | dB |
|---|---|
| Dry Wall | 1 |
| Plywood | 1 – 3 |
| Glass | 1 – 4 |
| Painted Glass | 10 |
| Wood | 2 – 9 |
| Iron Mat | 2 – 11 |
| Roofing Tiles/ Bricks | 5 – 31 |
| Concrete | 12 – 43 |

## 2.GEOLOCATION TECHNIQUES IN INDOOR ENVIRONMENTS

### *A. Localization using Infrared techniques:*

The famous one in this category is the Active Badge system which is one of the first location systems developed by AT & T in 1992 [2]. This system was designed to allow the location of personnel in a company so as to transfer, automatically, calls to the nearest telephone to the person concerned. This system consists of two parts, a badge containing an infrared transmitter worn by the user, and a network of receivers installed in the ceiling in the rooms of the building (Figure 1). These receptors are linked together to form a network which will be able to detect the active badge. Each badge emits a Tag with a unique code during one-tenth of a second every 15 seconds, to save energy, but also to allow localizing multiple badges and thus avoid the problems of interference. After receiving the signals, infrared sensors transmit them to a central server for processing information and determining the location of the person, so the calls will be directed at the right place and to the right person. [2]

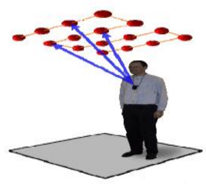


**Figure 1.Localization by infrared**

In this system, the possible positions are defined by the coordinates of infrared sensors installed. For use in small rooms, detection is easier because of the reflections in the room and the precision of this system is limited by the number and the distance between the infrared sensors. Also, the presence of sunlight is an obstacle for this technology because it disturbs the infrared transmission between the transmitter and receiver.

### *B. Localization using Ultrasound techniques:*

One of the characteristics of an ultrasonic signal is its propagation speed which is around 1.234 km/h, this facilitates the processing time of the signals exchanged between the transmitter and receiver. Moreover, as the infrared signals, ultrasonic signals do not penetrate the walls. This signal is used only for the location within a building or in a limited space because the signal range is relatively short, but the performance and location accuracy are very satisfactory (cm-level).

Most of these tracking systems are combined with another technology to obtain an estimation of the distance between the transmitter and receiver, the receiver successively receives an ultrasonic wave and a wave based on another technology (Radio Frequency). After a correlation of these two waves received, we extract the time difference of arrival, which allows estimating the distance between the receiver and the transmitter that issues these two signals. Among the systems based on this technique:

*1) The Active Bat System [3]:*

This system was developed in 1999 by AT & T, which allows a 3-D location and offers better accuracy than the one obtained by the Active Badge system. This system is based on a centralized architecture which consists of (Figure 2):

- Ultrasonic sensors placed at the ceiling of the room;
- Bat worn by the subject to locate and which includes an ultrasonic sensor and a radio receiver;
- A central server connected to the ultrasonic sensors.

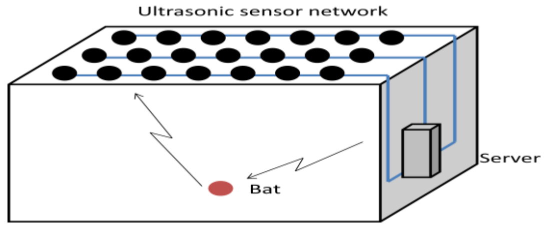



**Figure 2. Active Bat Architecture**

To detect a user, the server sends an RF signal to the mobile equipment (Bat), the Bat transmits a series of ultrasonic pulses. Then, every 200 ms, the server sends a radio message containing the identifier of the mobile to locate. The mobile equipments receive this message and decode it. The mobile that recognizes its address in the received message goes into transmit mode and sends an ultrasound message for 50 µs. Once the series of pulses emitted, the Bat returns to standby mode, and scans later the channel 195µs.

The server transmits two signals simultaneously, a RESET signal to ultrasonic receivers on the network, and RF signal intended for the Bats. From that moment, the receivers are trying to detect an ultrasonic signal in the next 20ms. Then, these receivers will calculate the time intervals between the RESET signal and the detection of the ultrasonic pulse sent by the Bat. This information is sent to the server who will determine the position of the Bat.

The Active Bat method is quite expensive which can be considered as a disadvantage.

*2) The Cricket system [4]:*

This system was developed by MIT laboratories, and is based on the same principles as the Active Bat system. The main difference between these two systems is that the system Cricket is based on a distributed architecture and processing are performed by mobile equipment. The Cricket system uses the TDOA of RF and ultrasound signals to measure Beacon-Listener distance accurately.

The design was driven by some specific goals: user privacy, decentralized administration, network heterogeneity (LAN, public telephone, Infrared), easy to deploy, and low cost (10$ US). The system provides particularly, an interference avoidance by two methods: (a) proper selection of system parameters to reduce the chance of false correlations, and (b) listener inference algorithms based on statistical analysis of correlated (RF, ultrasound) samples.

### C. Localization using RadioFrequency techniques:

Unlike ultrasonic and infrared signals, radio waves have the ability to penetrate walls which increases the coverage area, and minimizes the number of necessary equipment. The location systems based on Radio Frequency technologies use the received signal strength. These systems are limited by the complex nature of the radio signal but have they don't need the line of sight between the transmitter and receiver. Among the radio frequency tracking systems, we find:

*1) Localization by WLAN:*

The installation of WLAN in buildings presents a good opportunity for an indoor localization, because the information used in locating are available. This system consists of a set of mobile units connected to an access point forming a Basic Service Set (BSS) which is identified by a Basic Service Set Identifier (BSSI) corresponding to the MAC address of access point. These BSS are interconnected by a distribution system DS which can be a cable [5]. These tracking systems are based on RSSI (Received Signal Strength Information) contained in tags issued by either the mobile or the access point (Figure 3).

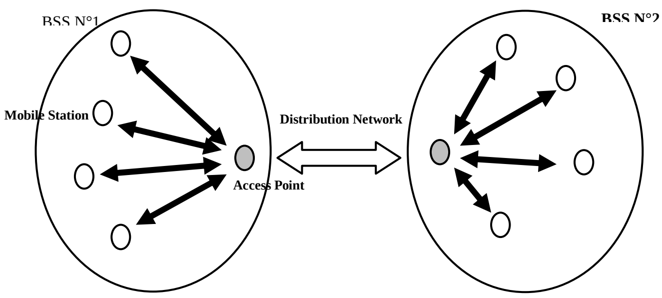



**Figure 3. WLAN Architecture**

We distinguish three methods of localization:

- Localization by the near access point: The mobile is located based on the position of the access point with the best signal. This method doesn't give a good accuracy because the coverage area of an access point is relatively large.

- Localization by attenuation: In their paths between the access point and the mobile, the signals suffer attenuation due to obstacles. The signal degradation is used to estimate the distance, but this method is unreliable because the margin of error is too large.
- Localization by fingerprinting: This technique involves two distinct phases:

**Offline phase:** The preliminary phase is to build a radio coverage map with storing the spatial distribution of power levels measured by a mobile from different access point. In indoor environments, the channel transmitter-receiver is disturbed by the presence of reflections, diffraction and multi paths, and signal strength is not easily predictable. For realistic radio coverage maps, the systems RF build a radio coverage map by measuring experimentally the signal strength of access points in a defined number of points. The coverage map obtained is stored in a database that lists the levels of signals received for each access point.

**Online phase:** The system measures the signal strength received by access points, and using the database created during the offline phase, we try to locate the point in the database for which we observe similar signals to those measured.

Nowadays, this method is most commonly used.

*2) Localization by RFID:*

Identification technology by radio frequency (RFID) was invented in 1948 by Henry Stockman. This system allows to write, store and read information in electronic label integrated in the objects to locate.

A RFID system consists of a microchip with an antenna (radio-tag), a reader (usually a transmitter) and a server connected to these readers. The Tag can be passive if the energy is obtained from the signals emitted by the RFID readers, or semi active if it has its own energy source allowing to record the information during a period of time (such as the passage close to fixed readers), or active Tag that includes also its own energy source and can emit at longer distances Km-level.

Once a receiving the signal transmitted by a reader, the tag transmits the information contained in memory, then the reader converts and transfers this information to the server who can provide the localization information of the Tag. For almost continuous coverage of the localization service, the environment must be equipped with a large amount of sensors. Despite the low cost of these sensors (passive or active), this becomes binding and costly, and will be an obstacle to the deployment of this technology.

Several systems based on RFID technology have been developed, among them the SpotOn system [6] achieved by the University of Washington, and the system Landmarc [7] proposed by the University of Hong Kong.

*3) Localization by Bluetooth:*

The operating principle of this technology is similar to the technique of WLAN or RFID because it is based on a network of terminals serving as access points, except the signal range of these terminals who is smaller, about ten meters. The Bluetooth network topology has the "Piconet" as basis element; this element follows star configuration: a master and several slaves. The master can manage up to 7 slave and 255 devices in idle mode. The master manages data transmission schedule of its slaves. The slaves can not communicate with each other and are synchronized to the clock and to the frequency of the master. The slave devices can have multiple masters. Different Piconets can be interconnected, thus, the network formed is called a "Scatternet" [8] (Figure 4). A device can act as a bridge while being a master in one Piconet and a slave in another and the data of localization can be provided over a scatternet by delivering messages from one piconet to another across the bridges between piconets. In the Bluetooth Core Specification, the devices can switch the roles, by agreement, and a slave can become a master.

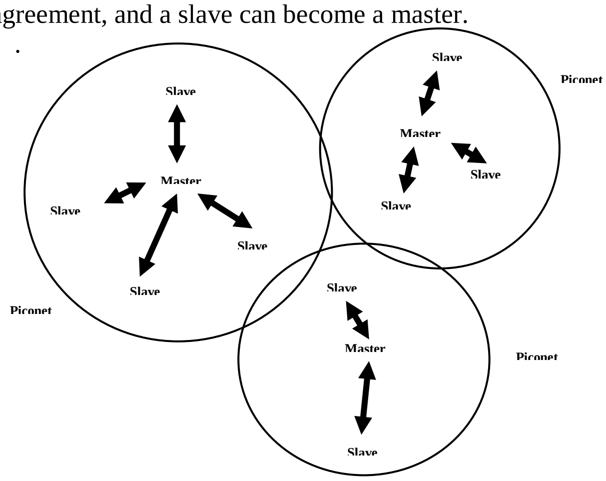



**Figure 4. Piconet architecture**

AeroScout has explored this technology before changing to a system using RFID systems based on WiFi network

*4) Localization by UWB:*

The UWB (Ultra Wide Band) Ultra Wide Band is a modulation technique that involves very short pulses of frequency modulated into position, amplitude or polarity in a frequency band of several GHz and a low spectral density (In general, any radio technology having a width of bandwidth exceeds 500 MHz or 20% of the center frequency can be considered as UWB. According to the U.S. regulatory [9] UWB is allowed in a frequency band [3.1 GHz - 10.6 GHz]).

The ratio of the bandwidth to the central frequency is much higher than in the ordinary modulations. This technique is perfectly adaptable to the applications of localization, and theoretically, with this type of modulation, it's possible to achieve accuracies of cm-level.

UWB-LDR (Low Data Rate) is based on the IEEE 802.15.4a standard; the notion of "localization" is a major issue (unlike the standard IEEE 802.15.3a UWB-HDR (High Data Rate), where it is an additional functionality).

The Ubisense system uses this technology and accuracy can reach 15 cm.

*5) Localization by ZigBee:*

This system is based on the IEEE 802.15.4 standard which is a communication protocol used in wireless personal (WPAN) because of their low power, low range and the low speed of their devices. This technology aims to provide a simple and a cheap solution.

ZigBee appeared after the Bluetooth and Wi-Fi to provide functionality that were not achieved with these two technologies. These specifications are available within the industrial community "ZigBee Alliance"[10], were ratified December 14, 2004 and in 2005, the community published the first official specification of ZigBee version 1.0. This version provides a flow rate and a range relatively low but with a high reliability and low power consumption (the nodes are designed to operate for several months (up to two years) in complete autonomy).

According to the IEEE 802.15.4 standard, three frequency bands are recommended: 868 MHz (868-868.6 MHz) 915 MHz (902-928 MHz) and 2.4 GHz (2.4 - 2.4385 GHz). The band most used, is centred on 2.4 GHz, the bit rate is 250 Kbits / sec, and the modulation type is Offset-Quadrature Phase Shift Keying (O-QPSK).

Regarding the localization, the standard provides an estimate of the location according to the received power; this information is used to determine the distance between the transmitter and receiver.

Multiple studies have been developed to judge the performance of this technology for indoor localization [11].

*D. Localization techniques by the infrastructure of cellular networks:*

These systems are also called mobile positioning system (MPS), they consist to determine the position of the mobile phone in the network. Unlike the GSM network, the localization features are included in the UMTS standard as proposed by the 3GPP group [12].
These techniques are based on the power measurements and antenna patterns. The simplest method is the identifier of the cell (Cell-id) where the mobile is located. In a rural area, the cells are large, and few base stations are deployed, making it difficult a precise location.

However, techniques such as E-CGI (Enhanced Cell Global Identity), E-OTD (Enhanced-Observed Time Difference) and U-TDOA (Uplink Time Difference of Arrival) are used for more precise localization [13].

*E. Satellite localization:*

In the Indoor environments, the GNSS (GPS for example) signal received decrease of 20-30 dB, making receivers work in a degraded or not working, that's why special receivers were designed to overcome this constraint.

*1) Assisted-GPS (A-GPS):*

The system A-GPS support the receivers to recognize witch GPS signal to follow, the TFF (Time to First Fix) is of the order of seconds. This system aims to improve the ratio signal to noise of the signals received by performing correlations on a longer time to have a higher correlation peak for low signal to noise ratio. The idea is to query a server that indicates the ephemeris and the visible satellites and their Doppler.

In A-GPS not only the satellites but also the terrestrial cellular network (GSM, UMTS …) are used to gain the position.

*2) High Sensibility-GPS (HSGPS)[14]:*

The technique known as high-sensitivity GPS was originally designed for Indoor localization. The receiver benefits from the high repetition of the C/A code centered on L1 to find an optimal report C/N0. The high sensitivity is obtained by increasing the acquisition time, providing more time tracking for the receivers.

The HS-GPS is used for applications not requiring centimeter accuracy as vehicular or pedestrian navigation.

*3) Localization by repeaters:*

The basic principle of a localization by repeaters is to make available, in the Indoor environment, the GPS signals through an amplification. Indeed, the solution is to transmit all signals received on an outside antenna into the building (Figure 5).

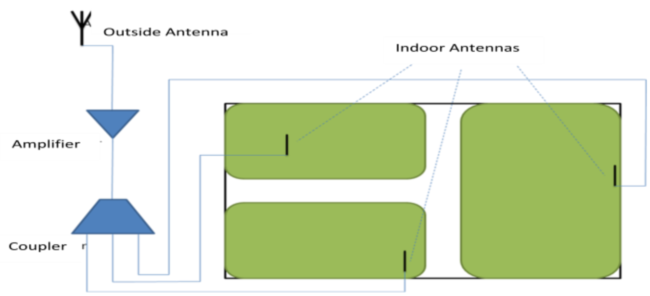



**Figure 5. Schematic of Location System based on Repeaters**

Thus, the propagation times actually measured by the receiver, do not give the Euclidean distance between the satellite and the receiver inside, but a summation of distances: that separating the satellite and the outside antenna, add the distance between indoor and outside antennas. Also, we should consider delays due to system deployed (amplifiers, couplers,…)

*F. Localization by inertial navigation system(INS):*

An inertial system is composed of the combination of sensors measuring the instantaneous acceleration (accelerometer), and others measuring the instantaneous speed of rotation (gyros) of the mobile.

The basic functioning of an inertial system is based on estimation, using the knowledge of the speed, direction and the previous position of the mobile; we can determine the current position. Over time, these estimates of position will be done at regular intervals. The Inertial localization system is often used in aviation and marine navigation [15].

It should be noted that, the major disadvantage of this technique is the cumulated errors of measurement made on the speed and direction. To reduce this imprecision, it is necessary to use sensors with low sensitivity to measure noise, or using the hybrid system such as GNSS/INS.

*G. Localization by navigation hybrid system:*

Hybrid navigation matches all types of navigation systems using two or more localizations techniques and could realize independently the estimation of the position (GNSS, GSM, WIFI, UWB, INS, …), and to get results more accurate and robust.

Many studies have been done in this area to combine different systems: WIFI/UWB, WIFI/INS, GNSS/INS and GNSS/GSM, GNSS/GSM/WIFI.

Each method has advantages and limitations that are not the same. According to a research conducted in this field, the comparison results are shown in TABLE II.

**Table 2. Comparison Between Various Localization System**

| System | Accuracy | Range | Signal | Cost |
|---|---|---|---|---|
| GPS | 1-5m | Outdoor | RF | High |
| Active Badge | 7cm | 5m | Infrared | Moderate |
| Active Bat | 9cm | 50m | Ultrasound | Moderate |
| Cricket | 2cm | 10m | Ultrasound | Low |
| Dolphin | 2cm | Room | Ultrasound | Moderate |
| UWB | 10cm | 15m | RF | Moderate |
| SpotOn | 3m | Room | RF | Moderate |
| LANDMARC | 1-2m | 50m | RF | Moderate |
| INS/RFID | 2m | Indoor | RF | Moderate |

The hybrid system's performances are a promising area of research which I intend to develop later, a localization system with a positioning accuracy approaching the results obtained in the outdoor environment, and ensure the continuity of "localization" functionality, by proposing a new design of hybrid system (Localization Information Fusion System), this in two steps, first by studying a system using two different technologies, initially we focus on RF and UWB, for results validation with the theoretical study, and second we generate it for a multiple technologies system Figure 6&7.

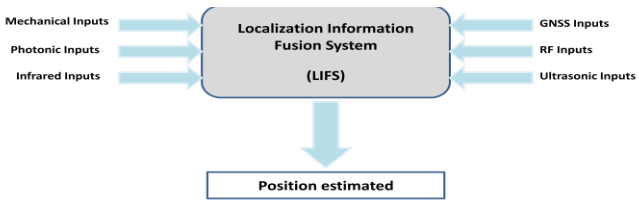



**Figure 6. Synoptic Diagram Of The System Proposed (LIFS)**

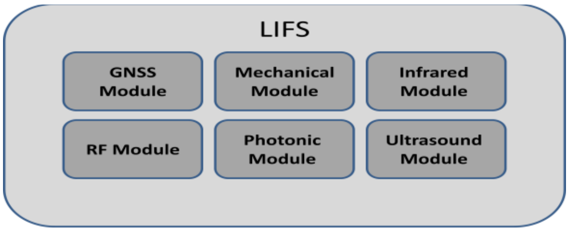



**Figure 7. Block Diagram of the System Proposed**

The hybrid system RF/UWB proposed is composed by receivers Ri, the mobile M to locate and a server to process data coming from the sensors installed. We discuss later, the system consisting by two stationary receivers R1 and R2 placed at points whose coordinates $R1(X_{R1},Y_{R1})$ and $R2(X_{R2},Y_{R2})$ are known in advance. These receptors can be similar (using the same technology UWB/ RF), as they can be in different nature.

Before implementing this system, a theoretical study based on a geometric approach is necessary. We consider that the received signal was reflected once on the walls or the existent obstacles, and we will assume that the sensor receives two signals Figure 8. The idea is to reconstruct the paths made by the four signals. It is necessary to know the coordinates of reflection points with the environment $A(X_A, Y_A)$, $B(X_B, Y_B)$, $C(X_C, Y_C)$ and $D(X_D, Y_D)$. This leads to a problem with 10 unknowns, requiring to be solved at least 10 independent equations.

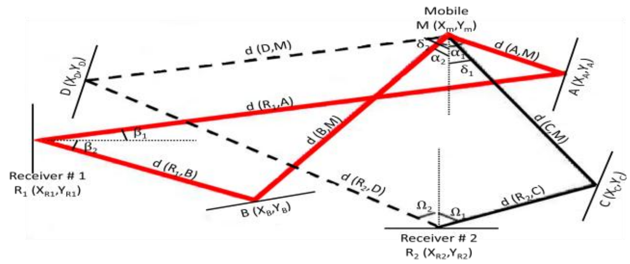



**Figure 8. Geometrical Configuration Overview**

Seen the speed of Mobile is negligible compared to the speed of data acquisition, we can consider that the emission point remains fixed for the duration of measures, and estimation of angles will not be affected. We obtain the following system of equations to minimize:

$$F_1 = | X_A – X_{R1} | - d(R_1,A) \cos \beta_1 \quad (1)$$
$$F_2 = | X_B – X_{R1} | - d(R_1,B) \cos \beta_2 \quad (2)$$
$$F_3 = | X_C – X_{R2} | - d(R_2,C) \cos \Omega_1 \quad (3)$$
$$F_4 = | X_D – X_{R2} | - d(R_2,D) \cos \Omega_2 \quad (4)$$

$$F_5= [d(R_1,B) + d(B,M)] – [d(R_1,A) + d(A,M)] – c(\tau_B–\tau_A) \quad (5)$$

$$F_6= [d(R_2,C) + d(C,M)] – [d(R_1,A) + d(A,M)] – c(\tau_C–\tau_A) \quad (6)$$

$$F_7= [d(R_2,D) + d(D,M)] – [d(R_1,A) + d(A,M)] – c(\tau_D–\tau_A) \quad (7)$$

$$F_8= [d(R_2,C) + d(C,M)] – [d(R_1,B) + d(B,M)] – c(\tau_C–\tau_B) \quad (8)$$

$$F_9= [d(R_2,D) + d(D,M)] – [d(R_1,B) + d(B,M)] – c(\tau_D–\tau_B) \quad (9)$$

$$F_{10}= [d(R_2,D) + d(D,M)] – [d(R_1,B) + d(B,M)] – c(\tau_D–\tau_C) \quad (10)$$

$$F_{11}= (X_A – X_M)(X_B – X_M) + (Y_A – Y_M)(Y_B – Y_M) + d(M,A)d(M,B)\cos(\delta_1-\delta_2) \quad (11)$$

$$F_{12}= (X_A – X_M)(X_C – X_M) + (Y_A – Y_M)(Y_C – Y_M) + d(M,A)d(M,C) \cos(\delta_1-\alpha_1 ) \quad (12)$$

$$F_{13}= (X_A – X_M)(X_D – X_M) + (Y_A – Y_M)(Y_D – Y_M) + d(M,A)d(M,D)\cos(\delta_1-\alpha_2 ) \quad (13)$$

$$F_{14}= (X_B – X_M)(X_C – X_M) + (Y_B – Y_M)(Y_C – Y_M) + d(M,B)d(M,C)\cos(\delta_2-\alpha_1 ) \quad (14)$$

$$F_{15}= (X_B – X_M)(X_D – X_M) + (Y_B – Y_M)(Y_D – Y_M) + d(M,B)d(M,D)\cos(\delta_2-\alpha_2 ) \quad (15)$$

$$F_{16}= (X_C – X_M)(X_D – X_M) + (Y_C – Y_M)(Y_D – Y_M) + d(M,C)d(M,D)\cos(\alpha_1-\alpha_2 ) \quad (16)$$

$$F_{17}= (X_A – X_{R1})(X_B – X_{R1}) + (Y_A – Y_{R1})(Y_B – Y_{R1}) + d(R1,A)d(R1,B)\cos(\beta_1-\beta_2 ) \quad (17)$$

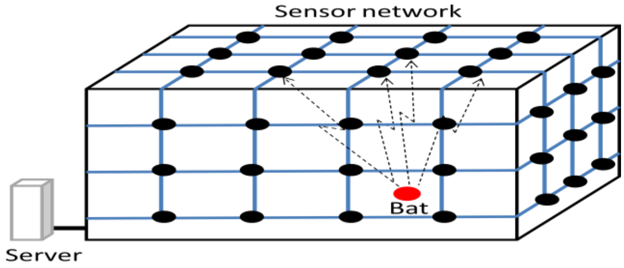
$$F_{18}= (X_C – X_{R2})(X_D – X_{R2}) + (Y_C – Y_{R2})(Y_D – Y_{R2}) + d(R2,C)d(R2,D)\cos(\Omega_1-\Omega_2 ) \quad (18)$$

Solving the nonlinear equations system is done using the research methods of the minimum through a numerical resolution by the method ***fmincon*** of the ***Optimization Toolbox Matlab***.

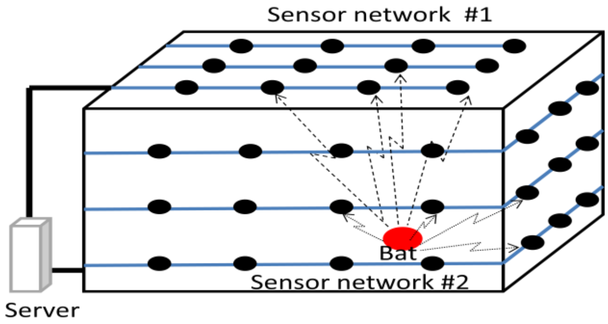
## 3.RESULTS VALIDATION

We place the sensors on the roof and the walls of the room, we study and compare the results of the two situations, first where the roof sensors are connected with those of the walls, and second where both sensor networks are separated.

**Scenario N1: High Mesh Network**




**Scenario N2: Partial Mesh Network**




We define an error objective function ε(x,y,z)

$$\varepsilon(x,y,z) = \sqrt{(x - xi)^2 + (y - yi)^2 + (z - zi)^2} \quad (19)$$

With:

$$\begin{cases} (x,y,z) \text{ the real coordinates} \\ (xi,yi,zi) \text{ the estimated coordinates} \end{cases}$$

## 4.CONCLUSION

After this theoretical study, the next step will be the validation of this result, and generate this model to a multiple technologies system.

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