Accurate 3D Localization Scheme Based on Active RFID Tags for Indoor Environment

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***Abstract*—In last decade, indoor localization of target objects has been intensively studied. In particular, schemes that use RFID tags for precise localization of sensor nodes have received more interests. 3D localization based on RFID tags in indoor environments has not been enough studied. In this paper and at the attempt of contributing in this topic, we propose an approach based on MDS for 3D localization using active RFID tags in indoor environments. The considered system is a centralized scheme that involves a server, readers and tags. The propagation model used to estimate the received power considers the path loss and shadowing effects. To show the accuracy of the proposed scheme, a selection of numerical results is used.**

I. Introduction

Indoor and outdoor localization of target objects, as sensor nodes, has been widely studied in the literature. The information of localization is required for many applications to operate, as the tracking and security applications. In the case of outdoor environments, satellite based localization, as Global Positioning System (GPS), is often used to locate persons and equipments. However, this technique is not adequate for indoor localization since the required line of sight links are not available.

Many existing techniques for wireless indoor localization are based on radio frequency (RF) signals as WLAN standards (IEEE 802.11); or ultrasound signals [1]. Ultrasound based techniques suffer from many problems, as their limited transmission range. Wireless Local Area Network (WLAN) localization systems require that target objects have to be equipped with WLAN RF components.

Localization systems based on Radio Frequency IDentification (RFID) tags are known by their attractive accuracy, low to moderate costs, and possibility of reading through obstacles, etc [2]. Indeed, in the objective of enhancing the accuracy, cost reduction and evolutionary, several techniques have been proposed. Typical used components, for 2D and 3D localization systems, are a server, readers and active or passive tags. The localization can be obtained by two ways: locating the target object by its attached tag; or the tag of the target object can read its coordination from readers with known coordination around it. The first way is a centralized localization technique however the second one is a distributed-scalable procedure.

Recently, indoor 3D-localisation techniques have received some interests in the literature. In [3], a fault-tolerant based passive RFID reader localization approach is proposed for 3D localization in indoor environment. This study can be extended to the case of active RFID tags. Thus, in this paper we are interested by 3D based active tags localization techniques for indoor environments. The considered system involves active tags, readers and a server. The aim of our proposed approach is to locate a number of tags simultaneously with less number of pre-deployed readers having known coordination. The proposed work is different from that of [3] and provides better accuracy than the known range-free 3-D localization approach [4].

The remainder of this paper is organized as follows: In Section II, we propose a look over existing RFID based tags localization schemes. We present the system model in Section III. In Section IV, we illustrate the main steps of the proposed localization scheme. Simulation results are discussed in Section V. Finally, conclusion and future work are given in Section VI.

II. Overview on existing RFID localization schemes

Several indoor localization algorithms for RFID systems have been proposed in the literature. In this section, we present a brief survey on known localization techniques which can be classified into two categories: 2D localization [5][6] and 3D localization methods [7][8]. 2D localization consists of determining the position of objects scattered in a planar area where readers are deployed. According to the well known 2D algorithm is Multilateration [9], the position is estimated as the intersection of three circles which approximate the communication ranges of readers. This type of localization algorithms is not effective for many tracking applications.

3D localization methods are proposed to find the positions of targets placed in 3D space. These positions can be seen as random distributions according to the three space axes (x,y,z) and independent of reader positions. SpotON [10] is known to be among the first RFID based 3D-localization schemes. In a first step, this scheme uses personalized targets and accumulation algorithm based on analysis of signal strength to estimate inter-target distances. Then, classic laterations are applied to find the position of a given target. The obtained localization precision and accuracy remain weak, for a high cost in the processing required at the server to calculate the coordination. Instead of deployment of personalized targets, the approach of [11] compute the coordination by associating

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each target to a reader in a given sub-region. This technique has a main drawback: the fluctuation of signals, due to propagation environment, affects the computed distances accuracy; afterward it is difficult to associate the target with a reader. Localization identification based on dynamic Active Rfid Calibration (LANDMARC) technique is proposed as a solution to this problem. LANDMARC consists of deploying reference tags in the area. The position of a given target is the middle point of the K closest reference points of the target localized object. The advantages of this scheme are reducing the number of expensive readers and replace them by cheaper reference tags. Nevertheless, the huge number of reference tags can cause signal interferences that could be a serious problem since, they affect the accuracy of estimated signal strengths. An improvement of LANDMARK is proposed in [12] by decreasing the candidate number of reference tags to find the neighbors of the target. If these algorithms have used active targets, other techniques are proposed for passive RFID targets. The scheme given in [13] is based on polar localization, where UHF anchors and targets supply only the presence information in an angular sector. Each antenna recovers the area by the rotation and collects target identities in its reading range. The angular section is explored by varying the transmission power. Hence, the precision of this approach relies upon the number of deployed anchors.

Recently, other 3D localization methods are proposed. APM [14] is a 3D localization approach for passive tags. In fact, this algorithm approximates the communication range of readers assumed to be a sphere. The major limit of APM algorithm is that invalid solutions can be observed in the cases of non-intersection spheres. The problem of signal coverage area is not raised in the case of active RFID tags. Active RFID tags outperformed passive tags for indoor localization in term of coverage area, since they are equipped with batteries. Then, they have larger communication range comparing to passive tags. In this work, we focus our study on the use of active RFID tags for 3D localization in indoor environments.

III. System model

A. System components

The studied system consists of active RFID tags attached to target objects to be localized, a number of readers and a server. An active RFID tag is an electronic component equipped with a battery. This system is capable of emitting radio signals towards any receiver in its range. In the following, this component is called target. The receivers (readers) of the signal emitted by targets have fixed positions in the zone of interest. A reader is known also as an anchor. These components take care to collect the signals emitted by targets and to forward them to a server. The server uses these informations to process the positions of targets. To show how this scheme operate,we use the UML sequence diagram given in Figure 1. This diagram illustrates how the exchange of information between different components happens.

The user demands the coordination of a given target, then, the target sends periodically radio signals to readers. Each reader measures the received signal strength (RSS) of each target. Then the server collects informations, calculates target-reader distances and inter-target distances. Finally, the server determines the estimated position of a given target and forwards the result to the user.

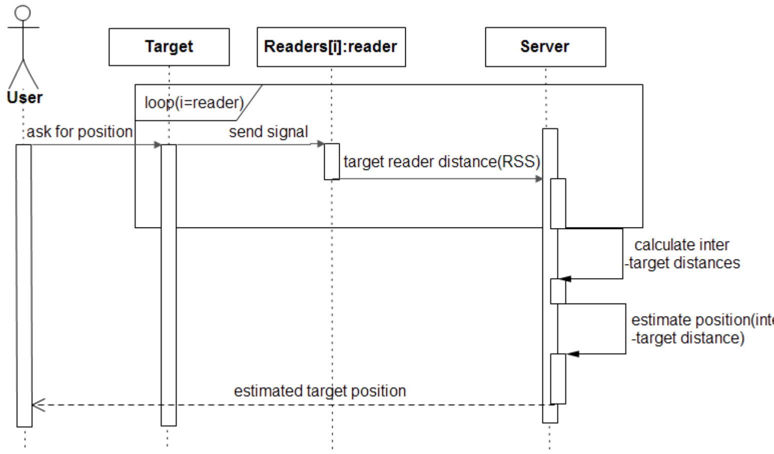

Fig. 1. Sequence Diagram of system.

B. Localization Model

The considered localization model is designed in order that all readers detect the signal emitted by targets in an indoor environment as a warehouse or an office. The proposed system model is obtained by putting the readers in vertices of a tetrahedron as shown in Figure 2. This model has a moderate cost because we use only four readers by sub-region.

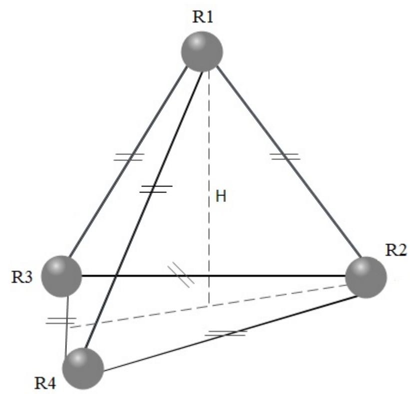

Fig. 2. 3D tetrahedron.

IV. Theoretical analysis of the proposed 3D localization scheme 3D-BATL

The proposed 3D-BATL scheme consists of three steps. First step, we use path loss plus shadowing model and the received signal strength to compute the distance between targets and readers. Then we estimate the distance inter-targets. Finally, we apply Multidimensional Scaling (MDS) technique.

A. Target-reader distance

The target-reader distance is obtained from the power of the attenuated received signal due to path loss and logarithmic shadowing effect. The path loss and shadowing effects are given by the attenuation coefficient PLS as follows:

$$PLS = P_t(dB) - P_r(dB) \tag{1}$$
$$= -G_r - G_t + 20log_{10}\left(\frac{4\pi d_0}{\lambda}\right) + 10nlog_{10}\left(\frac{d}{d_0}\right) + \psi_{dB} \tag{2}$$

Where G_t and G_r are the gains of respectively the broadcasting and receiving antennas, λ is the wavelength, d_0 is a reference distance, d is the distance between the broadcasting and receiving antennas, n is the path loss exponent, ψ_{dB} is a statistical variation of the signal around Path Loss. ψ_{dB} a centralized Gaussian distribution with a variation σ that represents the shadowing effect in logarithmic scale (dB).

The equation 2 can be used to estimate the distance between the target and the reader by supposing the constant $k = P_t + G_r + G_t - 20log_{10}\left(\frac{4\pi d_0}{\lambda}\right) - 10nlog_{10}(d_0)$, as:

$$\hat{d}(P) = 10^{\left(\frac{k-P_r}{10n}\right)} \tag{3}$$

The equation 3 gives the distance target-reader. The approach of MDS is based on the inter-targets distances that could not be determined directly from the path loss-shadowing model. So, we propose estimation method in order to calculate inter-targets distances.

B. Estimation of inter-Target distance

The main idea is to determine the distance inter-target using Pythagorean theorem. The triangle formed by two tags (t_1) (t_2) and one reader (a) is estimated as Right-angled triangle. So estimated inter-target distance is given as follow:

$$\sqrt{|d_{t_1a}^2 - d_{t_2a}^2|} \leqslant d_{t_1t_2} \leqslant (\sqrt{d_{t_1a}^2 + d_{t_2a}^2}) \tag{4}$$

where $d_{t_1t_2}$ is the estimated inter-target distance. This distance is limited by upper and lower bounds. These bounds correspond to the two cases.

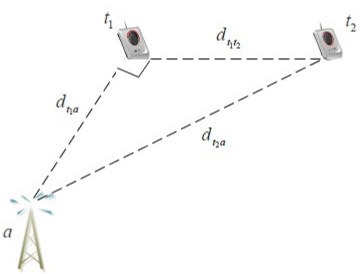

Fig. 3. First case of estimated inter-target distance.

The first case is that RFID tags are located on the same side of the reader, as seen in Figure 3. We approximate the angle a $\hat{t_1}t_2$ as a rigth angle. We apply Pythagorean theorem to a t_1t_2 triangle. The distance is estimated as follow:

$$d_{t_1t_2} = \sqrt{|d_{t_1a}^2 - d_{t_2a}^2|} \tag{5}$$

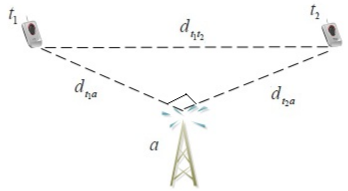

Fig. 4. Second case of estimated inter-target distance.

In the second case, the reader can be located between two targets as shown in Figure 4. We approximate the angle $t_1\hat{a}t_2$ as a rigth angle. Applying the Pyhtagorian theorem the inter-target distance is given by this formula:

$$d_{t_1t_2} = \sqrt{d_{t_1a}^2 + d_{t_2a}^2} \tag{6}$$

To minimize the error of distance estimation, we calculate the average value of each estimated distance by averaging of all the distances calculated from all readers, as:

$$d'_{t_it_j} = \sum_{a\in A}\frac{\sqrt{|\hat{d}_{t_ia}^2 - \hat{d}_{t_ja}^2|}}{|A|} \tag{7}$$

$$d''_{t_it_j} = \sum_{a\in A}\frac{\sqrt{\hat{d}_{t_ia}^2 + \hat{d}_{t_ja}^2}}{|A|} \tag{8}$$

where $|A|$ is the number of readers.

According to the location of the reader with regard to the target, the estimated distance is worth:

$$\hat{d}_{t_it_j} = d'_{t_it_j} \tag{9}$$

or

$$\hat{d}_{t_it_j} = d''_{t_it_j} \tag{10}$$

But in case the location is unknown,

$$\hat{d}_{t_it_j} = (d'_{t_it_j} + d''_{t_it_j})/2 \tag{11}$$

C. Application of Multidimensional Scaling MDS

In this section, we are interested in a type of a multidimensional Scaling (MDS), called " MDS classic metrics " [16] [18]. The word classic is related to a single matrix of disparity is used, and the word metric because the information of disparity is quantitative (measure of distances). We use MDS to estimate the positions of n targets defined by the matrix X=$^t[X_1, X_2, ..., X_n]$ in a space of minimal dimension and by minimizing the Constraint Function CF, as:

$$\hat{X} = \underset{X}{argmin} CF(X) \tag{12}$$

where the constraint function [17] is defined as:

$$CF(X) = \sqrt{\frac{\sum_{(i,j)}[\hat{d}_{ij} - ||x_i - x_j||]^2}{\sum_{(i,j)} ||x_i - x_j||^2}} \quad (13)$$

where $||x_i - x_j||$ is Euclidean distance between x_i and x_j.

The classical MDS defines the elements of $\hat{X}$ as the eigenvalue decomposition of double centered squared distance matrix. The elements of double centered squared distance matix is defined as:

$$b_{ij} = -\frac{1}{2}(d_{ij}^2 - \frac{1}{n}\sum_{k=1}^{n} d_{kj}^2 - \frac{1}{n}\sum_{k=1}^{n} d_{ik}^2 + \frac{1}{n^2}\sum_{k=1}^{n}\sum_{l=1}^{n} d_{kl}^2 \quad (14)$$

$$= \sum_{a=1}^{m} x_{ia}x_{ja} \quad (15)$$

The equivalent of previous equation in matrix writing is defined by:

$$B_{n*n} = -\frac{1}{2}JB^2J = X^tX \quad (16)$$

where,

$$J_{n*n} = I_{n*n} - \frac{1}{n}\ {}^tee \text{ with } e_{1*n} = [1, 1, ..., 1]$$

The obtained value of X has m dimensions. The reduction of the space in three dimensions is made by taking the three higher eigenvalues and their corresponding eigenvectors. This operation is true, since B is a symmetric positive definite matrix.

$$B = X^tX = UVU^t \quad (17)$$

so,

$$X = UV^{1/2} \quad (18)$$

X is the matrix of the positions of targets given by the algorithm 3D-BATL.

V. Simulation results

For performance analysis, we use the software MATLAB to implement algorithms and simulations.

A. Simulation parameters

The considered system model is defined previously in section III. The considered system consists of 4 readers placed in vertices of regular tetrahedron. The parameters of RFID system is as follows: signal frequency f= 9 10^8 Mhz, Wavelength = 3 10^8/f and range of RFID tags $R = 40m$. The deployment of tags was made according to a random mode generated by the simulator in three dimensions space $10m \times 10m \times 10m$.

The error estimation is defined as the difference between the real cordination and estimated one normalized by tag range R. We change the topology of the system 100 times.

B. Processing of localization error

First, we analyze the error of localization when the standard deviation of shadowing effect varies from 3 dB to 8 dB. The considered length of tetrahedron depth is $H = 10m$ and path loss exponent $n = 3$ for indoor environment. We use the first case of inter-target distance as defined in section IV. The Figure 5 shows that the average localization error increases when the standard deviation of RSS increases. Comparing to many 3D indoor localization algorithms, the proposed 3D-BATL algorithm can be considered as an accurate scheme for 3D indoor localization. Indeed, the maximal average error of this algorithm is under 0.35 R.

The main advantage of the proposed 3D-BATL algorithm is that it allows the computation of positions of a set of tags simultaneously. Figure 6 shows that 3D-BATL approach can be used to determine the positions of 20 targets simultaneously with a low error rate (under $0.4R$). This result illustrates that 3D-BATL algorithm is resistant to large density of targets.

To show the effect of the path loss exponent n of the estimated distance error, we evaluate the average localization error when n increases. The figure 7, illustrates that the error rate decreases when n increases. Indeed, if the path loss increases, the coverage area approaches a circle shape, since the error due to the effect of shadowing decreases.

The estimation error varies with the distance between readers. To show the effect of this distance, we measure the estimation error versus the distance between readers by varying the tetrahedron depth from $3m$ to $10m$. Figure 8 illustrates four curves corresponding to 3 targets localization for different tetrahedron depths. As shown in this figure, the accuracy of the localization increases when the distance between readers decreases for the same topology of deployed targets. Furthermore, to minimize the estimation error, we can reduce the distances between readers.

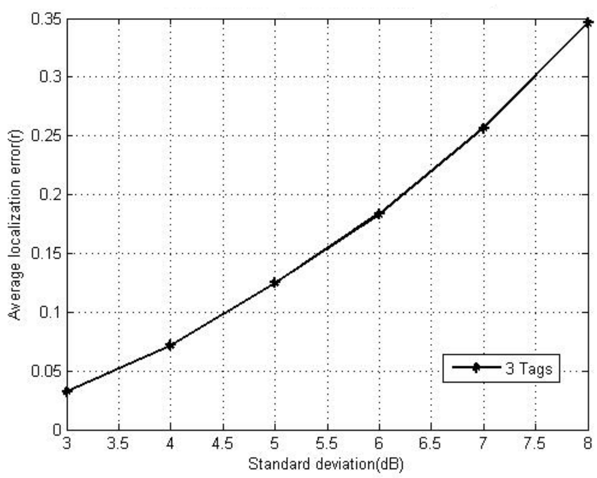

Fig. 5. Localization of 3 targets by the 3D-BATL method with H = 10m

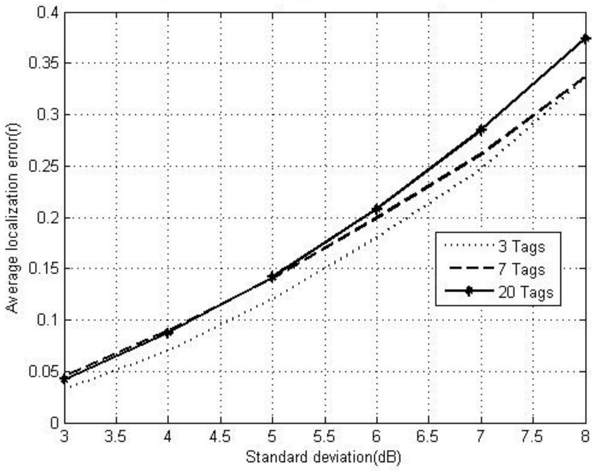

Fig. 6. Performance comparison for 3D-BATL method when the number of located targets increases with H = 10m

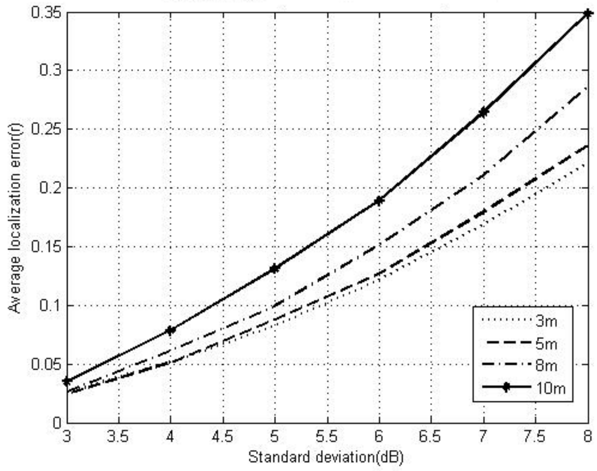

Fig. 8. Performance comparison for 3D-BATL method when tetrahedron depth changes with targets number = 3

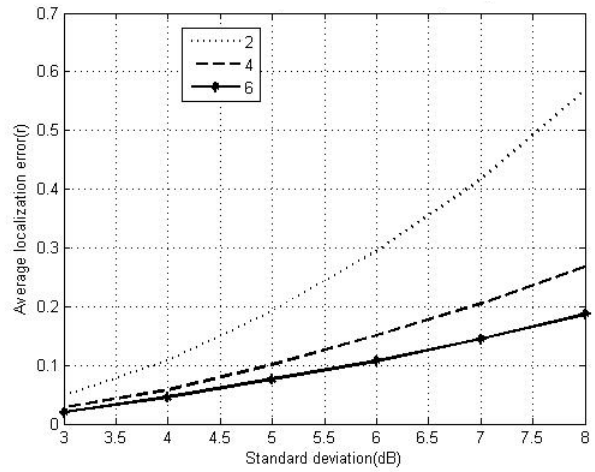

Fig. 7. Performance comparison for 3D-BATL method when path loss exponent raises with targets number = 3 and H = 10m

VI. Conclusion

In this paper, we have proposed a 3D indoor localization algorithm denoted 3D-BATL. This approach provides better accuracy in estimated localization compared to other existing algorithms. This study can be extended to localization systems that use passive tags known for their low cost.

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