A GPS-free Self-Organized Location Establishment Scheme for Environmental Wireless Sensor Networks

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1 Introduction

Wireless Sensor Networks (WSNs) have a large set of applications ranging from environmental monitoring to data gathering and dissemination. In particular, the monitoring and reporting of environmental disasters is a critical issue for efficient management and treatment of disasters, particularly in remote areas. For example, the reporting of disaster locations and disaster's scale such as explosions, fires and other various destructions caused to the environment is an important application area of sensor networks. Furthermore, such scenarios may have certain limitations and characteristics, such as limited or no availability of GPS, either due the high cost and high energy consumption of GPS devices [1], making them unsuitable for sensor nodes, especially in an environment where sensor node destruction is inevitable. Furthermore, there are environments where GPS reception is deterred, e.g. in enclosures, mines, underwater, underground etc. There have been previous localization schemes which use various means to estimate the location of nodes without the use of GPS in every node. These include range-based, [2, 3], and range-free [4, 5]. However, these solutions require the existence of "seeds", which are nodes which possess their location at all times (e.g. need to be equipped with GPS) in order for other nodes to effectively estimate their own locations.

In this paper we propose a distributed self-organized mapping scheme for wireless sensor networks. This allows relatively cheap sensors to be deployed for environmental monitoring without the need for the sensors to be equipped with the Global Positioning System (GPS), keeping their costs low and also minimizing energy consumption for these energy-constraint devices. The aim of this mapping scheme is to develop a coordinate scheme for the purpose of location derivation of sensor nodes in a field. In the proposed scheme nodes calculate their unique position coordinates based on hopcount and relative angular position based on only their local information. Hence nodes establish their relative position to the sink both in terms of hops and in terms of angular property in a purely self-organized, distributed manner, and independent of network size.

2 Self-Organizing Location Establishing Scheme

The *self-organized location establishment scheme* (SOLES) consists of nodes establishing their relative range (in hopcounts) and relative angular position from the sink, by only obtaining information from their one-hop neighbors. The basic two assumptions are that nodes are equidistant from each other, and all nodes have the same capability in hardware for maximum accuracy. In SOLES, each node is characterized by a unique *node ID* (NID) which is the physical address of the node, a *range ID* (RID) which reflects its relative distance from the sink in terms of hopcount, and *angular ID* (AID) which reflects its angular property relative to the sink. The NID is preset, whereas the RID and AID are calculated dynamically in a distributed manner from local information only. The combinatorial of RID_{AID} is unique for each node and defines its location in the network relative to the sink. The general Steps of the algorithm are as follows, and further illustrated in Fig. 1.

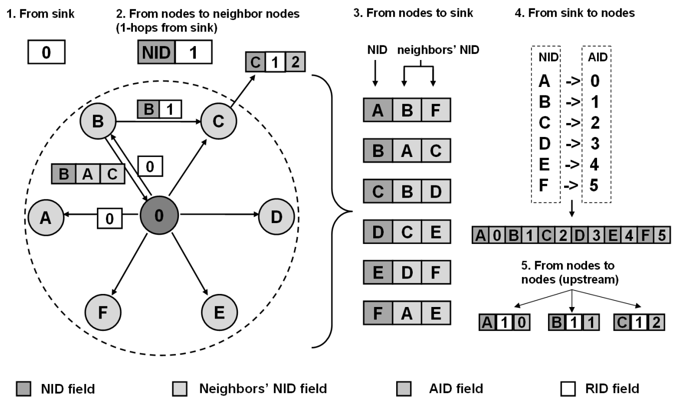

Fig. 1 SOLES initialization and progression.

1. Sink broadcasts hop messages to 1-hop neighbors.
2. 1-hop neighbors rebroadcast hops message.
3. 1-hop nodes discover their neighbors.
4. 1-hop nodes report their immediate 1-hop to sink neighbor sets to sink.
5. Sink sets the AID of its neighbors in a AIDSet message of form $\langle NID_i \rangle \langle \text{AID}_i \rangle \ldots \langle NID_j \rangle \langle \text{AID}_j \rangle$.
6. Neighbors of sink rebroadcast hops with their angular position (set by sink)
7. Upstream nodes set their hops and angular position according to those of their neighbors according to Eq. (1) and (2), and broadcast a Node Location (NOL) message in the format of $\langle NID \rangle \langle \text{RID} \rangle \langle \text{AID} \rangle$.

$$\text{RID}_n = \min\{\text{RID}_i \ldots \text{RID}_m\} \tag{1}$$

$$\text{AID}_n = \frac{\text{RID}_n}{m} \sum_{i=1}^{m} \frac{\text{AID}_i - 1}{\text{RID}_i} + 1 \tag{2}$$

The *range ID* (RID) corresponds to the hopcount number of the node from the sink. This is taken as the minimum of all RIDs of all the neighbors nodes from which the NOL message is received from. The Physical distance d and angle θ from sink of node n is given by (3) and (4):

$$D_n = \left| \frac{\mathrm{RID}_n x\sqrt{3}}{2\sin(\theta + \frac{\pi}{3})} \right| \quad (3)$$

$$\theta = \frac{\pi}{3\mathrm{RID}} (3\mathrm{RID} - \mathrm{AID} + 1) \quad (4)$$

Special cases: A node receiving NOL messages from neighbors whose AID difference in the messages is greater than 5 (in normal case), and where one of the AID is 1, recalculates the AID of the node's who's AID is 1 using $\mathrm{AID} = 6n+1$ by treating the AID as the next AID above the preceding node of equal RID, prior to calculation of Eq. (2).

3 Application of SOLES: Ambient Routing and Disaster Scale Reporting

Once the nodes have established their relative locations within the network using SOLES, the platform is ready for application implementation. There are two possibilities: If the 1-hop nodes from sink's geographical coordinates are known, then the estimated geographical location of all other nodes can be calculated. Otherwise, locations of other nodes in the field are only described in terms of $\langle$RID$\rangle$ $\langle$AID$\rangle$ coordinate system. Hence to physically locate the desired location (e.g. an affected area), complete path traversal (i.e. the route) can be inputted into a system (such as a robot) for a device to reach the desired location via the sink. If used in routing, the address of all nodes being traversed is appended towards the sink (e.g. source routing style), then the above scenario is possible. For example, a small robot can reach an affected area without the need for GPS, but simply by traversing the paths stored in a routing table obtained from the "alert" messages. The level of accuracy required is proportional to: 1) number of neighbors within one-hop (one-radii) range of sink, 2) density of nodes, and 3) equidistance of nodes from each other.

The topology is shown in Fig. 2 after the SOLES algorithm is applied to the network. In this figure, the sink is located at the center of the field. All nodes have established their relative distance and angle to the sink distributively. Furthermore, all nodes have a unique combination of RID/AID defining their relative positions.

4 Conclusion

In this paper we proposed a self-organized mapping scheme for WSNs, that may be used for environmental monitoring. The scheme is purely self-organized, and does not require the use of GPS devices. Simulation results show the effectiveness of the approach in a regular topology. The accuracy of this approach of course depends heavily on how well distributed the nodes are, with highest accuracy when

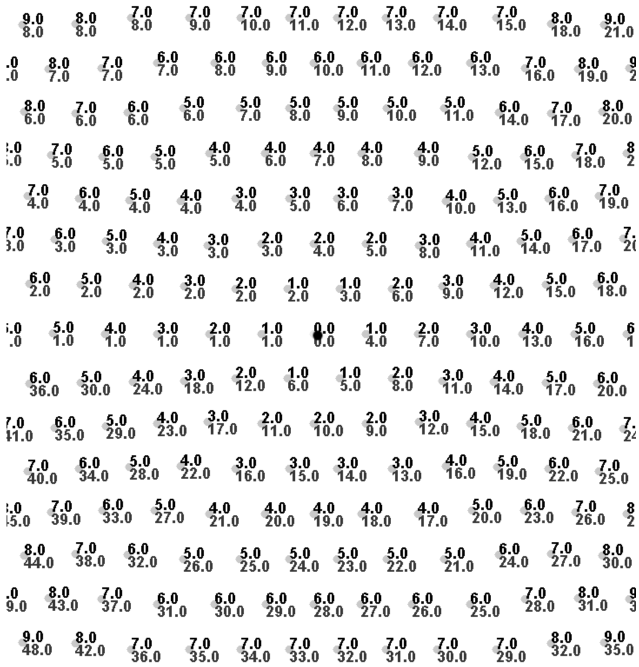

Fig. 2 Simulated scenario and topology.

nodes are equidistant from each other and deteriorating accuracy when nodes are less uniformly distributed. Density also plays an important factor in the accuracy of node positioning.

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