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A novel distance estimation approach for 3D localization in wireless sensor network using multi dimensional scaling

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ABSTRACT

Node localization is very important in Wireless Sensor Network (WSN) and distance estimation between pairs of nodes is the prerequisite for localization and thus the applicability of the reported events. The paper proposes a novel distance estimation algorithm to estimate distances of each node to every other node in the network. The main contribution of the paper is the definition of a dissimilarity matrix representing the distance of each node to every other node in the network. MDS based localization algorithm is used to determine coordinates of the node in a local coordinate system and Helmert Transformation is used to convert the local coordinates of the node into a global coordinate system. The effect of various parameters affecting the performance of proposed algorithm is also presented in the paper. Finally, the efficiency of the proposed algorithm is established through the simulation results.

1. Introduction

Localization refers to a process of finding location information of the objects in a given coordinate system. In order to gather more information for a specific region of deployment, there is a pertinent need of the awareness regarding the location of the node in the concerned area. Many issues exist with the localization of the nodes in WSN, such as deployment in the three dimensional space without any infrastructural support. Since sensor nodes are randomly deployed in 3D space, manually embedding of location information in each node is not feasible as in many applications, nodes get deployed by the use of aircrafts. WSNs may have mobile nodes, which may move from one point to another in the area of deployment, making manual updating of node's location information not viable. It is also a prominent issue that new nodes may join or old nodes may be eliminated from the existing deployment making the manual localization of nodes difficult. Global Positioning System (GPS) receivers can be used by the nodes to determine their location in the area of deployment, but putting GPS receiver on each node is not feasible due to increased cost. Therefore we need an automated, cost effective and efficient localization algorithm for WSNs. Localization approaches in WSN can be classified as node localization [1–3] which refers to the process of finding coordinates of sensor nodes with respect to the given coordinate system and target localization [4] which refers to the process of finding local coordinates of a moving target with respect to the sensors deployed for target tracking.

Distance between the nodes is necessary for most of the localization algorithms. One of the characteristic of radio communication [5–7] is the potential to partially determine the distance between the sender and the receiver. Based on the distance estimation technique used, localization algorithms can be classified as Range Based Localization and Range Free Localization.

The Range Based Localization means that the distance between the nodes is estimated by using physical properties of communication signal. The physical properties which are used to estimate the distance between the two nodes are Received Signal Strength Indicator (RSSI) [7], Time of Arrival (ToA) [5], Time Difference of Arrival (TDoA) [6] and Angle of Arrival (AoA) [8]. Estimation of location of the nodes using the above listed techniques is known as range based localization. Range Free Localization means that an indirect technique is used to determine the distance between the nodes [9]. Hop count is an indirect technique of distance estimation in wireless sensor network which is also commonly used. In this case, every node tries to determine shortest path to reach all other nodes in the WSN. The weight assigned to the link is the number of hops from source to destination. Hop count can be multiplied by the average transmission range of the node to convert into distance estimation.

Going forward anchor nodes are the nodes which know their location information. Based on the use anchor nodes, localization algorithms can be classified into Anchor Based Localization and Anchor Free Localization. The localization algorithm is called Anchor Based Localization when anchor nodes assists localization

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algorithm [10,11] to determine the location of other nodes in the network. Anchor Free Localization if anchor nodes are not used in the process of localization [12].

Based on the computation involved in the localization algorithm, it can be classified as Centralized Localization Algorithm and Distributed Localization Algorithm. If a central computing unit gets all the information from the network and computes the location information of all the nodes then it is known as centralized localization algorithm [13]. This approach increases communication overhead but reduces computation overhead of individual nodes. In Distributed Localization Algorithm, every node gathers information from its neighbors and computes its location locally [14]. This approach limits the overhead imposed on the network in terms of communication but increases computational overhead. But the increased computational overhead results in depletion of battery power of individual nodes.

This work addresses the problem of node localization that use range based approach to compute distance between the nodes. Anchor nodes are used in the algorithm to convert local coordinates of the nodes into global coordinates. Centralized computation is used to determine the location of the individual nodes because localization algorithms are computation intensive and nodes have limited computation facility available on board. By adopting centralized approach, proposed algorithm is reducing computation overhead of individual nodes. Therefore the paper proposes a centralized localization algorithm which is based on MDS. MDS is a statistical technique for arranging the data items in an n-dimensional space based on dissimilarities between the data items. Many versions of MDS [15] are available which are appropriate for different requirements of data analysis. Metric and non-metric MDS are two forms of MDS algorithm. MDS can further be classified as Classical MDS and Weighted MDS. Classical MDS uses dissimilarity matrix as input whereas Weighted MDS uses different weights in the dissimilarity matrix for every dimension. The choice of MDS for data analysis depends upon the dimensionality of the space in which data items need to be arranged and the accuracy in the measurement of dissimilarity between the data items. Since the paper proposes the use of Euclidian distance as dissimilarity parameter, classical MDS can be used in our proposed algorithm. Other significant reasons of using classical MDS is that our proposed distance estimation algorithm is capable of generating fairly accurate distance matrix and classical MDS can be efficiently applied on large matrix because it is a closed-form solution of data analysis. Since sensor nodes are having limited communication and battery power, these algorithms are not useful particularly for localization of nodes in WSN.

2. Related work

Many localization algorithms had been proposed to locate nodes in WSN and describe use of MDS for 2D localization with the help of few anchor nodes. Pei et al. [16] proposed an algorithm in which anchor nodes are dividing whole area into regions with their regional ids and locate position of nodes accordingly. It also applies an optimization technique to reduce localization error. The limitation of the algorithm is that it requires direct communication among the anchor nodes. Yu and Wang [17] proposed a Hierarchical MDS (HMDS) based on 2D localization algorithm which has three steps named as creation of cluster, intra-cluster localization and merging of local coordinates achieved in intra-cluster localization phase. The main drawback of this algorithm is that if there are many disjoint clusters exist in the system then it will be impossible to map local coordinate system into global coordinate system. The error in the shortest path based distance estimation is high which leads to high localization error. Bulusu et al. [12] have proposed anchor based conventional centroid localization algorithm for locating sensor nodes in the 2D space. The conventional centroid localization has been further enhanced by Chen et al. [18], they have proposed centroid theorem of coordinate tetrahedron in the volume-coordinate system to enhance localization accuracy for the application of algorithm in 3D space of WSN. Both the algorithms proposed uses a large number of anchor nodes and their localization accuracy is inversely proportional to the number of anchor nodes used.

Ji and Zha [14] have proposed the use of MDS for localization of nodes in WSN. They have considered the issue of anisotropic topology and complex terrain of sensor networks. They have proposed a distributed localization algorithm based on MDS where every node creates a local map of the network and these maps are stitched together to form a global map of the network topology. Further local optimization is used to reduce localization error. They are running a distributed and iterative algorithm on every node which results in more energy consumption during the localization phase. Shang et al. [19] proposed MDS MAP algorithm which uses classical MDS to generate the map nodes used in WSN which was further extended to MDS-MAP(P) [20] and MDS-MAP(R). MDS-MAP(P) [21] is a distributed algorithm that uses patches of relative map of individual nodes which are combined together to determine the original positions of the nodes. All these algorithms are distributed algorithms where individual nodes are weighed down for location computation.

The accuracy of MDS based localization depends upon the efficiency of distance estimation between all pair of nodes. Since sensor nodes are having limited communication range, it is not possible to estimate distance between all the pair of nodes by using radio resources. To estimate the distance between all pair of nodes an indirect approach is required which can produce accurate distance information. This paper proposes a novel approach for distance estimation between all pair of nodes in the network.

3. Localization process

This section describes the particulars of the proposed algorithm. Consider the scenario of a large set of sensor nodes deployed in an area that requires continuous monitoring. It is assumed that sensor nodes are deployed in a 3D space and nodes are static. It is well known that network is having two types of node, i.e. normal nodes and anchor nodes.

Normal nodes are homogeneous, i.e. they have identical sensing, processing and communication capabilities and the same initial battery power. Anchor nodes are equipped with GPS receiver, where links are bidirectional and broadcast type and network is adopting a flat topology.

The localization algorithm is divided into following steps:

- *Distance estimation*: the algorithm estimates distance between all pair of nodes in the WSN.
- *Location estimation*: the algorithm estimates local coordinate of the nodes in the network using MDS.
- *Coordinate transformation*: this step uses the local coordinates of the nodes and transforms them into a global coordinate system.

After completion of these three steps, every node knows its location with respect to global coordinate system defined by the anchor nodes in 3D space. To facilitate localization process, every node needs to determine its distance from its neighbors and send this information to a central server. The central server is responsible to run distance estimation process, MDS to determine local coordinate of individual nodes and synchronize transformation process to map local coordinates into global coordinate. Finally,