Movable-Charger-based Planning Scheme in Wireless Rechargeable Sensor Networks

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***Abstract*—In order to extend basic functions of wireless sensor network (WSN), many researchers have begun to study rechargeable wireless sensor networks that use of Wireless Charging Technology to supply power for sensor nodes so that the wireless sensor networks have the sustainability. The main classifications of wireless charger antenna are Directional Antenna and Unidirectional Antenna respectively. We combine the advantages of charging antenna and the movable feature via motor to improve the problem that the existing covered area are less but including excessive number of sensors. In this way, we can achieve effective arrangement to cover all target sensor nodes by each chargers. In this paper, we propose a heuristic algorithm called Movable-Charger-based Algorithm (MCBA). It uses overlapping times as a main principle thus we can find out a minimum number of deployed chargers. Finally, the simulation results show that our proposed method can effectively deploys the position of chargers according various status of the factory.**

I. Introduction

Wireless Sensor Network (WSN) is widely used in human's life such as medical, yield rate detection in the factory, the war and the fish perception in the fisheries [4] [11] etc. Because the sensor nodes are inexpensive devices, they are very easy to obtain [12]. Since WSN commonly used in very wide range and its used scale is very huge, once the sensor node runs out of energy that it causes the original intention of WSN is lost [5] [13]. In an unattend WSN [3], many additional resource waste and environmental pollution will generated by some sensor nodes difficult to take them back. Therefore, some researchers have proposed a new topic called Wireless Rechargeable Sensor Network (WRSN) [1] [6][10]. These studies use solar, wind and other energy harvesting techniques be the main energy of sensor nodes. After the passage of time, WRSN develops out many greater variety of wireless charging technology. The most popular are:

1) Magnetic Resonance: The coil creates a magnetic field after power on. There is around the same frequency, then coil will produces shock and generates current.

2) Electromagnetic induction: The idea is come from Faraday's law. It has magnetic when the coil power on.

3) Micro-wave conversion: It originally has energy. And it often used to transmits voice and information. It can collects these frequency then translating as the available power.

4) Laser light sensor: Principle of Laser light as same as Solar technology, we used laser light hit the solar panels then converting to current.

The above four wireless charging methods have own most suitable environment. Due to the object of this study is in the indoor factories, so although the magnetic resonance can provides more distant, there are some interferences from metal equipment in a factory, and the transmission range of electromagnetic induction method is too short as well as laser light limits that there are not any obstructions between the transmitter and the receiver, therefore, we think that the microwave conversion method is most appropriate way to be our selected method for this environment.

WRSN must get over some challenges which include how to do the interference avoidance and planning optimization etc in a three dimensional space. Existing researches have aimed at energy needed of sensor node, reasonable position of sensor nodes, limitation of chargeable distance and charger loading. However, these methods still make a lot of deployment cost since too much chargers be placed. Because the charging coverage is not enough large, so we will add the motor on each charger so that the charging coverage becomes larger and flexible. Due to the type of charger is changed, the chargers planning can also change. Therefore, we propose a noval

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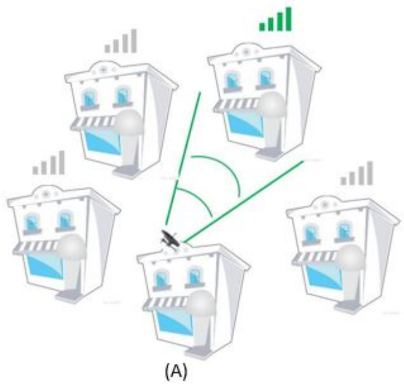

Fig. 1. Directional Antenna

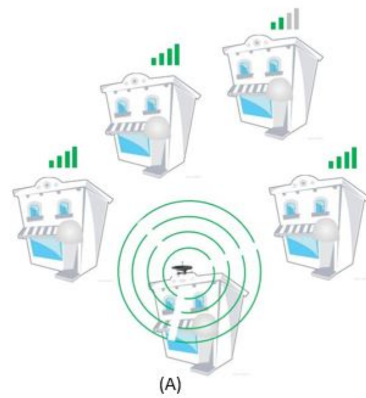

Fig. 2. Simulation results of Average Energy Consumption

algorithm with such concept thus achieves more complete charger deployment.

This paper is organized as follows: In section II, we introduce some related type of charging antenna and current developments of WRSN. In section III, we use linear programming to make a problem definition and further propose our solution . Section IV is the simulation results. Finally we will summarize the contribution of this paper, and simply distribute the future works.

II. Background

A. Micro-Wave Conversion

The devices of Micro-wave conversion generally classified as two types:

1) Directional Antenna: Signal radiation was Centralized in direction at an angle. Therefore it is suitable for open and long distance transmission with fixed orientation. Since its energy is highly concentrated, so its charging performance also high, but the charging range may small. Fig. 1 shows that A building has a directional antenna. And some buildings cannot receive the signal since they are outside the fan-shaped.

2) Omnidirectional Antenna: Signal range is global. it is suitable for short-distance or spacious place. But it has low charging efficiency because its energy divergence. Fig. 2 shows that each building also have sensor node. A building equipped with omni-directional antenna. All of the sensor nodes can received signal from A building.

B. Omni-directional Antenna

Currently, planning of WRSN has begun to study. It represents that there should be various devices has been trafficked on the market [8]. In [1], the authors design two algorithms for directional antenna device. One is Node Based Greedy Cone Selecting (NB-GCS) algorithm which based on a greedy principle in number of covered sensor nodes. The main concept is that to find out a set which includes maximum areas has not been covered by sensing range. After that, the authors proposed Pair Based Candidate Cone Generating (PB-CCG) to solve the problem from NB-GCS that NB-GCS may into the local optimal so that the number of chargers cannot reduce completly. PB-CCG use the concept of pair to make a decision which taking into account various interation of two sensor nodes. Both these methods can efficiently reduce the number of chargers, but they are still limited from inherent deficiencies of original hardware equipment. The most important point is the coverage range and the directional antenna especially. Because any chargers just provide conical coverage. In simple terms, in order to compensate for the lack of coverage, we have to increase the number of chargers. By this reason, we think that to add motor onto each charger is a best solution because it can support more coverage range thus decreasing the planning cost. Due to it is a noval architecture, so any algorithms must be redesign. In this paper, we propose a response to the movable charger algorithm to improve this drawback.

III. Problem Definition and Solution

WSNs have a lot of application scenarios, and the any deployment methods are different between various scenarios. We converge our focused issue into indoor scenarios. An important definition is that the sensor nodes can Freely deploy on the any entities in three-dimensional space. In other worlds, they can placed on any racks, floors and walls. Since intention of wireless technology is to avoid the cabling complex, so we consider that the charger should be placed on the ceiling [2]. Like just said, the original methods have to pay more of the cost, hence we use motor to enhance the charging range of charger. For better readability, we list common symbol table that shown as Table. I

The WRSN deployment space is regarded as a cuboid that Its length is L, width is W and height is H respectively. In order to efficiently avoid the interference from obstacles, we need to consider the actual situation thus achieve optimal coverage. So we placed the movable chargers in where is equal to H height as well as the sensor nodes are random distribute in the racks of factory.

Theoretically we can use aGPS to make WRSN space be coordination. This step will be completed before running algorithm so that any sensor nodes and chargars can obtain the three-dimensional coordinates of any necessary items. The effectual charging area between 180°-2θ. Effectual charging distance is R and the threshole of angle is defined as θ. By

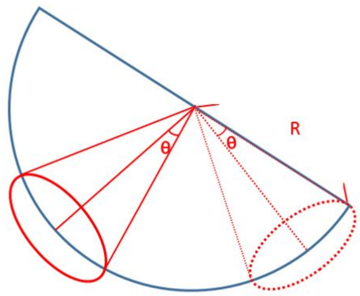

Fig. 3. Enhancement of chargeing range

this defiend way, the launched coverage range is lager than the original definition about 180°-2θ that shown in Fig. 3.

Due to the usage of each sensor nodes are different as well as the charging rate can be impacted from distance between charger and sensor nodes. Therefore, we define the charging rate is acceptable when the sensor nodes is inside the effectual charging distance R. And E is the unit of power consumption. We assume that each sensor power requirements are well known, and the limitation of the number of charger loading is P.

In order to minimize the number of chargers, we need to solve following problems:

- How to find out an optimal planning method let a charger can cover maximal sensor nodes?
- How to planning if charging requirements is lager than E?
- How to avoid the solution into local optimal?

According to above goals, we formulate our linear programming model:

$$Minimize \quad \Sigma_{i=1}^{k}|CR| \tag{1}$$

$$subject \quad to$$

$$p \geq 1 \tag{2}$$

$$0 \leq |CR| \leq \frac{|S|}{2} \tag{3}$$

$$0^{\circ} \leq \theta_i \leq 180^{\circ} \tag{4}$$

$$E \geq 1 \tag{5}$$

$$CR^{*} \in CR \tag{6}$$

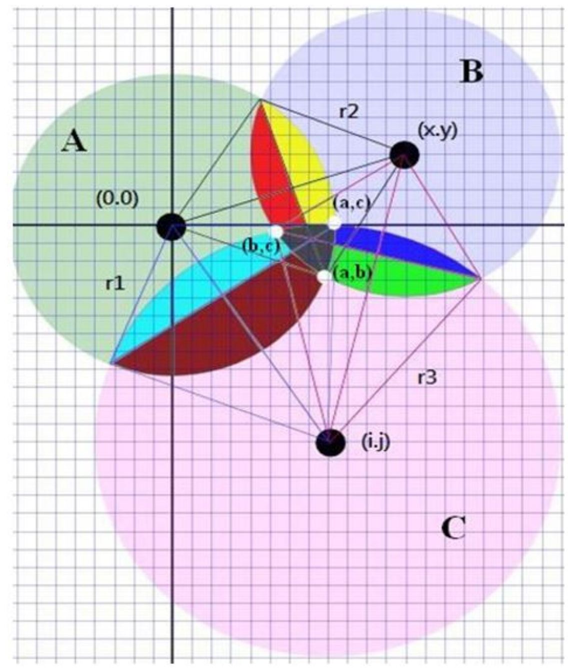

Fig. 4. Relationship between overlapping of circles

TABLE I. IMPORTANT SYMBOL LIST

Values	Definition
L	Factory length
W	Factory Width
H	Factory Height
R	Effectual charging distance
P	Limitation of number of sensor nodes for charger
θ	Thresheole of angle
$S = \{s_1, s_2, ..., s_n\}$	Set of sensor nodes
$CM = \{cm_1, cm_2, ..., cm_n\}$	Set of projection point of sensor nodes
K_i	Distance between sensor node i and cr
$CR = \{cr_1, cr_2, ..., cr_n\}$	Set of candidate charger
$CR^{*} = \{cr_1^{*}, cr_2^{*}, ..., cr_n^{*}\}$	Set of deployed charger
r_i	Radius of $i^{th}CR$
E	Energy consumption

A. Radius of Projection Points

Our proposed methods mainly use position of sensor nodes s be a initial point, which mapping to ceiling and then we can get cm. The radius of each cm is a_i that we use it be a center to extend a circle then calculate out CR. Its equation as following:

$$K_i = \sqrt[2]{(cm_i(z) - s_i(z))^2} \tag{7}$$

$$r_i = \sqrt[2]{(cr^2 + K_i^2)^2} \tag{8}$$

K_i is distance between i^{th} s and cm. Effectual charging distance R can be calculated by Pythagorean theorem.

B. Coordinate of Overlapping Coverage

We mainly use location of sensor nodes as the starting point to map to the ceiling. After that, we analyze the overlapping relation to get the candidate locations. For example,

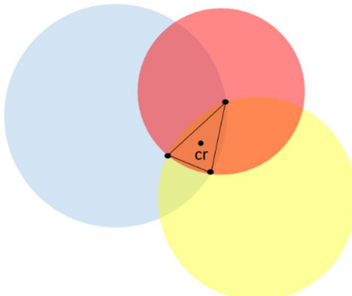

Fig. 5. The centroid of triangle withn three circles

TABLE II. MOVABLE-CHARGER-BASED ALGORITHM

Input: $S = S_1, S_2, ..., S_n$
Output: CR^*

BEGIN
Step 1: Find out the CM in a circle whith radius R and H hieght
Step 2: Find out the coverd points of CM
Step 3: Take out CR which cover S is maximal as well as not overlapping with S
    while CR do not cover S complete
        if $E > 1$
            start to scan S
        end if
    end while
END

Fig. 4 shows that $G(a, b)$, $G(b, c)$,$G(a, c)$ can caculated out by following simultaneous equations:

$$G_{(a,b)} \begin{cases} (a-0)^2 + (b-0)^2 = r_1^2 \\ (a-x)^2 + (b-y)^2 = r_2^2 \end{cases} \tag{9}$$

$$G_{(b,c)} \begin{cases} (b-x)^2 + (c-y)^2 = r_3^2 \\ (b-i)^2 + (c-j)^2 = r_2^2 \end{cases} \tag{10}$$

$$G_{(a,c)} \begin{cases} (a-0)^2 + (c-0)^2 = r_1^2 \\ (a-i)^2 + (c-j)^2 = r_3^2 \end{cases} \tag{11}$$

The following equation can find out the centroid of triangle. Use of such centroid of triangle can derived out CR. cr is a centroid of triangle of three circles that shown in Fig. 5. It ensures that CR must be able to cover $G(a, b)$, $G(b, c)$,$G(a, c)$.

$$CR = (\frac{a_1 + b_1 + c_1}{3}, \frac{a_2 + b_2 + c_2}{3}) \tag{12}$$

C. Movable Charger Algorithm

The set of sensor nodes is formulated as $S = \{S_1, S_2, ..., S_n\}$ and the set of projection point is formulated as $cm = \{cm_1, cm_2, ..., cm_n\}$. The candidate charger is respresented as $cr = \{cr_1, cr_2, ..., cr_n\}$ which $CR\{cr|cm \in cr, cmiscoveredviacr\}$. Our proposed algorithm choose the sensor node which has maximal number of overlapping. And the solution must be limited by $CR^* \in CR$. Table. II is our proposed algorithm called Movable-Charger-based Algorithm.

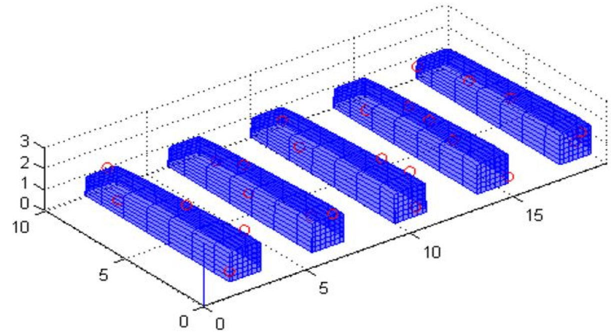

Fig. 6. 3D deployed scenario

TABLE III. PARAMETER SETTING

Metric	Values
Size of the venue	$25 \times 15m^2$
The number of sensor nodes	25
Effectual charging distance	$4m$
Rack height	$3m$
Loading quantity of Charger	6
The number of racks	5

IV. SIMULATION

A. Simulation Parameter Setting

We use MATLAB as our simulator [9]. The environment is constructed in a 20 × 15 square meters factory. We randomly deployed 25 sensor nodes in five racks which has 3 meters height. The Effectual charging distance is 4 meters. The details are listed in Table. III, and the Fig. 6 express the three-dimensional schematic that the red points are sensor nodes as well as the blue cuboids are racks. In order to simulate a more actual factory environments, we will not set the sensor nodes on any aisles.

B. Simulation Results

Fig. 7 shows the simulation scenario in two-dimension. We can saw that there are many green circles which represent the situations of projection. The problem will be converged to another problem that we must find out the areas which have maximum number of overlapping. Our proposed algorithm use the greedy principle to achieve this goal. In the 25 sensors, we need to spend 6 chargers to cover whole sensor nodes in factory. And this is a best use situation because there are at least 3 sensor nodes be covered by a charger. Even a charger can supports requirements from 5 sensor nodes in some case. that shown in Fig. 8. In this scenario, MCBA needs 6 charger only but the original method need 10 charger to cover all of sensor nodes. Many people will have questions that how we promise MCBA can provide best results? We have an important view that as long as any sensor nodes do not instantly dropped to 0%, we can rescue them immediately by mobility of motor provided. In other worlds, although our method causes there is less remaining power, but whole WSN

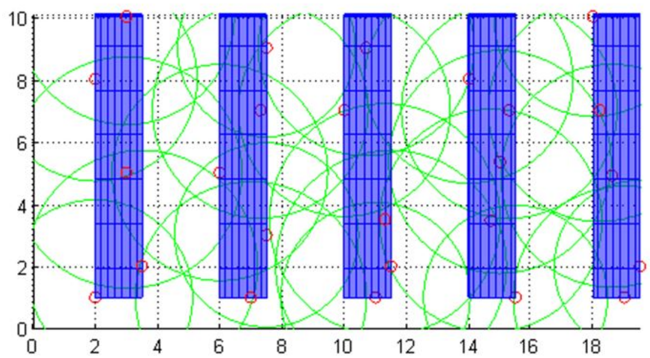

Fig. 7. Sensor nodes projected on the ceiling

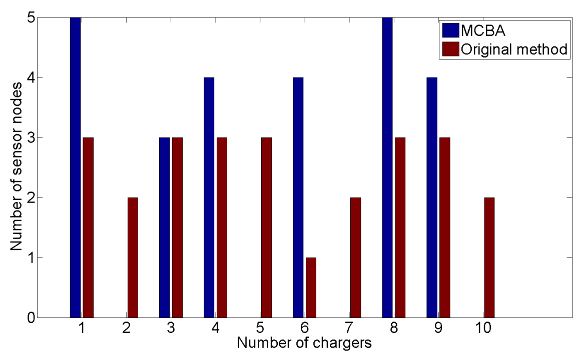

Fig. 8. Simulation results of number of sensor nodes and chargers

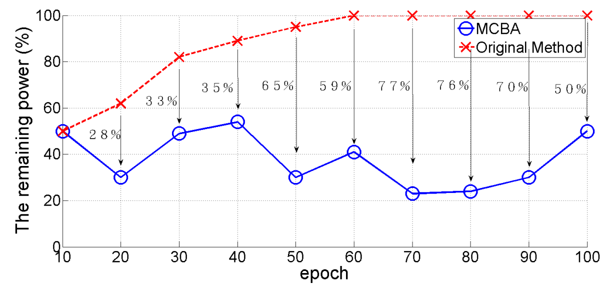

Fig. 9. Simulation results of number of sensor nodes and chargers

still within the acceptable range that shown in Fig. 9. The black arrow indicates the amount of power savings. For whole network, this method can save an average of 80% of electricity.

V. Conclusion and Future Works

To make the network lifetime of WSN extension, many scholars have begun to study WRSN. They think that renewable energy is a best solution that convert energy to sensor nodes by solar, hydro, wind, etc. Currently, the energy harvesting technologies provide more strength and flexibility. A best exmaple is electromagnetic waves technology. It make wireless charging scheme is a trend and a hottest topic.

In this paper, we proposed a Movable-Charger-based Algorithm which enhance sustainability of the original methods. The most important contribution of our study is that we add concept of motor on sensor nodes to let the charging range become larger. In this way, we can save very much planning cost since reduction of placed chargers.

We believe that the movable charger can bring protection of the environment. So this study has to carried out in that future. For vision of the future, we will concern the obstacle problem [14]because we did not consider to the shadowing effect in this paper but it no doubt is the existed problem. Further we will design an appropriate scheduling scheme for movable-charger-based scenario [7] due to the planning just a initiation. So to deal some problems from the unexpected situations, some realtime methods to reflect current usage.

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