Applied Soft Computing 36 (2015) 506–518

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Meta-heuristic approaches for minimizing error in localization of wireless sensor networks

S. Sivakumar [a,*], R. Venkatesan [b,1]

[a] Dept. of Information Technology, PSG College of Technology, Coimbatore, India
[b] Dept. of Computer Science & Engineering, PSG College of Technology, Coimbatore, India

ARTICLE INFO

Article history:
Received 28 November 2014
Received in revised form 2 April 2015
Accepted 22 May 2015
Available online 29 July 2015

Keywords:
Meta-heuristics
NP-hard problems
Mobile Anchor Positioning
Bat Optimization Algorithm
Modified Cuckoo Search
Firefly Optimization Algorithm

ABSTRACT

Sensor node localization is considered as one of the most significant issues in wireless sensor networks (WSNs) and is classified as an unconstrained optimization problem that falls under NP-hard class of problems. Localization is stated as determination of physical co-ordinates of the sensor nodes that constitutes a WSN. In applications of sensor networks such as routing and target tracking, the data gathered by sensor nodes becomes meaningless without localization information. This work aims at determining the location of the sensor nodes with high precision. Initially this work is performed by localizing the sensor nodes using a range-free localization method namely, Mobile Anchor Positioning (MAP) which gives an approximate solution. To further minimize the location error, certain meta-heuristic approaches have been applied over the result given by MAP. Accordingly, Bat Optimization Algorithm with MAP (BOA-MAP), Modified Cuckoo Search with MAP (MCS-MAP) algorithm and Firefly Optimization Algorithm with MAP (FOA-MAP) have been proposed. Root mean square error (RMSE) is used as the evaluation metrics to compare the performance of the proposed approaches. The experimental results show that the proposed FOA-MAP approach minimizes the localization error and outperforms both MCS-MAP and BOA-MAP approaches.

1. Introduction

Wireless sensor network is a kind of ad hoc network that consists of autonomous sensors with low cost, low energy sensing devices, which are connected by wireless communication links. These sensor nodes are tiny in size and possess limited resources [1]. A sensor network is similar to a general purpose mobile ad-hoc network (MANET) in many aspects; they are distributed, self-organized and multi-hopped but it lacks a fixed infrastructure. The main difference [2] lies in the fact that the former has the following constraints: lower cost, lesser bandwidth, smaller processing power, higher redundancy and more power-constrained.

A fundamental problem in designing sensor network is localization [3] i.e. determining the location of sensors. Location information is used to detect and record events, or to route packets using geometric-aware routing. These sensors are usually deployed in large numbers over the region of interest for object monitoring and target tracking applications. The densely deployed sensors are expected to know their spatial coordinates for efficient functioning of WSNs. Location awareness plays an important role in high-level WSN applications like locating an enemy tank in a battlefield, locating a survivor during a natural calamity and in certain low-level network applications like geographic routing and data centric storage.

It is important to note there is an uncertainty on the exact location of sensor nodes. One trivial solution is, equipping each sensor with a global positioning system (GPS) receiver that can provide the sensor with its exact location. As WSNs normally consist of a large number of sensors, the use of GPS is not a cost-effective solution and also makes the sensor node bulkier [4]. GPS has limited functionality as it works only in open fields and cannot function in underwater or indoor environments. Therefore, WSNs require some alternative means of localization.

This work is considered suitable for open fields and not for underwater or indoor environments. GPS information of the three anchors is used to calculate the estimates particularly suitable for open fields only and then localization error minimization is performed for the three proposed heuristic approaches. The speed of the mobile anchors is selected as 100 m/s in order to receive more number of beacon packets in a fixed time interval to have a significant increase in the percentage of localized nodes along

* Corresponding author. Tel.: +91 9865013204.
E-mail addresses: sivas_cbe@yahoo.co.in (S. Sivakumar), ramanvenkatesan@yahoo.com (R. Venkatesan).
1 Tel.: +91 9789219522.

http://dx.doi.org/10.1016/j.asoc.2015.05.053
1568-4946/© 2015 Published by Elsevier B.V.

with faster convergence. This is not a generalized procedure for all applications and is applicable only for military applications such as navigation, target tracking, search and rescue and in civilian applications such as disaster relief, time synchronization and surveillance operations. GPS will have limited functionality where line-of-sight (LOS) propagation does not exist. In particular, for indoor applications and under-water sensor networks, GPS will suffer from limited functionality.

Currently, the existing non-GPS based sensor localization algorithms [5] are classified as range-based or range-free methods. Range-based localization schemes rely on the use of absolute point-to-point distance or angle estimate between the nodes. They determine the position of unknown sensor nodes using location-aware nodes which are also called as anchors or beacons. The most preferred range-based localization techniques are received signal strength indicator (RSSI), time difference of arrival (TDoA), time of arrival (ToA), and angle of arrival (AoA). Range-based methods give fine-grained accuracy but the hardware used for such methods are expensive. In range-based mechanisms, the nodes obtain pair wise distances or angles [6] with the aid of extra hardware providing high localization accuracy. Hence, the uses of range-based methods are generally not preferred.

Range-free or proximity based localization schemes rely on the topological information (e.g., hop count and the connectivity information), rather than range information. Range-free localization schemes may be used with anchors or beacons. They do not require complex hardware and they are cost effective when compared to range-based schemes. Range-free methods use the content of messages from anchor nodes and other nodes to estimate the location of non-anchor sensor nodes. Centroid Algorithm and Distance Vector Hop (DV-Hop) Algorithm are examples for range-free algorithms. Range-free algorithms sometimes use mobile anchors for localization.

Localization problem can be mathematically stated as follows: consider a network formed by $L = M + N$ sensor nodes, where M represents the anchor nodes and N represents the non-anchor nodes. The anchor node is defined as a node that is aware of its own location, either through GPS or manual recording and entering position during deployment [7]. Anchor node position is expressed as $a_k \in \Re^n$, $k = 1,2,\ldots, M$ in n-dimensional coordinates. The non-anchor node is defined as a node that is unaware of its own location. Non-anchor node position is expressed as $x_j \in \Re^n$, $j = 1,2,\ldots, N$ in n-dimensional coordinates. The goal of a location system is to estimate coordinate vectors of all N non-anchor nodes. Generically, the localization schemes operate in two phases:

Phase 1: Inter-node distances estimation based on hop connection information or true physical distance calculation based on the inter-node transmissions and measurements.
Phase 2: Transformation of calculated distances into geographic coordinates of nodes forming the network.

The standard approach is to formulate localization problem as an optimization task [8] with the nonlinear performance function J_N as given by Eq. (1):

$$\min_{\tilde{X}} \left\{ J_N = \sum_{K=1}^{M} \sum j \in S_k (\hat{d}_{kj} - \tilde{d}_{kj})^2 + \sum_{i=1}^{N} \sum j \in S_i (\hat{d}_{ij} - \tilde{d}_{ij})^2 \right\} \quad (1)$$

where $\hat{d}_{kj} = ||a_k - \hat{x}_j||$, $\hat{d}_{ij} = ||\hat{x}_i - \hat{x}_j||$, a_k denotes the real position of the anchor-node k, $\hat{x}_i$ and $\hat{x}_j$ denote, respectively, the estimated positions of nodes i and j, $\hat{d}_{ij}$ and $\hat{d}_{kj}$ are the estimated distances between pairs of nodes calculated based on measurements, and S_i, S_k are sets of neighboring nodes defined by Eqs. (2) and (3) as follows:

$$S_k = \{(k, j) : ||a_k - x_j|| \le r_k\}, \quad j = 1, 2, \ldots, N \quad (2)$$

$$S_i = \{(i, j) : ||x_i - x_j|| \le r_i\}, \quad j = 1, 2, \ldots, N \quad (3)$$

where x_i and x_j denote real positions of nodes with unknown locations and r_i and r_k their corresponding transmission ranges. Various optimization techniques are used to solve the optimization problem as defined by the above Eq. (1). Hence, there is a need to choose an algorithm or technique that efficiently eliminates localization errors and optimizes the obtained locations such that it brings forth better accuracy in localization. Many researchers have suggested the use of heuristic methods and hence three meta-heuristic optimization techniques have been proposed in this work to minimize the error in localization.

Localization in wireless sensor networks is considered as intrinsically an unconstrained optimization problem [9]. The proposed meta-heuristic optimization approaches namely, Bat Optimization Algorithm, Modified Cuckoo Search algorithm and Firefly Optimization Algorithm have been applied over the initial location estimation using Mobile Anchor Positioning (MAP). The MAP is a range-free approach, where the anchor nodes broadcast their location while moving and the obtained localization result is optimized by means of the optimization strategies as stated above.

The remainder of this paper is organized as follows: Section 2 categorizes the related research and reviews the relevant literature. Section 2.1 enumerates the pros and cons of some existing range-based localization approaches. Section 2.2 highlights the pros and cons of some existing range-free localization approaches. Section 2.3 highlights the pros and cons of some existing hybrid localization approaches. Section 2.4 discusses the pros and cons of some existing mobile anchor based localization approaches. Section 2.5 discusses the pros and cons of some existing evolutionary based localization approaches. Section 3 elaborates on proposed meta-heuristic approaches for localization. Section 3.1 illustrates the range-free localization approach namely, Mobile Anchor Positioning (MAP). Section 3.2 depicts the flowchart for localization steps used in Bat Optimization Algorithm with MAP (BOA-MAP). Section 3.3 portrays the flowchart for localization steps followed in Modified Cuckoo Search with MAP (MCS-MAP) Algorithm. Section 3.4 lists the localization steps for Firefly Optimization Algorithm with Mobile Anchor Positioning (FOA-MAP) and its flowchart. Section 4 details on the experimental results, simulation settings in NS-2, RMSE table and graph for comparing performance of the three proposed meta-heuristic approaches. Section 5 discusses the concluding remarks and the scope for future research.

2. Literature review

Localization techniques in the literature are categorized as range-based localization techniques, range-free localization techniques, hybrid localization techniques, mobile anchor based localization techniques and evolutionary based localization techniques.

2.1. Reviews on range-based localization techniques

Range-based localization techniques rely on the availability of distance (or) angle information between the nodes to determine the unknown sensor node's position. Sensor nodes are equipped with extra hardware, which is capable of estimating distance (or) angle by means of techniques such as received signal strength indicator (RSSI), time of arrival (ToA), time difference of arrival (TDoA), (or) the angle of arrival (AoA). The typical geometrical approaches widely used for location estimation are Tri-lateration