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Localization of Wireless Sensor Networks Using a Single Anchor Node

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***Abstract*—Localization of nodes in a sensor network is essential for the following two reasons: (*i*) to know the location of a node reporting the occurrence of an event, and (*ii*) to initiate a prompt action whenever necessary. Different localization techniques have been proposed in the literature. Most of these techniques use three location aware nodes for localization of an unknown node. Moreover, the localization techniques also differ from environment to environment. In this paper, we proposed a localization technique for grid environment. Sensor nodes are deployed in a grid pattern and localization is achieved using a single location aware or anchor node. We have identified three types of node in the proposed scheme: (*i*) Anchor node, (*ii*) Unknown node and (*iii*) Special node. First, the special nodes are localized with respect to the anchor node, then the unknown nodes are localized using trilateration mechanism. We have compared the proposed scheme with an existing localization algorithm for grid deployment called Multiduolateration. The parameters considered for localization are localization time and localization error. It is observed that localization time and error in the proposed scheme is lower than that of Multiduolateration.**

***Index Terms*—GPS, Localization, RSSI, Trilateration, Wireless sensor networks (WSN)**

I. Introduction

Wireless sensor networks (WSN) consist of a large number of densely deployed nodes which are tiny, low power, inexpensive, multi-functional connected by wireless medium. These nodes interact with their environment, sensing the parameters of the interest such as temperature, light, sound, humidity, pressure, etc. They also perform computation, and communicate with other nodes in the network. Application of WSN depends on the field of their deployment. These includes: security and surveillance, data aggregation, environment sensing, industrial process control, structural health monitoring and many more [1]. Performance of WSN is affected by various factors such as node deployment, localization, synchronization, routing, data aggregation etc. For successful deployment of WSN the above factors need to be addressed.

Nodes in WSN are un-aware of their location at the time of deployment. They obtain their location information through localization process. Location information is necessary for the following reasons: (*i*) Providing location stamps to sensed data, (*ii*) Facilitates efficient routing of sensed information within the network, (*iii*) Performing efficient spatial querying, in which a sink or a gateway node can issue queries for information about specific location, (*iv*) Determining the quality of coverage of all active sensors using their position, (*v*) Location information can be used to divide the network into different partitions to facilitate collaborative processing and hierarchal routing, (*v*) To achieve load balancing within the network, and many more.

The primary task of a sensor deployed in a sensor field is to monitor an event of interest and report to sink node. Sink on receiving the event of interest initiate a suitable action. For initiating a prompt action, sink should know the node location reporting the event. At the time of deployment sensor nodes are un-aware of their location. They obtain their location information through localization. Location of a sensor node cannot be pre-programmed as it is un-know where it will be deployed during its operational phase. The widely known solution to find the location is to equip each node with GPS. However, nodes enabled with GPS has the following limitations: (*i*) Power consumption by GPS reduces the battery life, which in turn reduces the network life time, (*ii*) GPS does not work well in indoors and dense forests, (*iii*) GPS antenna increases the size of sensor node, and (*iv*) Use of GPS will increase the cost of each sensor node.

Therefore, to obtain location information we need a technique which incur lesser cost and provide more accurate location information. One such technique is to use few location aware nodes or anchor nodes that are GPS enabled, and obtain the location information of other nodes from these location aware nodes. Localization techniques such as trilateraion and multilateration uses three and more than three beacon nodes (location aware node) respectively.

In this paper, we consider a grid environment, where nodes are deployed in a grid pattern. A localization technique using single beacon node is proposed and compared with an existing technique for similar environment called Multiduolateration.

Rest of the paper is organized as follows: Section 2 provides an overview of various localization techniques. Proposed localization algorithm is discussed in Section 3. Simulation and results are presented in Section 4, and few conclusions are drawn in Section 5.

II. Localization in Sensor Network

The technique of finding physical co-ordinates of a node in a sensor field is known as localization. Number of localization algorithms has been proposed in the literature, which can be broadly classified into two categories: (*i*) *range based* and (*ii*) *range free* . Range based localization algorithms use the range (distance or angle) information from the beacon node to estimate the location [2]. Several ranging techniques exist to estimate an unknown node distance to three or more beacon nodes. Based on the range information, location of a node is determined. Some of the range based localization algorithm includes: Received signal strength indicator (RSSI)[3], Angle of arrival (AoA)[4], Time of arrival (TOA)[5], Time difference of arrival (TDoA)[4]. A qualitative comparison of these methods is shown in Table - I.

Range-free localization algorithms use connectivity information between unknown node and landmarks. A landmark can obtain its location information using GPS or through an artificially deployed information. Some of the range-free localization algorithm includes: Centroid[6], Appropriate point in triangle (APIT)[7], and DV-HOP[8]. In centroid the number of beacon signals received from the pre-positioned beacon nodes is counted and localization is achieved by obtaining the centroid of received beacon generators. DV-HOP uses the location of beacon nodes, hop counts from beacons, and the average distance per hop for localization. A relatively higher ratio of beacons to unknown nodes, and longer range beacons are required in APIT [9]. They are also more susceptible to erroneous reading of RSSI. He *et al*. [9] showed that APIT algorithm requires lesser computation than other beacon based algorithms.

Range-based algorithms achieve higher localization accuracy, at the expense of hardware cost and power consumption. Range-free algorithms have lower hardware cost and are more efficient in localization. A brief review of different localization algorithms is presented below :

Simic *et al.* [10] proposed a range free distributed localization algorithm, in which each unknown node estimate its position within the intersection of bounding box of beacon nodes. In their proposed scheme a sufficient number of beacon nodes should be deployed in order to localize entire network.

Whitehouse [11] showed that the technique proposed by Simic *et al*. [10] fails in the localization of non-convex network (nodes not present in convex-hull of beacons), and under noisy range estimate.

Shang *et al*. [12] proposed a centralized algorithm called MDS-MAP, which work using pair-wise distance between nodes in the network. MDS-MAP provides a higher degree of accuracy with a complexity of $O(n^3)$, where n is the number of nodes in the network. A modified version of MDS-MAP called MDS is presented in [13]. MDS operate in two stages: In first stage, relative map of nodes is formed using pair-wise distance and in second stage relative map is transformed into the absolute map using few number of beacon nodes.

Zhang and Yu [14] proposed a range free localization algorithm called LSWD, in which unknown nodes are equipped with omni-directional antenna and are localized with a single mobile beacon node which is equipped with a directional antenna.

Khan *et al.* [15] proposed a distributed, iterative localization algorithm called DILOC, which estimate location of unknown nodes using barycentric co-ordinates.

Lee *et al*. [16] proposed a localization algorithm for indoors by employing jumper setting of nodes. Their algorithm operate in two stages: First, edge nodes are localized using internal division and then the remaining surface nodes, are localized using edge nodes.

Hasebullaha *et al*. [17] proposed a localization algorithm using a single anchor node and considered both the coarse grained, fine grained scenarios. In coarse grained, anchor nodes are equipped with larger number of antennas in order to cover full network area. In fine grained, beacon node is equipped with only one antenna, which rotates at a constant angular velocity. In the the technique proposed by Kumar and Varma [18] sensor nodes are equipped with directional antenna in order to determine the angle (position) with respect to anchor node.

III. Proposed Localization Scheme

In this section, we proposed a distributed range based localization algorithm for a grid environment called LUSA. We made the following assumptions:

(a) Sensors are deployed in a grid pattern as shown in Figure - 1.
(b) We identify three types of node: (*i*)*Beacon node:* A node which can locate its own position, and is usually equipped with GPS, (*ii*) *Special node:* Nodes which are perpendicular to the beacon node, and can determine their co-ordinates with respect to beacon node. For every beacon node there exist two *Special node*, (*iii*) *Unknown node:* Nodes which are un-aware of their location. They use localization algorithm to determine their position. Special nodes are treated as unknown nodes.

For localization in the proposed scheme, the beacon node initially broadcast its location information. *Special nodes* compute their distance from the beacon node using RSSI and determine their co-ordinates with respect to beacon node. After computing their location information, *Special nodes* also act as beacon node. *Unknown nodes* use trilateration mechanism to compute their location information.

We illustrate the localization process in the proposed scheme using Figure - 3. Node 12 in the figure is a beacon node, node 13 and 17 are special nodes, and the remaining are unknown nodes. Initially, node 12 broadcast its position. This is received by the special nodes 13 and 17 along with other unknown nodes within the transmission range of node 12 as shown in Figure - 3(a). Node 13, and 17 calculate their distance with respect to node 12, and localize themselves. At this stage all the nodes within the transmission range of node 12 has the position estimate of beacon node 12. In next stage, node 13 and 17 act as beacon nodes and broadcast their estimated position, as shown in Figure - 3(b), which is received by nodes 7, 8, 11, 14, 18, 22, and 23. These nodes localize themselves using trilateration. As more and more nodes gets localized, they act as beacon nodes. The process continues until whole network is localized. Figure - 2 shows the progress of localization in the proposed scheme in a 9×9 grid environment. Nodes encircled with same numerical value are likely to get localized at the same time instant.

IV. Simulation Results

We simulate the proposed scheme using Castalia simulator that runs on top of OMNET++. In the simulation, the transmitting power of nodes is considered to be -5 dBm, and the path loss coefficient (η) to be 2.4. A grid network of size 9×9 is considered for simulation. Metrics of interest in our simulation are: (*i*) *Localization time*; and (*ii*) *Localization error*, which is computed as following:

$$\overline{Error} = \frac{\sum_{i=1}^{N-R} ||\hat{\theta}_i - \theta_i||}{N-R}$$

where $\hat{\theta}_i$ is estimated position, θ_i is actual position, N is the total number of sensors in the network, and R is number of beacon nodes. We consider two scenarios: (*i*) Beacon node is placed at the corner of the grid as shown in Figure - 4, and (*ii*) Beacon node is placed at the middle of the grid as shown in Figure - 5. In each of the above scenarios we placed one beacon node, two special nodes and many unknown nodes in the grid.

The time for localization and the average localization error in the above two scenarios is shown in Table - II. It is observed from the Table - II, that localization error when the beacon node is at the corner of grid is lower in comparison to placing at the center of the grid where their localization proceeds parallely in four quadrants as shown in Figure - 6. As a result of parallel localization process, *localization error* propagates in more than one direction resulting in increase in the average localization error.

We compared the proposed scheme with Multiduolateration (MDL) which closely resembles with our proposed scheme. MDL is also proposed for a grid environment. It works using internal division. First, it localizes the edge nodes and then the remaining surface nodes. In MDL, four beacon nodes are placed at the four corners of the grid. For comparison with MDL, we also placed four beacon nodes at the four corners of the grid in LUSA. Metrices considered for comparison are localization time and localization error. We consider two scenarios: (*i*) without intereference, and (*ii*) with intereference. We consider the grid of following size: (*i*) Square grid of size: 9×9, and 6×6, and (*ii*) Rectangular grid of size: 9×5, and 6×4.

A. Localization Error

The geographical distribution of error without interference in LUSA and MDL for different grid size is shown in Figure - 9. Distribution of error in LUSA is shown in Figure - 9(a), 9(c), 9(e) and MDL in Figure - 9(b), 9(d), 9(f) for grid size of 9×9, 6×6, and 6×4 respectively. In each figure - dot '$\bullet$' represents actual position of node and symbol '$\times$' represents corresponding estimated position. The line joining '$\bullet$' and '$\times$' represents the magnitude of error. From Figure - 9, it is observed that LUSA has lower localization error than MDL. Higher localization error in MDL is attributed to the localization of surface nodes. Each surface node localize itself on the basis of four nearest edge nodes (left, right, above, below) using internal division. Localization of each surface node is independent of other surface nodes and depends solely on the edge nodes. Therefore, if any of the edge node does not get its exact location during edge node localization , it affects the location estimation of all those surface nodes which utilizes the edge node position for location estimation. We have shown the mean localization error in the corresponding grids for LUSA and MDL in Figure - 8(a).

Next, we consider the effect of interference on location estimation. Effect of interference in LUSA and MDL is shown in Figure - 10 where Figures - 10(a), 10(c), 10(e) corresponds to LUSA and Figures - 10(b), 10(d), 10(f) corresponds to MDL in a grid size of 9×9, 6×6, and 6×4 respectively. Effect of interference on the localization error in grid of different size is shown in Figure - 8(b). It is observed that MDL is heavily affected in the real environment as compared to LUSA.

B. Localization Time

Localization time of LUSA and MDL for different grid size is shown in Figure - 7. Higher localization time in MDL is attributed to the localization of surface nodes. In MDL, localization proceed in two stages : (*i*) First, it localizes the edge nodes, and (*ii*) Then, it localizes the remaining surface nodes. In the second stage, each surface node select a reference edge node based on shortest path. This contributes to higher localization time. Whereas, in the proposed scheme, localization of node's proceeds simultaneously and does not put any constraint on the selection of reference nodes.

V. Conclusion

In this paper, we proposed a localization method for grid network called LUSA. Three types of nodes: anchor, special and unknown node is identified. For every anchor there are two special nodes and they are placed perpendicular to the anchor node. Localization in LUSA is achieved by a single beacon node and two special nodes. Proposed scheme is compared with MDL, an another localization technique proposed for grid network. It is observed that the proposed scheme has lower localization error and lower localization time in comparison with MDL.

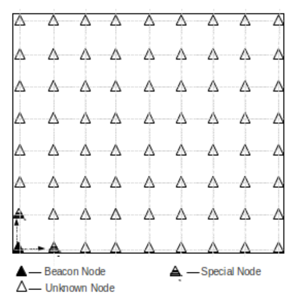


Fig. 1: Deployment of Beacon node, Special node and Unknown node in a grid.

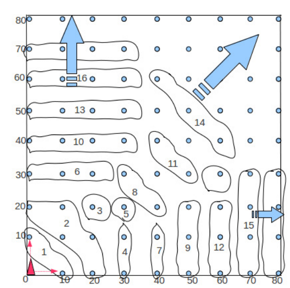
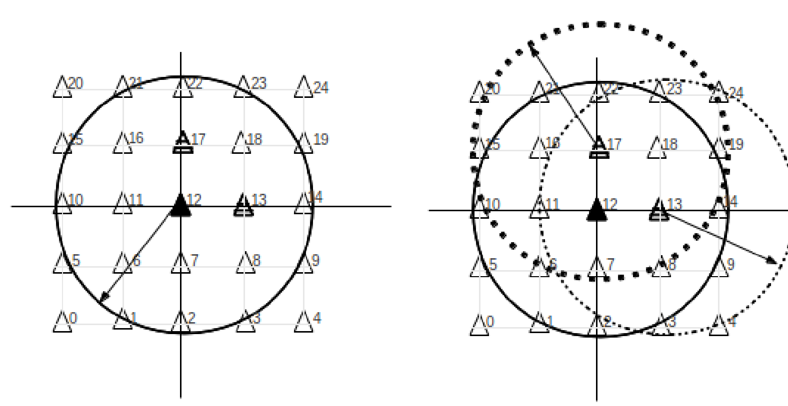


Fig. 2: Localization pattern

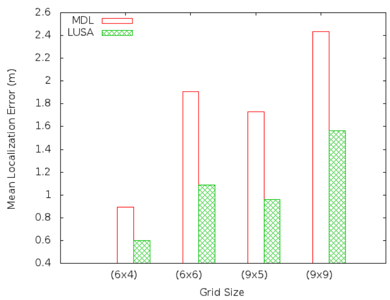


(a) (b)

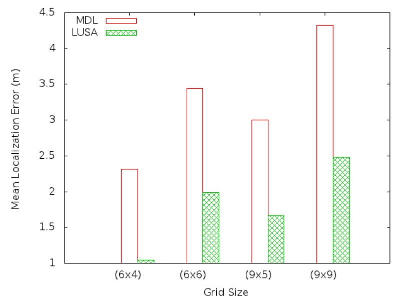
Fig. 3: Localization in LUSA.

TABLE I: A qualitative comparison of range based localization techniques

Technique	Addational Hardware	Issues	Precision
AoA [4]	Arrays of Microphone	Directivity, Shadowing	Few degrees
ToA [5]	None	Synchronization	Centimeters $(2-5$ cm)
TDoA [4]	Speaker, Microphones	–	Centimeters $(2-5$ cm)
RSSI [3]	None	Interference	Meters $(2-3$ m)



(a)



(b)

Fig. 8: Mean localization error (meters) in various grid: (a)Without interference, (b) With interference.

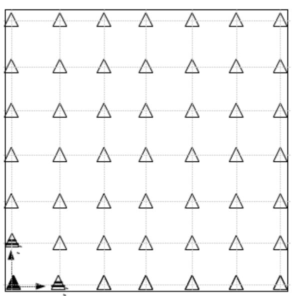


Fig. 4: Beacon node at the corner of grid

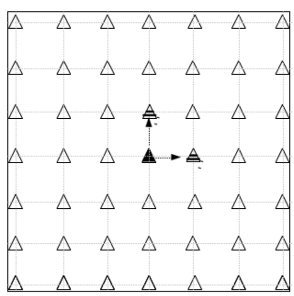


Fig. 5: Beacon node at the center of grid

TABLE II: Evaluation of proposed algorithm on placing beacon node at different places within the network.

Location of Beacon node	Localization Time	Localization Error
At Corner	4.636377959069	0.000175
At Center of grid	3.422031239100	0.001892

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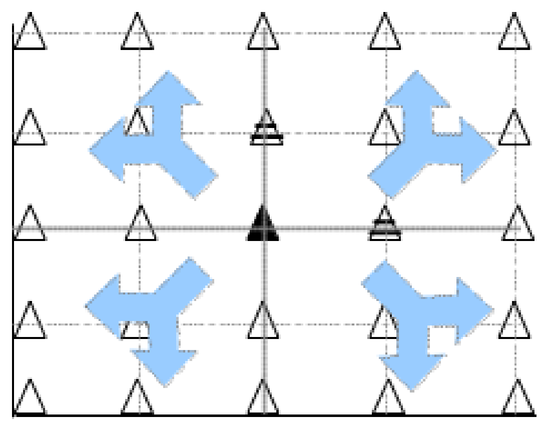

Fig. 6: Process of localization when the beacon node is placed at the center of the grid.

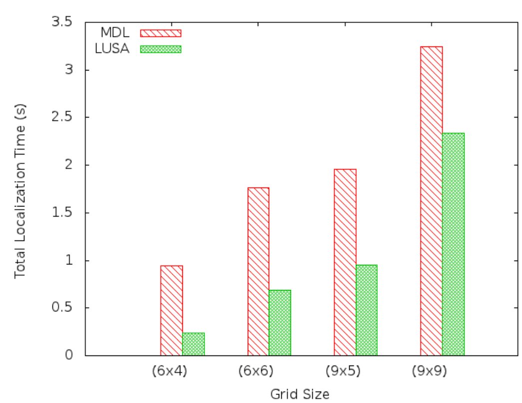

Fig. 7: Localization Time.

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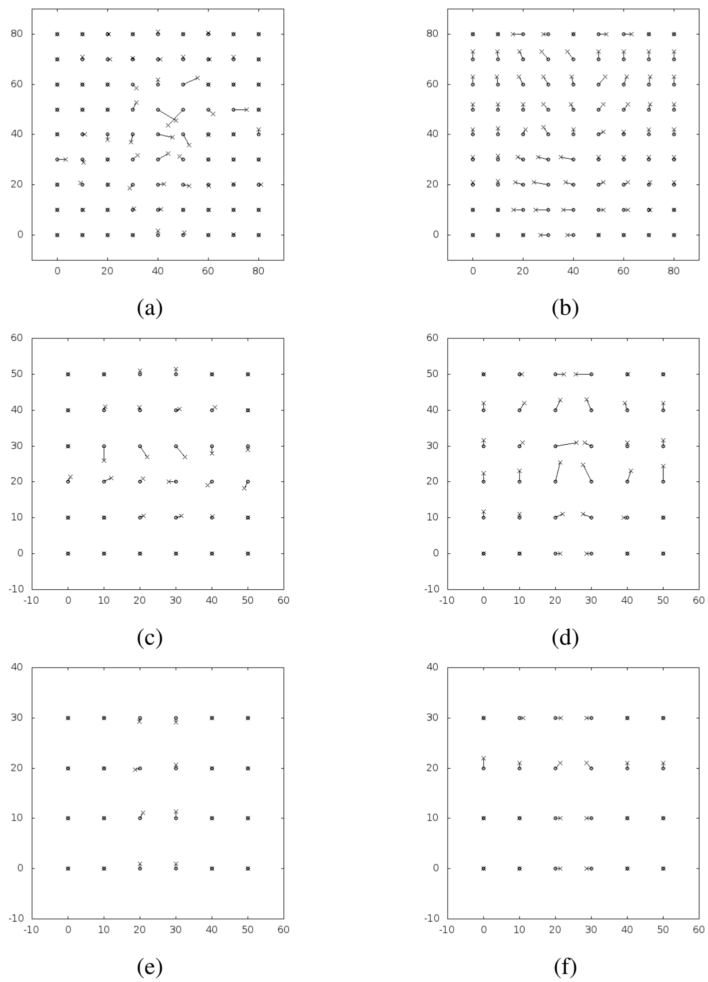

Fig. 9: Distribution of localization error without interference in LUSA and MDL.

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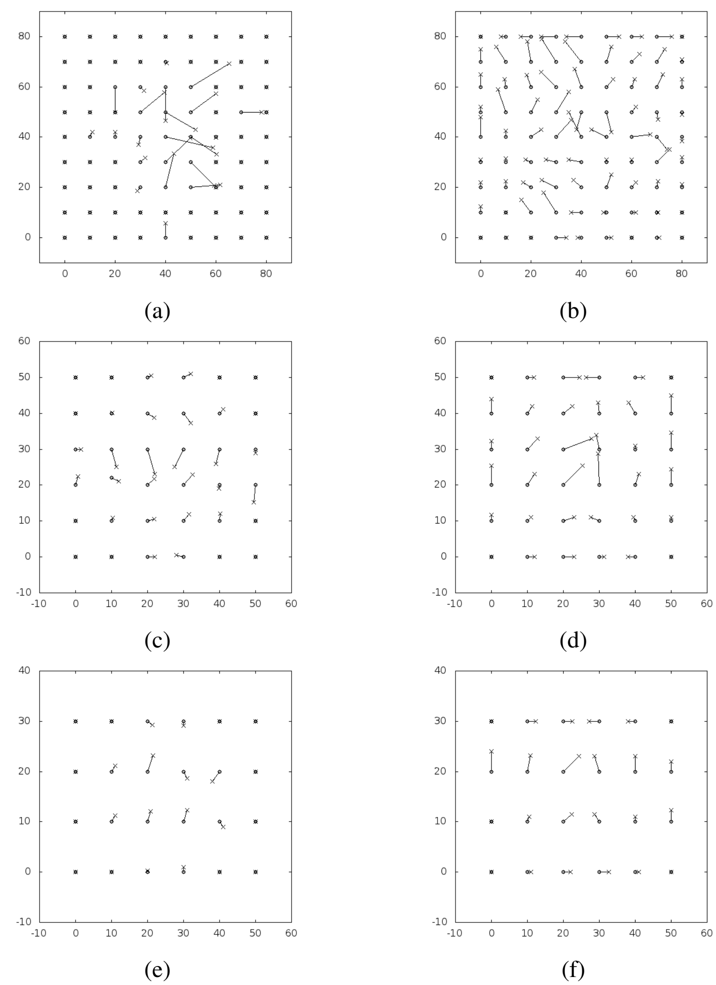

Fig. 10: Distribution of localization error with interference in LUSA and MDL.