Joint Localization of Primary and Secondary Users in Cognitive Radio Network

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***Abstract*—In this paper we implemented a local geometry alignment algorithm for locating the primary user (PU) in cognitive radio network. Based on the estimated distance between PUs and Secondary users (SUs) for the neighbors within certain communication range, the relative configuration of all users in the network is obtained initially and is refined finally to get the global position of every user in the network. The localization performance of the proposed approach is compared to multidimensional scaling and principal component analysis.**

Keywords—localization; cognitive radio; wireless sensor networks

I. Introduction

Cognitive radio network is a promising concept for the spectrum efficiency in wireless technology. Information about the Primary user (PU) location enables several capabilities in cognitive radio networks, as it can be used to avoid harmful interference to the primary network and to improve the spectrum utilization [1]. The problem of PU localization in cognitive radio networks has attracted attention over the past few years. Since the PU is non cooperative in nature, it is a challenging task to find the location of the PU. Secondary users (SUs) cooperate to find the location of PUs using passive localization. The distance between each SU and its neighbor SUs within a certain communication range can be measured based on the received signal strength (RSS), time of arrival (TOA), time difference of arrival (TDOA) or angle of arrival (AOA). The distance between the SU and the PU is estimated from the received power at the SU.

Dimensionality reduction techniques have been widely used in the past for wireless sensor networks localization. In [2] authors proposed ISOMAP method, while in [3] multidimensional (MDS) is used to find the position of three dimensional sensor nodes based on pairwise distance and connectivity information, using additional geometric optimization. In many applications where the network is not isotropic, MDS technique have large error due to the reason that it is based on shortest path distances between every sensor node in the network, propagating larger errors throughout the network [4].

Due to non cooperative nature of PU, the estimated distances between PU and associated SUs will have large measurement error [5][6]. To avoid this, our proposed algorithm constructs the local geometry based on the pairwise distance measurements between each user and its closest neighbors since the measurements error is quietly small between the closer users. Then local configuration is aligned to the global relative configuration using local affine transformation, as proposed in [4]. Therefore, in the proposed algorithm, local coordinates of the users are computed. They form local patches, which are glued together using global optimization process. Finally the global relative coordinates are refined to actual position of the users by global optimization. Due to affine transformation and global optimization, the proposed approach is more resilient, efficient and robust in the presence of noisy range measurements.

II. Mathematical Background of the Proposed Algorithm for Localization

A cognitive radio network of *m* SUs and *n* PUs is considered in 2-dimensional space. The estimated distance between *i*-th SU and *j*-th PU, and RSS distance between the SUs can be obtained as

$$r_{ij} = \| x_{pi} + x_{sj} \| + \eta_{ij} \qquad s_{ij} = \| x_{si} + x_{sj} \| + \eta_{ij} \tag{1}$$

To get the neighbors of each user in the network, the topological structure of the network is represented by a network graph G, where each vertex represents PU or a SU. For a certain communication range, an edge is constructed between user *i* and *j*. Weight matrix W is defined such that w*ij* = 1, if there is an edge between users *i* and *j,* otherwise w*ij* = 0. The local distance matrix D*i* contains the pairwise distances between user *i* and *j*. Double center matrix Ui can be obtained from D*i.* Local coordinates of the users are obtained by singular value decomposition on U. Final positions Θ can be obtained from

$$\begin{aligned} \tilde{\boldsymbol{\Theta}}_i &= \boldsymbol{v}_i \sqrt{\boldsymbol{c}_i}. \\ \hat{\boldsymbol{\Theta}}_i &= \boldsymbol{\beta}_i \tilde{\boldsymbol{\Theta}}_i + \boldsymbol{\alpha}_i \\ \boldsymbol{\alpha}_i &= \tilde{\boldsymbol{\Theta}}_i (\boldsymbol{I} - \hat{\boldsymbol{\Theta}}_i \tilde{\boldsymbol{\Theta}}_i^{+}) \end{aligned} \tag{2}$$

and from

$$\begin{aligned} \sum \| \boldsymbol{\alpha}_i \|^2 &= \sum \tilde{\boldsymbol{\Theta}}_i \, \| (\boldsymbol{I} - \hat{\boldsymbol{\Theta}}_i \tilde{\boldsymbol{\Theta}}_i^{+}) \|^2 \\ \boldsymbol{\Theta}_i &= \zeta \kappa^T (\hat{\boldsymbol{\Theta}}_i) + \lambda \\ \arg\min_{\zeta\kappa\lambda}(\mathrm{II}) &= \sum_{i=1}^{k} (\hat{\boldsymbol{\Theta}}_i - \boldsymbol{\Theta}_i)^T (\hat{\boldsymbol{\Theta}}_i - \boldsymbol{\Theta}_i) \end{aligned} \tag{3}$$

where, υi are the Eigen-vectors and c_i are the Eigen-values, α is the local reconstruction error, β is the local alignment matrix, and ζ, κ and λ are the optimal values for rotation, scaling and translation factors respectively, found through global optimization problem for the given number of SUs with known location (4),

$$\zeta = \frac{\sqrt{\Theta_i^T \hat{\Theta}_i \hat{\Theta}_i^T \Theta_i}}{\hat{\Theta}_i^T \Theta_i}$$

$$\kappa = \boldsymbol{A}_0 - \lambda \zeta^T \boldsymbol{C}_0$$

$$\lambda = \frac{\mathrm{Tr}(\Theta_i \zeta^T \hat{\Theta}_i)}{\mathrm{Tr}(\Theta_i \Theta_i^T)} \quad (4)$$

where A_0 and C_0 are the centroids for SUs with known location.

III. Simulation Results

To evaluate the performance of the proposed algorithm, we performed simulations in Matlab. All users in the network are considered to be randomly distributed in a 20×20 square area. For the proposed approach we considered that every user in the network is having 5 neighbors or less for the given communication range.

Fig. 1 shows the results of proposed algorithm where there are 48 SUs and 2 PUs. The line shows the positioning error for every user in the network. Fig. 2 shows the impact of additive Gaussian noise to the range measurements. It can be seen that the proposed algorithm is more robust to noise variance comparing to MDS and PCA.

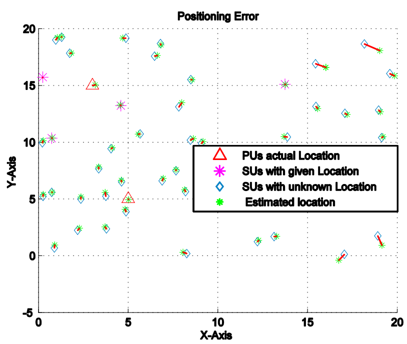

Fig. 1. The results for 48 SUs and 2 PUs.

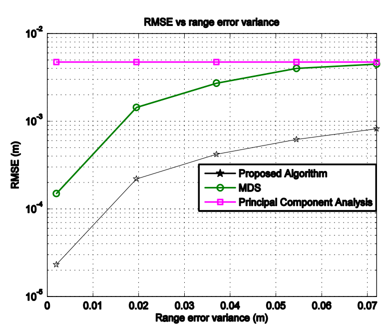

Fig. 2. The impact of additive Gaussian noise to the range measurements.

Fig. 3 shows that with increasing the number of users in the network, the proposed algorithm provides better accuracy comparing to MDS and PCA.

The performance of the proposed algorithm is evaluated by root mean square error (RMSE) given as

$$RMSE = \sum_{i}^{m+n} \frac{\sqrt{(\hat{x}_i - x_i)^2 + (\hat{y}_i - y_i)^2}}{m+n} \quad (5)$$

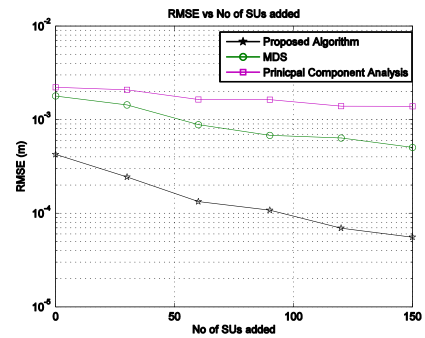

Fig. 3. Root means square error (RMSE) vs Number of users in the network.

IV. Conclusion

In this research we have introduced a novel algorithm for cognitive radio network localization in order to find the location of primary and secondary users in the network.

The proposed algorithm has better localization performance than the MDS and principal component analysis methods, especially in large scale networks with low density.

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