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An Efficient Charger Planning Mechanism of WRSN using Simulated Annealing Algorithm

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***Abstract*—The limited energy of sensor can be regarded as an optimization problem aimed at finding some useful deployment strategies for a set of chargers, but it typically might spend a lot of computation costs. In order to provide a *good* solution for reducing a large number of chargers caused by all the sensor nodes need to be covered, add the motor to some particular chargers is an alternative solution. That is why some recent studies attempted to develop the movable charger-based algorithms to enhance transmission range. However, most movable charger-based algorithms are the greedy or rule-based algorithms, they will easy fall into local optimum at early iteration and consequently the end results will far away to global optimum. That is why it still has rooms for improvement. This paper will present a simulated annealing-based algorithm to improve the deployment result of wireless sensor network. The simulation results show that the proposed method can reduce the number of chargers significantly for full coverage.**

***Index Terms*—Wireless rechargeable sensor network, network planning, and metaheuristic algorithm.**

I. Introduction

With the advance of network technologies, we are able to use network devices to construct a more convenient environment to human. In order to meet growing demands of human, wireless sensor network (WSN) [1] has been proposed to understand the status of the environment, monitor the specific regions, or response to the things for their mission. This technology bring a huge progress in many areas as long as these areas need automatic process. It can be easy to expected that these WSN technologies can provide some smart approaches without increasing much more additional manpower. And WSN devices can be set in any places where are difficult to reach by human [2]. For instance, WSN was often used in the medical technologies. We were able to monitor body condition through a tiny sensor so that we will able to immediately deal some emergency. No matter the war technology, biological observation and every technologies [3] are also suitable for use of WSN.

However, there are still several open issues have to be solved. One of most important problem is the power saving issue [4] due to the energy of sensor nodes are limited by battery capacity. If we do not take into account this issue, it cannot guarantee that the basic functions of WSN will run continuously. As well as some environments require plan a large scale WSN which needs a lot of sensor nodes, it will not easy to withdraw out these dead sensor nodes, especially some environments are different to reach by human. The environmental pollution consequently will be generated. To deal with the mentioned problems, a large number of studies presented the lifetime extension schemes by reducing power consumption through adjusting the sleep schedule of each sensor nodes in a WSN. But the energy of the sensor nodes may still run out as long as they have worked for a long time, hence sustainability of WSN has begun to research.

Wireless rechargeable sensor network (WRSN) [5] [6] has been introduced to solve the lifetime problem. The main concept of WRSN is that use of wireless charging technology to help some sensor nodes which has lower remaining power to work. There is a premise that the sensor nodes must support rechargeable technology. Because power source can be the solar power, wind power, or hydro power, they cannot directly convert into power, hence the specific component is needed to get these energies. The sensor nodes then can continue to work until hardware damaged if they are able to convert such power source to alternating current. Since not every charging methods can be used in every environment, such as the solar power cannot be applied in indoor environment. For the perspectives of power translation methods, the wireless charging mechanism can be divided into four types which are magnetic resonance, electromagnetic induction, micro-wave conversion, and laser light sensing. Due to this study focus on the indoor environment, micro-wave conversion will be used as the focus.

The difference between WRSN and WSN is that WRSN must consider to charger planning issue but WSN is not. This issue is a preliminary before the WRSN operations. WRSN planning has still much challenges. The reasons is that there are contains huge interactions will be happened from chargers and sensor nodes, thus, we cannot deploy chargers without the consideration of situations of sensor nodes. That is why this issue become a complex problem, even it also has the RF interference problem, difference of charged demand of each sensor node problem and local optimum avoidance problem and other related problems. In order to ensure the WRSN function can be a normal, sustainable and exhaustive work. We use a metaheuristic algorithm [7] to find out an optimal solution for charger planning for WRSN. The simulation results show that the proposed method can avoid fall into local optimum with only a few additional computation costs as well as it can provide WRSN a more stable working environment.

The rest of the paper is organized as follows. Section II

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introduces background and related works of WREN and some preliminaries. Section III will give the problem definition. Section IV presents our proposed metaheuristic algorithm. The simulation presents in section V. Finally, we will summarize research contributions and discussing the future works in last section.

II. Related Works

Several wireless charging technologies have been presented to prolong the lifetime of WSN in recent years, each of them has its pros and cons. In this section, a number of wireless charging technology will be discussed. The motivation of this resarch is the charger planning mechanism of [8] will easy fall into local optimum, thus we will try to use a metaheuristic algorithm to improve the final results. For better readability, the description of previous work and selected metaheuristic algorithm are as follows.

A. Wireless Rechargeable Sensor Network

Wireless charging technologies typically can be divided into two categories according to the types of energy sources. The first type is nature power which is including solar power, wind power and hydro power. This kind of technologies have a common features that they has energy translation mechanism to convert nature power to the electric current which able to use by any devices. There are not any places have such environment which has an endless supply of natural energy. For instance, solar power can not continuous supply the indoor devices. Wind power and hydro power need special infrastructure and specific location so that these two technologies are not suitable for use in an urban environment. In order to decrease the impact of control variables, wireless charging technologies gradually to go along to second category.

The second type of wireless charging technologies always use the hardware to implement the power reception and transmission. This type can be subdivided into four four ways:

1) Magnetic Resonance: The concept is that the coil will creates a magnetic field [9], then coil will produces shock and generates current if there is same frequency around the it. Resonance phenomenon not only can generates the current, but also increasing the transmission power as long as resonance phenomenon becomes stronger. The advantage of magnetic resonance is that its transmission power is larger than the other types of wireless charging technology so that the effectual charging distance, and charging efficiency are the best. Electric car is one of well-known applications by using this kind of solution.

2) Electromagnetic induction: Transmitter and receiver are also have a coil respectively. When the coil of transmitter is energized, the electric current will produced magnetic force. Then current will be produced in the coil of receiver since the sensed electromagnetic signals will change the magnetic energy conversion [10]. This type of wireless charging technology has a limitation that the distance of transmitter and receiver cannot greater than $5mm$. Once the distance over $5mm$, the rechargeable devices may encounter overheating problems. Efficiency of electromagnetic induction is currently the best wireless charging technology. A common application like electric toothbrushes and so on.

3) Laser light sensing: Principle of laser light sensing [11]is similar to solar power that the light power translate to the electric current. Though it has avoided most of environment impact, it also has a main limitation that the receiver must places in front of charger and there is not any obstructions. Therefore, laser light sensing is not suitable for use in people's livelihood technology. It always apply in military purposes.

4) Micro-wave conversion: Radio frequency already has energy [12]. We use this energy to deliver the information. According to our common sense, we can boldly speculate such energy can also translate to electric current for any rechargeable devices to use. Through the efforts of many researchers, this speculation has come true. This type of wireless charging technology has two ways for RF transmission. First is directional transmission, and second is omni-directional transmission. Directional transmission means that the RF direction is fixed so that the transmission power will be concentrated. In this way, although it has smaller transmission range, but has stronger power. Omni-directional transmission can emitted RF to all directions. But its transmission power will be relatively divergent.

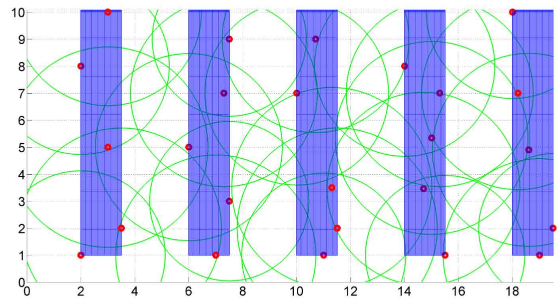

Fig. 1. Sensor nodes projected on the ceiling

B. Movable-Charger-Based Algorithm

In the previous study [13], we use the directional transmission to design the WRSN mechanism, because the chargers will place on the ceiling then emitted down the RF to cover the sensor nodes, called Movable-Charger-based Algorithm (MCBA). In that way, it will reduce many cabling costs. The coverage is too small so that we must plan more chargers to cover all of sensor nodes. In order to solve this problem, we add the motor to any chargers that the transmission range has huge improvement.

The MCBA usually has two steps to find the solution. First one is to mark candidate chargers: We firstly coordinate the entire environment, we can easy to get the position of chargers and sensor nodes by aGPS, and then we map transmission range of sensor nodes to the ceiling [14]. After MCBA calculated all the information of the circles on the ceiling, IT will able to make sure the sensor nodes can be charged by the deployed chargers, as long as the charger is placed in the overlapping area between each adjacent circle that shown in Fig. 1. The second step is that to find the optimal deployed position from the set of candidate points. If the intersections of circles on the ceiling have increased, it means that the overall coverage will also be increased at the same time. According to this rule that the MCBA then can able to choose the candidate position which will cover the most sensor nodes. That is why MCBA we will find out a better solution to cover all of sensor nodes, but does not require a larege of chargers.

III. Problem Definition

Wireless charging technology can be applied in many environments. Each WRSN environment has different deployment ways which can simply to be divided into indoor and outdoor deployment. The focus of study is on indoor charger planning. In the indoor scenario, reduction of the wiring complexity is a most important goal, thus we stipulate that the chargers can be installed on the ceiling only, and then they emit RF down to all of deployed sensor nodes. Therefore, the solution range will converge to a two-dimensional space.

In the previous work, we have proposed MCBA to solve charger planning problem. The simulation results of MCBA shown that it can provide an efficient planning way with fewer number of chargers. However, MCBA is a greedy-based algorithm that is easy to fall into local optimum, because it only take into account the area which has most overlapping from the charging range of other sensor nodes. In order to make sure the accuracy and fairness, the experiment scenario will follows the MCBA work environment. The sensor nodes can be placed on the every entities. And each charger is also equipped with a motor to extend the charging range. For better readability, we list common symbols table that shown as Table I. Since each charger has limited charging range, even some times the different chargers have different effectual charging distance, so that we define the effectual charging distance E as following:

$$E = \sqrt{(C_{ci}(z) - S_i(z))^2}. \tag{1}$$

According to the mentioned expected goals, we define a linear programming model for this problem:

$$\begin{aligned} &Minimize\ C_e \\ &\quad s.t. \\ &\qquad \sum_{j=1}^{m} P_{i,j}^S(d) \geq C_i^S \\ &\qquad P_{i,j}^C \geq 1 \\ &\qquad 0^\circ \leq \theta_i \leq 180^\circ \end{aligned} \tag{2}$$

We know that a larege of chargers will bring more costs, hence the major goal is to minimize the number of the chargers. Because of we need to ensure the WRSN can sustainable working, the definitions of several restrictions are as following. The first restriction is to limit received power must be larger than the consumed power, otherwise sensor nodes will be rapid death due to the power is in short supply. The details are given in next section. $P_{i,j}^C \geq 1$ represents that a sensor node must be covered by at least one charger. Practically, all of sensor nodes have demand to be charged so this value cannot less than 1. θ_i is the rotation angle of motor that each charger works on a plane so this value is defined between 0° to 180°.

TABLE I
Important Symbol List

Values	Definition
$P_{i,j}^S$	the power is received by the i^{th} sensor node from the j^{th} charger;
G_c	a value of antenna gains of chargers
G_s	a value of antenna gains of sensor nodes
η	a value of rectifier efficiency
L_p	polarization loss
λ	wavelength of RF
$d_{i,j}$	the distance from i^{th}sensor to j^{th} charger
β	an adjustable parameter in indoor environment
$P_{i,j}^c$	amount of energy is generated from the j^{th} charger to the i^{th} sensor node
C_i^S	power consumption of i^{th} sensor
C_l	at least number of sensor nodes which can cover the entire area
E	effectual charging distance
C_c	set of candidate chargers
C_s	ser of sensor nodes which are covered by C_C
C_e	set of finalized position of deployed chargers

IV. Proposed Mechanism

A. Wireless Charging Model

For each charger has own effectual charging distance, the effectual charging distance defined as that the charging power is greater than the power consumption of sensor nodes. We further define the wireless charging model that shown in the follows:

$$P_{i,j}^S(d) = \frac{G_c G_s \eta}{L_p} \left(\frac{\lambda}{4\pi(d_{i,j} + \beta)}\right)^2 P_{i,j}^C, \tag{3}$$

where $P_{i,j}^S(d)$ represents that the power is received by the i^{th} sensor node from the j^{th} charger. $P_{i,j}^C$ represents that the amount of energy is generated from the j^{th} charger to the i^{th} sensor node. G_c is a value of antenna gains of chargers, and G_s is a value of antenna gains of sensor nodes. L_p is polarization loss. λ represents wavelength of RF. η is a value of rectifier efficiency. And β is an unique adjustable parameter in indoor environment. By Eq. (3), we can calculated received power for each sensor node. Under reasonable circumstances, the received power must larger than the power consumption, hence we define the following limitation:

$$\sum_{j=1}^{m} P_{i,j}^S(d) \geq C_i^S, \tag{4}$$

where C_i^S represents that the power consumption of i^{th} sensor nodes. Every sensor nodes may have different power consumption. It means that there are some sensor nodes has more works to consume more power so that they must need more than 1 charger to cover. By Eq. (4), we can found how many number of charger just to cover them.

Since the main goal of this study is that to solve local optimum problem from MCBA. The preliminaries is same to MCBA that using overlapping area of circles to find out some candidate locations which can deploy chargers then record them to a set. We can use this set as the input data for proposed algorithm. And we can use following equation find C_l sensor nodes can exactly cover the entire area:

$$C_l = \frac{\sum_{i=1}^{n} S_i}{S_{max}}. \tag{5}$$

The principle is that C_l can be found through the number of all sensor nodes divided by maximum number of sensor nodes covered by chargers. The former is summation of S_i, and latter is S_{max}. All of those values can get by initialization of MCBA that shown in line 1-2 of Algorithm 1.

B. SA-Based Charging Algorithm

The reason by using SA as basic method is that WRSN environment may frequent changes so that the requirement of chosen method need a quicker convergence rate, therefore the SA is the better one rather then other meta-heuristic algorithms [15]. In main body of our proposed SA-Based Charging algorithm (SABC), the first step is that randomly generating $|C_l|$ candidate chargers by Eq. (5). Next it will randomly choose a candidate charger then decide whether it is replaced or to add a byte randomly that shown in lines 6-9 of Algorithm 1. The initial value of variable A need to be set a very small value at the beginning that 0.1 is chosen value in this case, and this value will plus a reciprocal of running times if the better solution cannot be found. Another variable T is set to randomly between $0-1$. The propsoed mehtod will replace an original candidate charger if T is greater than A, otherwise to add a candidate charger and A will increase as the number of iterations. But A will be updated when the new candidate charger is added. The proposed algorithm will allow the replacement process as long as the replaced candidate charger is better than the original candidate charger, otherwise it will then maintain the status quo. In order to avoid fall into local optimum, the proposed method still choose the poorer candidate charger if the SA condition has meet that shown in line 10-13. In these ways, we can found the optimum chargers planning solution.

For better readability, we depict a schematic. In Fig. 2, there are three lists in SABC. first list records each candidate charger number. Second list records sensor nodes number which are covered by each charger. Third list records whole information of all of sensor nodes. Number 1 represents that sensor node is covered, otherwise denoted as 0. When $T > A$, the proposed algoritm will randomly choose a candidate charger to do the replacement process. In Fig. 2(b), chosen candidate charger is better than original candidate charger then replace the corresponding value. If not, it will not be replaced that shown in Fig. 2(c). When $T < A$, the proposed algorithm add a new candidate charger. In Fig. 3, it will adopt such result if added candidate charger is better than original candidate charger. Another case can refer to Fig. 3(c).

Algorithm 1 SA-Based Charging algorithm (SABC)

Input: $C_c, C_s, C_{s,max}$
Output: C_e
1: Initial Calculated size of C_l;
2: Randomly choose the candidate chargers from C_c to fill C_l ;
3: **repeat**
4: Randomly choose a candidate charger from C_c;
5: **If** $A > T$
6: Randomly producing a new bit ;
7: Add it to the just produced candidate charger;
8: **Else**
9: Randomly choose a candidate charger from C_l;
10: Replace it with the just produced candidate charger;
11: **End**
12: **If** the subsolution is the best $|| \; A^{'} < F^{'}$
13: keep the solution after replacement;
14: **Else**
15: Keep the original C_l
16: A= A+1/times
17: **End**
18: **until** Find out a C_e that all of sensor nodes are covered by chargers

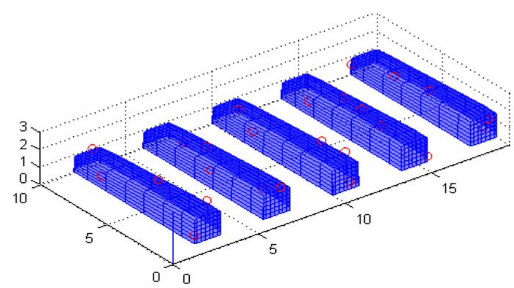

Fig. 4. 3D deployed scenario

V. Simulation

A. Simulation setting

In this section, the simulation is performed by utilizing MATLAB (Version 7.11, R2010b). Our simulation scenario is in a 25×15 indoor environment. The sensor nodes are freely deployed on the entities in a three-dimensional space that shown in Fig. 4. The effectual charging distance is $4(m^2)$. There are 5 machines which has $3(m)$ height. Each charger can serve up to 6 sensor nodes. We will observe the various phenomena between $25 - 175$ sensor nodes. The details is shown in Table II.

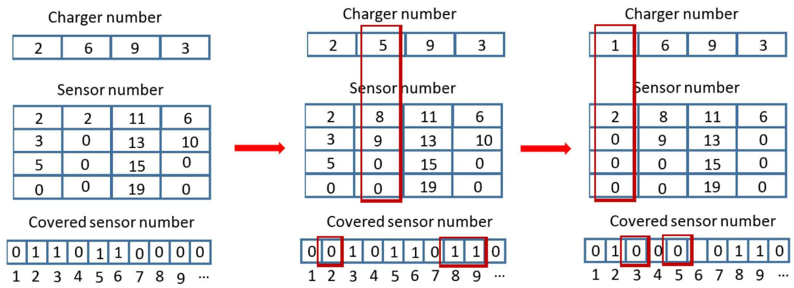

Fig. 2. Schematic diagram of proposed algorithm for replacement process

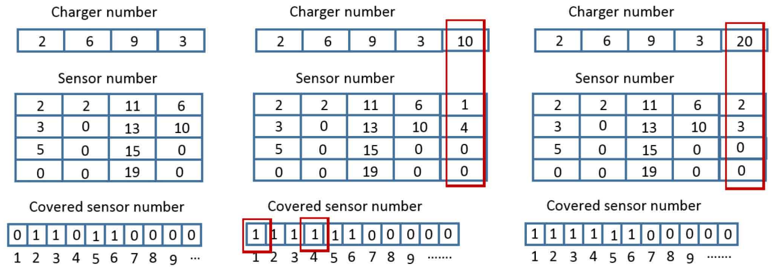

Fig. 3. Schematic diagram of proposed algorithm for new bit adding process

TABLE II
SIMULATION PARAMETERS

Parameters	Values
Size of venue	$20 \times 15(m^2)$
Number of sensor nodes	25
Effectual charging distance	$4(m^2)$
Deployed plane height	$3(m)$
The maximum load of charger	6
The number of machines	5

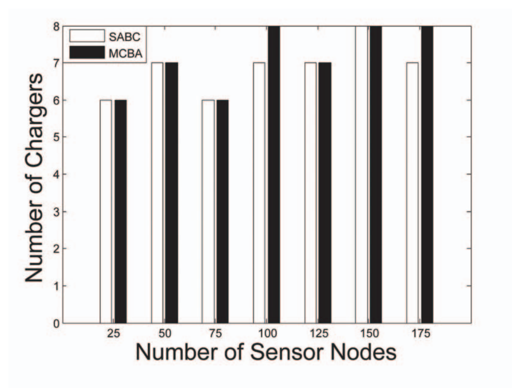

Fig. 5. Comparison of number of chargers

B. Simulation results

The first simulation began from 25 nodes,then successive increase in 25 nodes until number of sensor nodes is 175. This study will compare the needed number of chargers with SABC and MCBA. It can see Fig. 5 that even the number of sensor nodes is increased, the number of chargers did not over 7. The reason is that a chargers will cover to more sensor nodes when the density of sensor nodes are increased. This three-dimensional space does not become larger. The simulation results shown that MCBA is larger than SABC for 100 and 175 sensor nodes, because MCBA has determined they are the optimal solution. Obviously, it encounter the local optimum.

Each simulation will be performed by $1,000$ times then calculated the the average of all results so that the efficiency indicators can be evaluated impartially for each charger. Efficiency indicators is represented by that the ratio of the number of sensor nodes served by each charger. The efficiency of charging will decrease when the number of sensor nodes are increased. In smaller cases, both SABC and MCBA can found the good solution, but the efficiency of MCBA will be decreased due to the number of sensor nodes increasing, as shown in Fig. 6. According to our observation, it is because the probability that MCBA falls into the local optimum will increasing.

We further comparing the computation time with MCBA and SABC. The simulation results shown that SABC and MCBA have similar computation time in the smaller cases

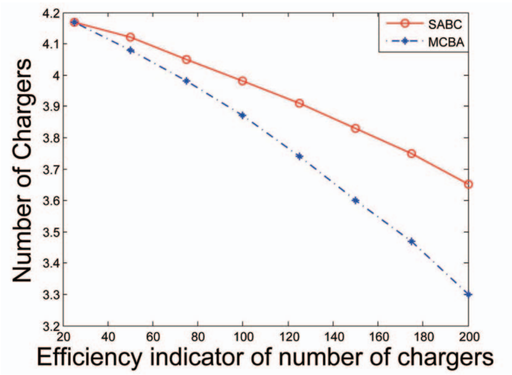

Fig. 6. Comparison of efficiency indicators of chargers

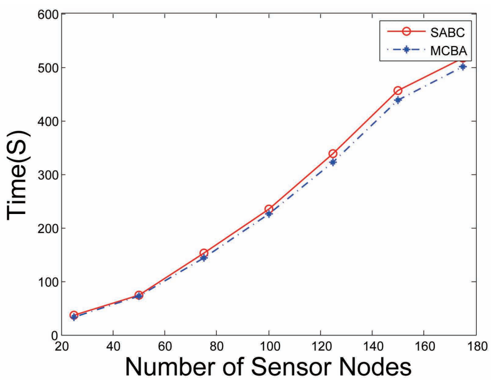

Fig. 7. Comparison of computation time

due to the input data is also not enough to affect the overall mechanism. However, as the number of sensor nodes become more, the combinations of the possible solutions will increase with exponential growth that shown in Fig. 7. Note that the planning problem belong to preliminary work before WRSN works. Therefore, SABC only extra spend average $150sec$ that this result is acceptable.

VI. Conclusion

WRSN is one of efficient solution for lifetime issue of WSN. Many Some recent studies used Unmanned Aerial Vehicle (UAV) [16], [17] to carry a charger then charging the sensor nodes on the ground. However, such outdoor mechanisms is not able to directly applied in the indoor environment, therefore the indoor WRSN has begun to be concerned. Set the chargers on ceiling is a promising way WRSN, but it still need to high deployment costs of chargers. In order to solve this problem, we presented a metahuristic algorithm based simulated annealing to find better results for WRSN in this paper, called SABC. The basic idea of proposed algorithm combine the Movable-Charger-based Algorithm and SA. The simulation results shown that SABC able to find a lower power working environment by using a quite small extra computation time. In summary, although SABC can find a better solution than other methods we compare in this paepr, it still may the optimal solution. Because of the main goal of SABC is number of chargers, each charger has no rest time if there are not much chargers to cover entire Field of Interest (FoI). It means that the working chargers will be broken very soon. Moreover, power of single charger is too high that such method suitable for sparse sensor networks only. Because there are many areas not be covered by charging range so that the extra power consumption will be generated, and consequently we need to consider this problem as multi objective optimization.

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References

[1] C.-F. Huang and Y.-C. Tseng, "A survey of solutions to the coverage problems in wireless sensor networks," *Journal of Internet Technology*, vol. 6, no. 1, pp. 1–8, 2005.

[2] W. Ouyang, C. W. Yu, C.-C. Tien, C. W. Hao, and T. H. Peng, "Wireless charging scheduling algorithms in wireless sensor networks," *Journal of Internet Technology*, vol. 13, no. 2, pp. 293–306, 2012.

[3] H.-H. Cho, C.-Y. Chen, T. K. Shih, and H.-C. Chao, "A survey on underwater delay/disruption tolerant wireless sensor network routing," *IET Wireless Sensor Systems*, vol. 4, no. 3, pp. 112–121, 2014.

[4] F.-H. Tseng, H.-H. Cho, L.-D. Chou, and H.-C. Chao, "Efficient power conservation mechanism in spline function defined wsn terrain," *IEEE Sensors Journal*, vol. 14, no. 3, pp. 853–864, 2014.

[5] S. He, J. Chen, F. Jiang, D. Yau, G. Xing, and Y. Sun, "Energy provisioning in wireless rechargeable sensor networks," *IEEE Trans. Mobile Computing*, vol. 12, no. 10, pp. 1931 –1942, 2013.

[6] M. Zhao, J. Li, and Y. Yang, "Joint mobile energy replenishment and data gathering in wireless rechargeable sensor networks," in *Proceedings of IEEE International Teletraffic Congress*, San Francisco, USA, 2011.

[7] C.-W. Tsai and J. J. Rodrigues, "Metaheuristic scheduling for cloud: A survey," *IEEE Systems Journal*, vol. 8, no. 1, 2014.

[8] Cerny and Vladimir, "Thermodynamical approach to the traveling salesman problem: An efficient simulation algorithm," *J. Optimization Theory Appl.*, vol. 45, no. 1, pp. 41–51, 1985.

[9] Kiani, Mehdi, and M. Ghovanloo, "The circuit theory behind coupled-mode magnetic resonance-based wireless power transmission," *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 29, no. 9, pp. 2065–2074, 2012.

[10] O. H. Stielau and G. A. Covic, "Design of loosely coupled inductive power transfer systems," in *Proceedings of IEEE International Conference on Power System Technology*, vol. 1, 2000.

[11] N. N. H. Ching, H. Y. Wong, W. J. Li, P. H. W. Leong, and Z. Wen, "A laser-micromachined multi-modal resonating power transducer for wireless sensing systems," *Sensors and Actuators A: Physical*, vol. 94, pp. 685–690, 2002.

[12] N. Shinohara, "Power without wires," *IEEE Microwave Magazine*, vol. 12, no. 7, pp. S94–S73, 2011.

[13] W.-J. Jian, H.-H. Cho, C.-Y. Chen, H.-C. Chao, and T. K. Shih, "Movable-charger-based planning scheme in wireless rechargeable sensor networks," in *IEEE International Workshop on MobiWorld*, hong kong, 2015.

[14] J.-H. Liao and J.-R. Jiang, "Wireless charger deployment optimization for wireless rechargeable sensor networks," in *Proceedings of IEEE International Conference on Ubi-Media Computing (UMEDIA)*, 2014.

[15] S. Kirkpatrick, C. D. Gelatt, and M. P. Vecchi, "Optimization by simulated annealing," *Science*, vol. 220, no. 4598, pp. 671–680, 1983.

[16] Y. Ping, Y. Zhang, Y. Gu, M. Pan, Z. Han, and P. Li, "Design of loosely coupled inductive power transfer systems," in *Proceedings of IEEE Global Telecommunications*, vol. 1, 2000, pp. 1–6.

[17] C.-M. Yu, C.-Y. Chen, C.-S. Lu, S.-Y. Kuo, and H.-C. Chao, "Acquiring authentic data in unattended wireless sensor networks," *Sensors*, vol. 10, no. 4, pp. 2770–2792, 2010.