Pro-MAP: A new Localization Algorithm for Wireless Sensor Networks

Manel Khelifi [1], Samira Moussaoui [2], Ilham Benyahia [3] and Farid Naït-Abdessalem [4]

[1] ReSyD, Doctoral School in Computer Science, UAMB University, Bejaia, Algeria
manel.khelifi@gmail.com, manel.khelifi@univ-bejaia.dz

[2] Department of Computer Science, USTHB University, Algiers, Algeria
Moussaoui_samira@yahoo.fr, smoussaoui@usthb.dz

[3] Department of Computer Science, UQO, Outtaouis, Canada
ilham.benyahia@uqo.ca

[4] LIPADE, Paris Descartes University, Paris, France
naf@parisdescartes.fr

***Abstract*—Knowing the location of sensor nodes is crucial in wireless network applications including environment monitoring, geographic routing, and topology control. When the positions of the sensors are unknown and only local distance information is given, we need to infer the positions from these local distance measurements. In this paper, we consider the problem of sensor network localization using only the connectivity information. We propose an improved algorithm of MDS-MAP that relies upon distance information to localize nodes. It primarily applies the multidimensional scaling MDS algorithm to construct a relative map and approximate position of each node. Our algorithm uses a new technique to refine the process of conversion from relative coordinates computed by MDS to absolute coordinates.**

The performance of our algorithm is demonstrated using a computer simulation technique. The simulation studies are conducted under regular square topology. The initial results show that Pro-MAP significantly outperforms the classical multidimensional scaling MDS and provides lower position estimation error.

Keywords- Sensor Networks, multidimensional scaling, node localization.

I. INTRODUCTION

Due to recent advancements in micro-electromechanical systems, sensors are becoming tinier and cheaper and are used in everyday life. More importantly, these sensors have the capability to communicate through wireless networks to monitor an area of interest and provide information about this area. The knowledge of nodes location is of great importance and actually it is required for many networks applications that rely on the information's location, such as industrial automation, defense applications, and smart environments, just to name a few [1]. For example, some defense applications are monitoring friendly forces, battlefield surveillance, battle damage assessment and nuclear, biological and chemical attack detection. If the sensor network is used for monitoring an area, nodes may be deployed from an airplane and the precise location of most sensors may be unknown. Finding the exact physical locations is a crucial issue for continual network operation and its management. Thus, the information gathered from the network can often be useless if not matched with the location where it is sensed. Hence, the node's geographical information not only serves to identify the source of the collected data in the network, but also for the development of routing protocols and middleware services such as geographic routing protocols, location-aware services and enhanced the coverage of area of interest.

Therefore, a lot of work have been conducted to provide the sensors positions. Most important solutions and schemes designed for localization sensor nodes in WSNs can be categorized into range-based and range-free [2][3].

The range-based algorithms use one of the localization technologies, such as RSS [4], ToA [5], TDoA [6] or AoA [7] to estimate distance or angle between nodes in order to calculate their positions. Range-free approaches, nevertheless, do not need the distance or angle sensors' information neither require extra hardware to obtain these information. They exploit the connectivity information between nodes to obtain their estimated locations. Range free algorithms are more attractive than the range-based schemes because the estimated location is achieved with low cost and consumes less energy. In contrast, the range-based schemes have highly accurate positioning as they require complex hardware to obtain angle and/or distance measurements.

One of the leading range-free algorithms for WSNs is the MDS-MAP algorithm [8]. This algorithm relies on the Multidimensional Scaling (MDS) technique to determinate the relative nodes positions. MDS is a s-et of analytical techniques that has been used for many years in disciplines such as mathematical psychology, economics and marketing research. This technique can also be used in WSN where only distances between nodes are known. Hence, the MDS-MAP algorithm uses only the connectivity information between nodes to construct a relative map and thus, approximate position of each node.

Of course there is the possibility of map rotation or incorrect scaling, for this reason by using at least three anchors as sensors that are aware of their positions, a cost function is created and to be refined using a least-squares minimization.

Although this step allows converting the relative map to an absolute one, the anchors involved in the transformation process are selected arbitrarily, thus, the rotation and the translation are also made randomly.

In this paper, we investigate classical multidimensional scaling (MDS) technique for nodes localization in two dimensional WSN. We apply a new technique on the relative maps computed by MDS to refine the conversion process. This technique is the Procrustes Analysis [9]. It is applied on the anchors to find the scaling factors, orthogonal rotation, and the translation vector that will be used to the relative coordinates nodes to obtain the estimated ones.

The rest of this paper is organized as follows. In the second section, a collection of relevant localization algorithms related to MDS-MAP are briefly summarized. The third section provides a detailed description of the MDS-MAP algorithm and the Procrustes Analysis. Our proposed localization algorithm Pro-MAP is presented in section five. Section six gives an analysis and a complete comparison between our protocol and the original MDS-MAP. Finally, we conclude the paper in section seven.

II. RELATED WORK

Many research groups have investigated different techniques for nodes localization in wireless sensor networks. This section briefly exhibits the most research works published related to MDS-MAP.

In [10] [11], an algorithm namely CCA-MAP which is similar to MDS-MAP is proposed. The similarity with MDS-MAP is that CCA-MAP builds local maps for each node in the network and then, merges them together to form a global map. The main difference from MDS-MAP is that CCA is employed in computing the node coordinates in the local map. Moreover, the size of each local map may be adjustable in dependent on sensor radio range and the number of its neighbors. CCA-MAP can be carried out in a distributed manner if the maps are merged in parallel in different parts of the network; otherwise it is implemented in a centralized fashion where a central point is used to merge the maps in sequence.

The work presented in [12] is an improved MDS-based algorithm called MDS-MAP(P). The main idea of this algorithm is to build a local map at each node, by restricting the hop count to 2 or 3 hops within its neighbors. Then, all the local maps are merged or patched to create a global relative map. Finally, by using the anchor positions, the global relative map is transformed into the global absolute map. Simulation results from [12] show that MDS-MAP(P) has a better performance than MDS-MAP.

Another localization algorithm is proposed in [13]. This algorithm is called Weighted-Multidimensional Scaling (dwMDS). dwMDS emphasizes the most accurate range measurements for node localization and incorporates local communication constraints within the sensor network. It employs a weighted cost function and introduces an adaptive neighbor selection method that avoids the biasing effects of selecting neighbors based on noisy range measurements. dwMDS allows arbitrary non-negative weights which is different from local MDS-MAP and MDS-MAP(P), and adopts a majorization method which has the property that each iteration is guaranteed to improve the value of the cost function and takes O(LN) time. Where L is number of iteration and N is number of node.

In [14], the authors propose a Hierarchical MDS-based Localization Algorithm (HMDS). HMDS divides the network into multiple clusters. In this hierarchical network architecture, a sensor node may play roles of cluster head or cluster member. The cluster head computes distances of all pairs of sensors. Thereafter, it applies MDS algorithm on the distance matrix to compute the relative coordinates of each cluster member and forms a local map. Finally, each cluster with at least two clusters merges into a unified coordinate system. The cluster creation is important because the method for forming clusters and the size of cluster have influence on location accuracy error. If the size of cluster is big, the probability which is the estimated distance error between nodes is increased and, thus, the accuracy is decreased. Experimental results revealed that HMDS algorithm outperformed the MDS-MAP algorithm in terms of accuracy.

Alternative Least-Square Scaling Algorithm (ALLESA) is a recently work proposed in [15]. ALLESA, is a centralized Multidimensional Scaling-based localization algorithm. It uses an iterative approach to solve for the coordinates of discrete points. To do so, it unconstrained optimization of the function SSTRESS. This algorithm has proven to provide very accurate location estimates even with very noisy inter-point distance measurements.

Zhao, Q-S and Hu, Y-L in [16], propose a new Multidimensional Scaling (MDS) localisation algorithm based on particle swarm optimisation; MDS(PS). This algorithm firstly uses MDS algorithm to obtain the unknown nodes initial coordinates. Secondly, it adoptes Particle Swarm Optimisation (PSO) algorithm to obtain the unknown nodes final coordinates by optimising the local cost function. The simulation results show that MDS(PS) has not only better localisation result, convergence, but also strong robustness compared to dwMDS algorithm.

III. MDS-MAP AND PROCRUSTES ANALYSIS OVERVIEW

Our new algorithm Pro-MAP is based on the MDS localization algorithm [8] and the Procrustes analysis. Here we briefly review the MDS-MAP algorithm and the Procrustes analysis.

A. MDS-MAP algorithm

MDS-MAP is based on a technique called classical multidimensional scaling (MDS) [8]. MDS is a method used for data analysis of similarity or dissimilarity of a set of objects. The idea behind MDS is simple. Suppose there are ***n*** points, suspended in a volume. We don't know the positions of the points, but we do know the distance between each pair of points. The distance data can be represented as a map in two-dimensional or three-dimensional space. In fact, the MDS-MAP relies on the MDS technique to determinate the relative nodes positions. It is divided into three stages.

In the first stage, the distance between nodes is estimated according to their hops number. The distance information allows the calculation of the shortest paths between all pairs of nodes. The values of the shortest paths are used to generate a distance matrix D as follows:

$$D = \begin{Bmatrix} 0 & d_{12} & d_{13} & \cdots & d_{1n} \\ d_{21} & 0 & d_{23} & \cdots & d_{2n} \\ d_{31} & d_{32} & 0 & \cdots & d_{3n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ d_{n1} & d_{n2} & d_{n3} & \cdots & 0 \end{Bmatrix}$$

Where d_{ij} is the Euclidean distance between node *i* and node *j*.

In the second stage, a relative matrix is generated according to the following steps:

- Compute the matrix *J* with $J = I - e * e^T / n,$
  Where e =(1,1,1,…,1);
- Transform the distance matrix D into its Gram matrix H by assuming that the geometric center of the sensor node coordinates is at the origin. H is given by:

$$H = -\frac{1}{2} J D^2 J$$

- Compute the eigen-decomposition $H = UVU^T$
  We denote the matrix of largest eigenvalues by V_i and U_i the first *i* columns of *U*. The coordinate matrix of classical scaling is: $X = U_i V_i^{\frac{1}{2}}$

In the final phase, the absolute coordinates of all nodes in the network are determined. To do this, the relative map is transformed into an absolute map. This conversion is based on the absolute position of a sufficient number of anchors (3 or more for 2-D).

B. The Procrustes analysis

Procrustes analysis [9] is a set of mathematical least-squares tools to directly estimate and perform simultaneous similarity transformations among the model point coordinates matrices up to their maximal agreement. No prior information is requested for the geometrical relationship existing among the different model objects components. By this approach, the transformation parameters are computed in a direct and efficient way based on a selected set of corresponding point coordinates. For example, we suppose to have two matrixes A and B. The matrix A contains the actual coordinates of sensor nodes while B is a matrix which represents the estimated coordinates. In this case, Procrustes is the least squares solution of the problem that is the transformation of matrix A into matrix B. This transformation is according to an orthogonal transformation matrix T, a scalar component b and a translation component c, in such a way to minimize the difference between the actual coordinates A and the calculated coordinates B (as in the above formula).

$$B = b * A * T + c$$

Matrices B and A are (p x k) dimensional, in which contain p corresponding points in the k-dimensional space.

IV. THE PROPOSED ALGORITHM: PRO-MAA

In this paper, we propose a new approach in WSNs environments where sensor nodes are randomly scattered in a large sensing field that requires monitoring.

For this purpose, we have done the following assumptions:

- No sensor node has mobility.
- Each sensor node has its unique ID and the same sensing area and data transmission area.
- Between any pair of sensor nodes on the network, at least one routing path exists, to which, all sensor nodes are connected.
- Each sensor node is capable of measuring distances using RSS.

The proposed algorithm uses the MDS localization algorithm to obtain nodes relative coordinates, and then uses the Procrustes analysis to obtain the unknown nodes final coordinates.

The localization process is divided into the following phases:

- Phase 1:

  a) Dijkstra's algorithm [17] is used to build the shortest distance between nodes.

  b) Weight any dissimilarities generated in step one to be one quarter the weight of actual measurements.

  c) Perform the MDS algorithm upon the now filled dissimilarity matrix to obtain the relative coordinates of nodes.

- Phase 2:

  a) Apply the Procrustes analysis only on the anchors coordinates to get the values of the translation, reflection and orthogonal rotation that match the configuration of the absolute anchor nodes.

  b) Use the obtained values of rotation, reflection and translation to transform the other nodes relative coordinates (location-unknown nodes) to get the estimated coordinates.

V. PERFOMANCE ANALYSIS

In this section, we use computer simulation technique to demonstrate the performance of the proposed algorithm Pro-MAP in MATLAB simulation platform. MATLAB was developed by MathWorks Inc [18]. It is a software package for high performance numerical computation and visualization. The combination of analysis capabilities, flexibility, reliability, and powerful graphics makes MATLAB the premier software package for scientific researchers.

In our simulation, we assume a typical sensor network composed of hundreds of sensor nodes deployed uniformly across a monitored area. Sensors are equipped with an omni-directional antenna, hence only nodes within certain radio range *R* can communicate with each other.

Our algorithm is simulated in square regular grid topology. For this purpose we have considered a network which includes 300 nodes that are spread randomly in a $1000*1000m^2$, so that density, connectivity and communication range are approximately the same through the network.

Figure 1 shows an example of simple square network with 300 speared nodes.

As we can see in this figure, bleu points represent nodes while the red ones represent the anchors.

We adopt the same number of anchors as used in [8], i.e., the anchors form 20% of the total number of nodes. The anchor nodes are also speared randomly on the network.

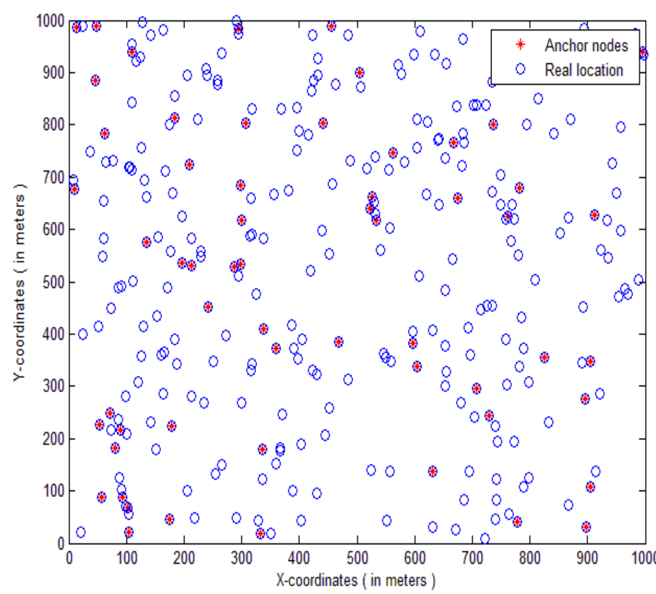

Figure 1: 300 nodes with anchor nodes randomly placed in a simple network.

Figure 2, illustrates results of running MDS-Map on the sensor network, while Figure 3 shows results of applying our new localization algorithm Pro-MAP on the same sensor network.

As we can see in Figure 2, a significant difference exists between the true locations and those obtained via MDS-MAP (the estimated locations).

However, Figure 3 shows that, on the contrary to the previous results of performing MDS-MAP, the estimated locations with Pro-MAP are so close to the true nodes positions.

These results confirm the effecciency of our algorithm in obtaining the estimated nodes coordinates. Indeed, Pro-MAP provides less difference between the real nodes positions and those estimated than the MDS-MAP algorithm.

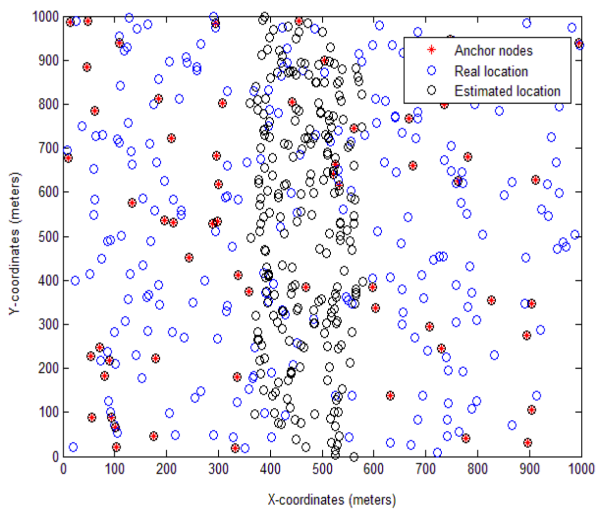

Figure 2: Location estimates using MDS-MAP algorithm.

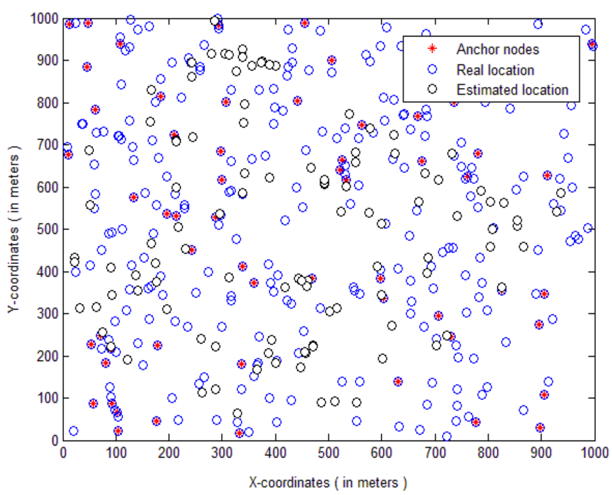

Figure 3: Location estimates using Pro-MAP algorithm.

The aim of the localization algorithm is to establish a network layout that correctly reflects the real network deployment. The efficiency of localization process is mostly described by a location error value. The lower localization error represents more precise network layout estimation, thus the localization algorithm should achieve as low a localization error as possible. In order to compare the localization performance of Pro-MAP, we simulate the two algorithms MDS-MAP and our algorithm Pro-MAP separately and compare their location error. The location error is defined as follows.

$$Location\ Error = \frac{1}{N}\sum_{i=1}^{N}((x_i - \tilde{x}_i)^2 + (y_i - \tilde{y}_i)^2)$$

Where (x_i, y_i) and $(\tilde{x}_i, \tilde{y}_i)$ are the real and the estimated coordinates, respectively, of a given unknown sensor. N equals the number of nodes in the network.

	MDS-MAP	Pro-MAP
Error of localization	7.79	1.45

Table1. Error of location estimates based on MDS-MAP And Pro-MAP in the simulation environment

As we can observe from Table 1, the results confirm the efficiency of the linear transformation adopted in Pro-MAP. This transformation from relative to absolute maps is assured by Procrustes. These results are easily explained by the controlled transformation ordered from the values of the orthogonal rotation, scaling factor and the translation vector provided from Procrustes. Consequently, Pro-MAP strongly decreases the error of localization compared to MDS-MAP.

VI. CONCLUSION AND FUTURE WORK

In this paper, we presented a new improved MDS-based algorithm (Pro-MAP) for node localization in wireless sensor networks. We enhanced the MDS-MAP algorithm by using the Procrustes transformation in obtaining the estimated coordinates of nodes. Indeed, our algorithm relies only on available connectivity information between nodes to construct a relative map and thus, approximate position of each node. The initial simulation results show that Pro-MAP provides a lower estimated error position than MDS-MAP under a square regular topology.

As future work, we plan to explore our algorithm on sensor network with mere connectivity and conduct experiments in the randomly C-shape distribution topology with different communication radius and different number of anchors.

REFERENCES

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirici, ''A survay on sensor networks'', Commun. ACM, pp. 102–114, Aug. 2002.

[2] B. Fidan G. Mao, ''Localization Algorithms and Strategies for Wireless Sensor Networks'', Information Science Reference, crc press edition, 2009.

[3] Y. Liu, Z. Yang, X. Wang, and L. Jian. ''Location, localization, and Localizability'', Jounral of Computer Science and Technology, 25(2), 2010.

[4] I. F. Akyildiz and M. C. Vuran, ''Wireless Sensor Networks'', John Wiley Publishing Company, ISBN 978-0-470-03601-3, August 2010.

[5] A. Boukerche, ''Algorithms And Protocols For Wireless Sensor Networks'', Wiley, 2009.

[6] F. Gustafsson and F. Gunnarsson, ''Positioning using time-difference of arrival measurements'', ICASSP, vol. 6, pp. 553–556, 2003.

[7] M. Ben Ahmed A.A. Boudhir, M.Bouhorma, ''New Technique of Wireless Sensor Networks Localization based on Energy Consumption'', International Journal of Computer Applica-tions (0975 - 8887) Volume 9 - No.12, November 2010.

[8] Y. Shang, W. Ruml, Y. Zhang, and M. P. J. Fromherz, ''Localization from mere connectivity information'', InProceedings of ACM MOBIHOC, 2003.

[9] D. Akca, ''Generalized Procrustes Analysis and its Applica-tions in Photogrammetry'', Internal Technical Report, IGP/ETH, Zurich, June 2003.

[10] L. Li and T. Kunz,''Cooperative node localization using nonlinear data projection'', ACM Transactions on Sensor Networks (TOSN), vol. 5, February 2009.

[11] A. Al-Odhari ; S. Alikhani ; A. Dirie ; H. Omid Beki and L. Sirko. ''Implementation of the CCA-MAP Localization Algorithm on a Wireless Sensor Network Testbed'', 7th International Wireless Communications and Mobile Computing Conference (IWCMC), pp : 992 - 997, 2011.

[12] Y. Shang, W. Ruml, and Y. Zhang, ''Improved MDS-Based Localization'', in Proc. IEEE Infocom, Hong Kong, China, pp. 2640-2651, March 2004.

[13] J. A. Costa, N. Patwari, and A. O. Hero, ''Distributed Weighted-Multidimensional Scaling for Node Localization in Sensor Networks'', ACM Transactions on Sensor Networks, vol. 2, no. 1, pp,2007.

[14] G. Yu and S. Wang, "A Hierarchical MDS-based Localization Algorithm for Wireless Sensor Networks", in 22nd IEEE International Conference onAdvanced Information Networking and Applications. ICAINA, 2008.

[15] G. B. E. Carlos, L. G. Sison, ''ALESSA: MDS-based Localization Algorithm for Wireless Sensor Networks'', IEEE, vol. 2, pp. 856 – 859, 2009.

[16] Zhao, Q-S. and Hu, Y-L, ''A multidimensional scaling localisation algorithm based on particle swarm optimisation'', Int. J. Wireless and Mobile Computing, Vol. 5, No. 2, pp.154–160, 2012.

[17] Ke Wei, ''Wireless Sensor Networks and key technology research Challenges'', Telecommunication Science, June 2005.