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Maximizing the Network Life Time of Wireless Sensor Networks Using a Mobile Charger

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Abstract In Wireless Sensor Networks (WSN) the wireless nodes work untethered and have limited power resource. Wireless charging provides an alternative approach to recharge the batteries of the wireless nodes. Localization provides the position information. Previous works have considered either on recharging techniques or on the localization. This paper proposes a wireless recharging and also localization using a single mobile anchor. First the mobile anchor locates the static node later it receives the battery level. Finally if the battery of the static node is lesser than the threshold limit β, it recharges the static nodes wirelessly. Also the mobile anchor follows an energy efficient path V curve algorithm. The proposed method can handle the dynamic energy demand efficiently.

Keywords Wireless sensor network · Mobile anchor · Wireless energy transfer · Path planning · Back tracking algorithm

1 Introduction

A sensor is a transducer that converts any physical parameter into an electrical signal [7]. A sensor node is a fundamental unit of sensor network. It is comprised of on board sensors, microprocessor, memory, transceiver and power supply. Wireless Sensor Network (WSN)

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is an Adhoc network with a collection of huge number of sensor nodes. WSN is an important part of Internet of Things (IoT). It is for monitoring the environment [10], habitat and building. It is also used in target tracking [25]. Also it is used in many fields like intrusion detection [18], disaster rescue and in health care applications. Wireless sensor nodes sense the physical parameter and transmit the data to the sink by multiple hop mechanism, Sink node acts as a gateway between the WSN and the other network. WSN offers unique advantages like improved Signal to Noise Ratio (SNR), increased efficiency, improved robustness and scalability. However there are several challenges in designing the WSN such as hardware design, software development, deployment, localization, routing protocol and coverage.

In many applications localization plays a vital role. Each sensor node is subjected to transmit the data along with its current location. It must be accurate for effective data communication and computation. Therefore, effective localization system has to be developed in the advancement of wireless sensor networks. A number of prerequisites are considered in localization system which includes auto organization, robustness and efficiency. The main components of localization systems are distance or angle estimation, position computation and localization algorithms. The distance or angle estimation is obtained by calculating the distance or angle between the nodes. The important techniques used by localization system as in [1] are Received Signal Strength Indicator (RSSI), Time of Arrival (ToA), Time difference of Arrival (TDoA) and Angle of Arrival (AoA). Based on the RSSI, the distance between the two nodes is calculated. But it requires more complex hardware and is expensive. The distance between the two nodes is directly proportional to the time that the signal takes to propagate from one node to other. The time-based measures like ToA [9] or TDoA [19] are used for the distance estimation. This resultant time, is then multiplied by the propagation speed to find the distance. The limitation is that the local- clocks must be synchronised. In [17] the author has used an AoA which estimates the angle at which the signals are received and uses trigonometry laws to calculate the node location.

To compute the position of the node, there are several methods like Trilateration, Multilateration and Triangulation. In Trilateration, the unknown sensor node computes its position by the intersection of three circles formed by the reference nodes. In Multilateration, more than three reference nodes are used. In Triangulation method, instead of distance, estimation angles are used.

The localization algorithm is the vital part of localization system. This can be classified as Centralized and Distributed localization algorithms, Range based and Range free algorithms and One hop and Multi hop communication based algorithms.

Centralized localization algorithm requires a powerful central base station. It computes the location of each node accurately. However, the limitation is that, it requires the global information of the network. In [21] the author proposed a Multi-Dimensional Scaling–Mathematical Psychology (MDS–MAP) algorithm. It uses the shortest algorithm to find the distance between the nodes. The limitation of MDS–MAP is that, it requires a powerful central unit and is power consuming. In [3] the author has used a centroid along with the connectivity metric. A distributed localization algorithm is proposed in [14] in which each node determines its position based on the multi hop communication.

Range based techniques are more precise but they require more computation and various parameters like RSSI, ToA, TDoA or AoA. Range free localization algorithms do not require distance or angle measurements. So several range free algorithms have been proposed for reducing the complexity and cost. An Approximate Point In Triangle (APIT) algorithm is suggested in [8] for range free localization (RFL). In this the unknown sensor node use a set of signal strength from the anchor to determine the nearby three nodes forming a triangle within which it is located. In Adhoc Positioning System [16] a number of anchor nodes are used to locate the unknown sensor nodes. Each sensor node estimates its position in a multi hop way. A DV-hop, DV-distance and Euclidean methods are proposed.

2 Related Work

Few sensors in WSN are equipped with GPS [9] for localization problem. GPS will receive the data from the satellite; using the ToA it estimates its distance. Mobile anchors are used to assist the nodes in estimating their location. In Ref. [22] a mobile beacon is used for localization. [13] Proposed a range free localization algorithm with mobile anchor points. A distributed localization using mobile beacon is proposed in [2]. Flying anchors are used in [4] for sensor position determination.

The researchers then concentrated on the predetermined path of the mobile anchor. In [12] the author developed three different trajectories namely SCAN, Double SCAN and Hilbert. In SCAN the mobile anchor travels along either along X or Y direction. However, because of collinearity of beacons in SCAN, the author selected Double SCAN. In this, the anchor performs scanning in both the direction. It results in double resolution with loss in energy. Again the author developed Hilbert curve which does not cover the entire area.

Further in [20] the author developed two trajectories Circle and S curves. The limitation is, they leaves the corners uncovered.

The Z curve algorithm is developed in [11] to localize the node using three beacons. In this, the mobile anchor detours around the obstacle and catches up the trajectory. The limitation is that the area coverage depends on the size of the obstacle.

In [5] the author proposed a path-planning algorithm, along with obstacle avoidance. Here also, the limitation is coverage area. The V curve algorithm proposed by the author in [15] to reduce the path length travelled by the beacon so as to make the system energy efficient. The static and dynamic obstacles are avoided using back tracking algorithm.

In wireless sensor networks, the function of the sensor is to sense the data and also to communicate with the base station via Multi hop communication. Lack of energy even in a single node, results in serious effect. Instead of using solar and wind energy harvesting system, wireless charging can be used as it is easy to predict the energy and control the energy replenishment. A Wireless Rechargeable Sensor Network (WRSN) provides a wireless energy harvesting technique.

A joint energy replenishment mechanism is introduced in [24] to prolong the wireless sensor network lifetime. In [6] the author proposed a framework to facilitate multi-hop wireless charging by means of resonant repeaters. The author developed a post optimization algorithm that adds more stopping locations for charging vehicles. The efficiency is maintained by mutual inductance. A Push—Shuttle—Back (PSB) algorithm is developed in [23] to minimize the number of chargers and the optimal shuttling distance.

The author in [15] developed an efficient path for the mobile anchor for localization called V curve algorithm used a back-tracking algorithm to handle the static and dynamic obstacles. This paper enhances the previous work. It uses the mobile anchor for localization and also for recharging the already deployed sensors.

3 Limitations of Existing Schemes

There is collinearity problem in SCAN algorithm, the path length of mobile is doubled in DOUBLE SCAN algorithm, uncover edges in CIRCLE algorithm the author in [15] developed a V curve algorithm. Many of the literature surveys deals with the localization problem and wireless charging problem separately. This paper proses a wireless charging and localization using a single mobile beacon.

4 Proposed Wireless Charging Methods

4.1 Assumption

Wireless sensor network model has a field of LxL with 'n' static sensor nodes. The sensing radius of the static node is Rn and is randomly distributed in the field. A mobile anchor with radius Rm is introduced in the network. It travels in the field, in the predetermined V curve path. Rn varies based on the number of sensors, the field area and requirement of sensor. In most of the cases the Rm value will be greater than Rn.

4.2 Performance Evaluations

The network area of 200 $\times$ 200 is taken with 20 static nodes. The static nodes are charged with a battery of different charge levels. The mobile charger travels in the sensing field. The power of the mobile node is calculated as Pm = Pmc + Pt + Ps, where Pm is the power of the mobile anchor, Pmc is the power consumed by the micro controller, Pt is the power consumed by the transceiver and Ps is the power consumed by the sensor. In that path if Rm meets Rn, it locates the static node and checks the battery level of the static node. If the battery charge is less than the threshold value, β, 30% of the charge, then the mobile anchor recharges the static node wirelessly using induction principle. If the battery level reaches 80%, it stops charging and continue its path. When the mobile charger is about to get drained of its charge, it goes back to the base station for battery replacement. To maintain an uninterrupted operation of the network, the mobile anchor needs to put its full effort to recharge the nodes before their energy depletes.

Algorithm:

- Consider the sensing field LxL
- Place the static sensor nodes in Sij
- Move the anchor in the V Curve path
- Locate the static sensor node
- Receive the battery level of the static node
- If is less than β recharge it upto 80%
- Repeat the steps till the anchor reaches the destination

5 Results and Discussions

5.1 Without Charging the Static Node

The mobile charger range is selected such that it can travel in the V curve algorithm to provide 100% coverage. In this case the mobile charger moves in the predetermined path and locates the static nodes along with its % of charge. The time at which the mobile charger meets the static node and the charge remaining in the static node at the end of execution time is given in Figs. 1 and 2.

The visit order of the static node by the mobile charger and the static node's position is also given in Figs. 3 and 4.

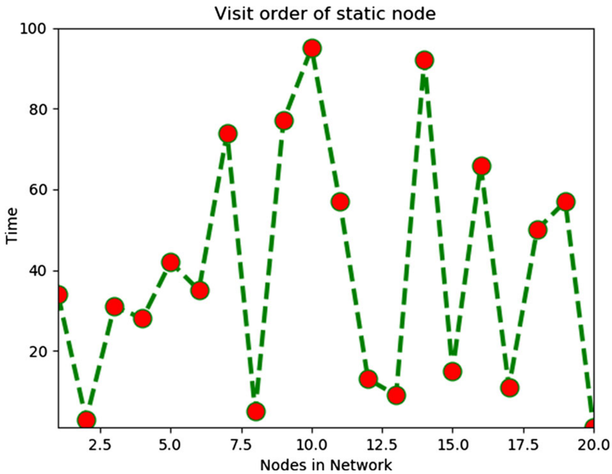

Fig. 1 Visit order of the static node

```
Total Nodes : 20                  Nodes visited: 16
                                 Note : 0-Not visited   1-Visited
Node 1 :    1 -->Time: 34 sec     ---> Charge remaining : 10.0%
Node 2 :    1 -->Time: 3 sec      ---> Charge remaining : 10.0%
Node 3 :    1 -->Time: 31 sec     ---> Charge remaining : 10.0%
Node 4 :    1 -->Time: 28 sec     ---> Charge remaining : 10.0%
Node 5 :    1 -->Time: 42 sec     ---> Charge remaining : 40.0%
Node 6 :    1 -->Time: 35 sec     ---> Charge remaining : 30.0%
Node 7 :    1 -->Time: 74 sec     ---> Charge remaining : 10.0%
Node 8 :    1 -->Time: 5 sec      ---> Charge remaining : 30.0%
Node 9 :    1 -->Time: 77 sec     ---> Charge remaining : 30.0%
Node 10 :   1 -->Time: 95 sec     ---> Charge remaining : 10.0%
Node 11 :   1 -->Time: 57 sec     ---> Charge remaining : 10.0%
Node 12 :   1 -->Time: 13 sec     ---> Charge remaining : 30.0%
Node 13 :   1 -->Time: 9 sec      ---> Charge remaining : 10.0%
Node 14 :   1 -->Time: 92 sec     ---> Charge remaining : 20.0%
Node 15 :   1 -->Time: 15 sec     ---> Charge remaining : 10.0%
Node 16 :   1 -->Time: 66 sec     ---> Charge remaining : 10.0%
Node 17 :   1 -->Time: 11 sec     ---> Charge remaining : 30.0%
Node 18 :   1 -->Time: 50 sec     ---> Charge remaining : 10.0%
Node 19 :   1 -->Time: 57 sec     ---> Charge remaining : 10.0%
Node 20 :   1 -->Time: 1 sec      ---> Charge remaining : 10.0%
                 Total time taken : 100 sec
```

Fig. 2 Time taken and the battery level

```
mobile_node_data.txt - Notepad
File  Edit  Format  View  Help
                 Data collected by Mobile node
-----------------------------------------------------

                 Node20 Found at [xpos:0][ypos:0]            Node20 -> Charge:40
                 Node2 Found at [xpos:70][ypos:10]           Node2 -> Charge:29
                 Node8 Found at [xpos:90][ypos:20]           Node8 -> Charge:78
                 Node13 Found at [xpos:120][ypos:40]         Node13 -> Charge:56
                 Node17 Found at [xpos:130][ypos:50]         Node17 -> Charge:75
                 Node12 Found at [xpos:150][ypos:60]         Node12 -> Charge:74
                 Node15 Found at [xpos:190][ypos:30]         Node15 -> Charge:43
                 Node4 Found at [xpos:100][ypos:90]          Node4 -> Charge:26
                 Node3 Found at [xpos:60][ypos:80]           Node3 -> Charge:35
                 Node1 Found at [xpos:20][ypos:60]           Node1 -> Charge:23
                 Node6 Found at [xpos:50][ypos:110]          Node6 -> Charge:63
                 Node5 Found at [xpos:40][ypos:120]          Node5 -> Charge:69
                 Node18 Found at [xpos:140][ypos:100]        Node18 -> Charge:25
                 Node11 Found at [xpos:200][ypos:130]        Node11 -> Charge:22
                 Node19 Found at [xpos:180][ypos:150]        Node19 -> Charge:32
                 Node16 Found at [xpos:110][ypos:160]        Node16 -> Charge:10
                 Node7 Found at [xpos:30][ypos:170]          Node7 -> Charge:10
                 Node9 Found at [xpos:20][ypos:190]          Node9 -> Charge:42
                 Node14 Found at [xpos:160][ypos:180]        Node14 -> Charge:24
                 Node10 Found at [xpos:190][ypos:190]        Node10 -> Charge:13
```

Fig. 3 Data collected by the mobile node

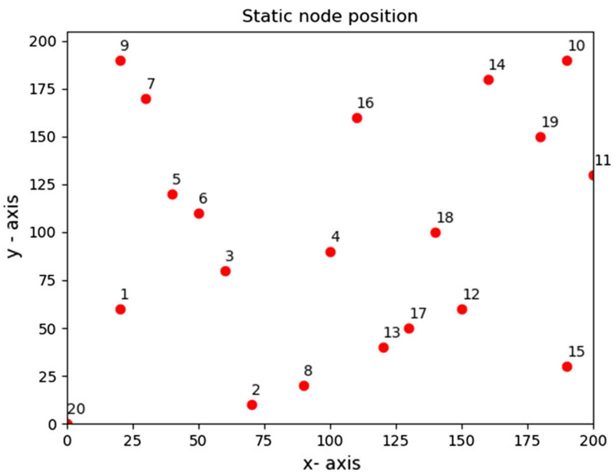

Fig. 4 Visit order and the Position of the static node

```
Total Nodes : 20                Nodes visited: 20

                    Note : 0-Not visited   1-Visited

Node 1 :   1 -->Time: 52 sec     ---> Charge remaining : 73.5%
Node 2 :   1 -->Time: 9 sec      ---> Charge remaining : 69.0%
Node 3 :   1 -->Time: 43 sec     ---> Charge remaining : 0.0%
Node 4 :   1 -->Time: 40 sec     ---> Charge remaining : 76.5%
Node 5 :   1 -->Time: 60 sec     ---> Charge remaining : 40.0%
Node 6 :   1 -->Time: 53 sec     ---> Charge remaining : 30.0%
Node 7 :   1 -->Time: 120 sec    ---> Charge remaining : 66.5%
Node 8 :   1 -->Time: 11 sec     ---> Charge remaining : 30.0%
Node 9 :   1 -->Time: 123 sec    ---> Charge remaining : 30.0%
Node 10 :  1 -->Time: 154 sec    ---> Charge remaining : 93.0%
Node 11 :  1 -->Time: 87 sec     ---> Charge remaining : 82.0%
Node 12 :  1 -->Time: 19 sec     ---> Charge remaining : 30.0%
Node 13 :  1 -->Time: 15 sec     ---> Charge remaining : 10.0%
Node 14 :  1 -->Time: 144 sec    ---> Charge remaining : 104.5%
Node 15 :  1 -->Time: 21 sec     ---> Charge remaining : 0.0%
Node 16 :  1 -->Time: 104 sec    ---> Charge remaining : 77.5%
Node 17 :  1 -->Time: 17 sec     ---> Charge remaining : 30.0%
Node 18 :  1 -->Time: 74 sec     ---> Charge remaining : 85.5%
Node 19 :  1 -->Time: 85 sec     ---> Charge remaining : 10.0%
Node 20 :  1 -->Time: 1 sec      ---> Charge remaining : 0.0%
Total time taken : 159 sec
```

Fig. 5 Time taken and the battery level

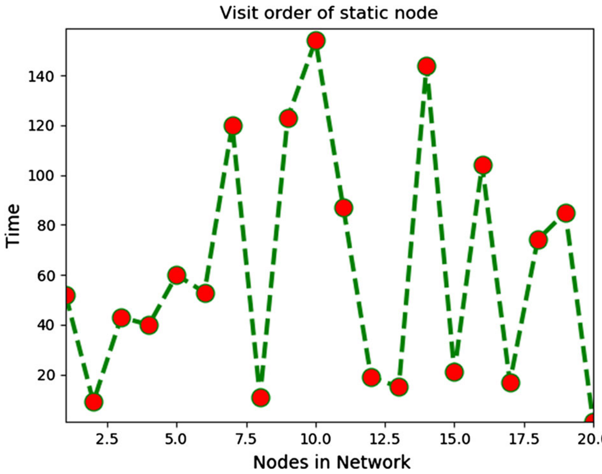

Fig. 6 Visit order of the static node

5.2 With Charging the Static Node

In this case, the mobile charger travels in the V curve path and locates the static nodes. The mobile charger receives the battery level of the static nodes. If it is less than threshold value that is β, 30%, the mobile charger, charges the static node wirelessly to 80%. This continues till it reaches the destination.

The time taken by the mobile charger to reach the static node and the battery level of the static node with charging is given in Figs. 5 and 6.

The visit order of the static node by the mobile charger and the static node's position with charging is given in Figs. 7 and 8.

```
mobile_node_data.txt - Notepad
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                Data collected by Mobile node
-----------------------------------------------------

                Node20 Found at [xpos:0][ypos:0]        Node20 -> Charge:40
                Node2 Found at [xpos:70][ypos:10]       Node2 -> Charge:29      Charged by Mobile node
                Node8 Found at [xpos:90][ypos:20]       Node8 -> Charge:78
                Node13 Found at [xpos:120][ypos:40]     Node13 -> Charge:56
                Node17 Found at [xpos:130][ypos:50]     Node17 -> Charge:75
                Node12 Found at [xpos:150][ypos:60]     Node12 -> Charge:74
                Node15 Found at [xpos:190][ypos:30]     Node15 -> Charge:43
                Node4 Found at [xpos:100][ypos:90]      Node4 -> Charge:26      Charged by Mobile node
                Node3 Found at [xpos:60][ypos:80]       Node3 -> Charge:35
                Node1 Found at [xpos:20][ypos:60]       Node1 -> Charge:23      Charged by Mobile node
                Node6 Found at [xpos:50][ypos:110]      Node6 -> Charge:63
                Node5 Found at [xpos:40][ypos:120]      Node5 -> Charge:69
                Node18 Found at [xpos:140][ypos:100]    Node18 -> Charge:25     Charged by Mobile node
                Node11 Found at [xpos:200][ypos:130]    Node11 -> Charge:22     Charged by Mobile node
                Node19 Found at [xpos:180][ypos:150]    Node19 -> Charge:32
                Node16 Found at [xpos:110][ypos:160]    Node16 -> Charge:7      Charged by Mobile node
                Node7 Found at [xpos:30][ypos:170]      Node7 -> Charge:0       Charged by Mobile node
                Node9 Found at [xpos:20][ypos:190]      Node9 -> Charge:42
                Node14 Found at [xpos:160][ypos:180]    Node14 -> Charge:24     Charged by Mobile node
                Node10 Found at [xpos:190][ypos:190]    Node10 -> Charge:13     Charged by Mobile node
```

Fig. 7 Data collected by the mobile node

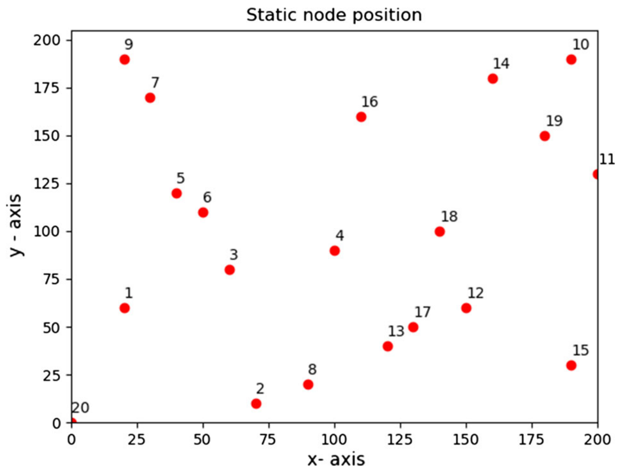

Fig. 8 Visit order and the Position of the static node

The network lifetime is compared between, with charging and without charging given in Fig. 9. It is clearly shown that the network is alive till 180 s without charging and alive till 367 s with charging. So the network lifetime time can be prolonged by the mobile charger.

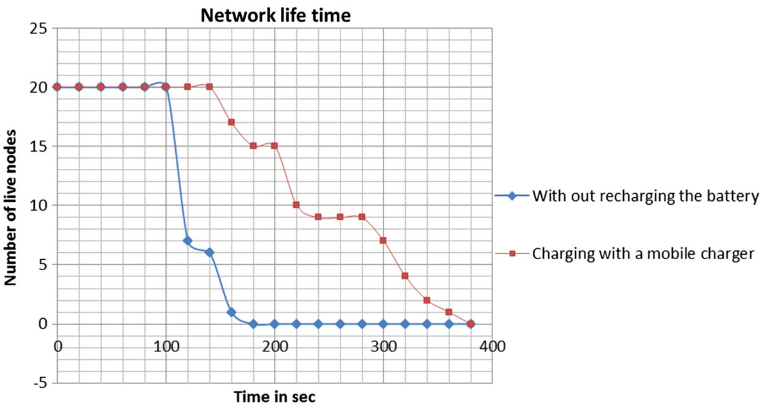

Fig. 9 Network lifetime comparisons

6 Conclusion

This paper addresses the localization problem along with the wireless charging. In WSN the sensor senses the data and communicates with the base station via Multi hop communication along with its location. If a node drains because of lack of energy causes significant changes in the network. An effective and controllable energy harvesting scheme has to be adopted in Wireless Rechargeable Sensor Network (WRSN). The advantage of this proposed method is that it improves the network's lifetime. Nevertheless, the drawback is, the mobile charger is bulkier so as to locate and energise the static nodes throughout the field.

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