Coverage Restoration Method for Wireless Sensor Networks of Distributed PV System

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Received 20 August 2014; Revised 2 February 2015; Accepted 2 February 2015

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Continuous capacity increase of distributed grid-connected photovoltaic (PV) system produces more obvious disturbance on the grid. Monitoring network technology can provide protection for the safety and stability of power grid operation, but sensor nodes of the monitoring network will fall to failure due to environmental interference. According to the performance degradation problem caused by nodes failure in PV monitoring network, particle swarm optimization (PSO) of natural selection based on random weight is proposed in this paper to optimize monitoring performance. This method can restore the monitoring network by arousing redundant nodes. Simulation results show the effectiveness of the proposed algorithm.

1. Introduction

The distributed photovoltaic technology is developing rapidly [1, 2]. With the connected capacity increase of distributed photovoltaic power generation system, the inherent randomness and uncertainty can lead to fluctuations to active power in power system [3]. The construction of a flexible and reliable monitoring network can guarantee the safe and stable operation of power grid. In the field of condition monitoring, WSNs are a kind of low-complexity, low-power, and low-cost monitoring technology [4]. According to the dispersion and the random, intermittent characteristics of photovoltaic power generation system, scholars have conducted research aiming at building a reliable WSN monitoring network for photovoltaic power generation system [5, 6]. WSNs-based PV system monitoring network consists of sensor nodes (referred node), which carry finite energy and cannot continue to work due to environmental interference. The depleted nodes will result in failure of a monitoring network. Therefore, it is necessary to study the restoration techniques of monitoring performance; there is still a lack of research in this field.

At present, the research on monitoring network restoration is mainly focused on network coverage and connectivity [7–9]. When the communication radius of nodes is at least twice the sensing radius, complete coverage of network implies connectivity of working nodes [10, 11]. Hence, the monitoring network failure nodes will result in reduced coverage, which will seriously affect the perception ability of the monitoring network, communications, and other properties [12, 13]. Whether nodes are in optimal placement will largely influence the operation and performance of the network [14]. We can start from the studies of monitoring network coverage optimization. Among all the coverage solutions, hexagonal method uses the least number of nodes, but if it is used for PV monitoring, nodes must be manually placed [15]. Additionally, the monitoring restoration methods using relay nodes are proposed, such as Spider Web approach [8]. Normally the relay node is responsible only for communication, which impacts the overall information collection of PV power system. Furthermore, virtual force algorithm (VFA) can be applied to fill the coverage holes and it has the high convergence [16]. However, compared with common nodes, mobile nodes take large volume and high cost. Besides, the PV array often has to be settled in a certain angle, and it is difficult for nodes to move. Therefore, the implementation of mobile nodes cannot be suitable for the deployment on the photovoltaic array. To solve the coverage problems of monitoring network, heuristic algorithm,
especially intelligent algorithm, has evident advantages over VFA or other algorithms [7, 8, 17]. Based on multiobjective of node position and energy, a coverage optimization method of PSO for the monitoring network is proposed in [18]. But this method is a process of non-Pareto optimal (multiobjective optimization) solution; it is difficult to obtain a monitoring coverage optimal solution, and there is always a “premature” problem. To overcome the premature problem, the chaotic PSO is used in [19]. But the algorithm takes a long time, not suitable for the fast performance restoration to monitoring network [20].

This paper presents for the first time the PSO method of natural selection based on random weight, which is improved from PSO method. The improved method can arouse redundant nodes in monitoring network to improve network monitoring coverage with the purpose of achieving ultimately monitoring performance restoration. According to different node failure conditions of the monitoring network for PV monitoring performance restoration. According to different monitoring coverages with the purpose of achieving ultimately monitoring network initialization of nodes scheduling, two factors should be taken into account as follows. (1) Each node has sensing phase, transmission phase, sleeping phase, and waking phase. The lifetime of network increases as the use of nodes energy decreases. (2) Considering Figure 1, the network should ensure the maximal coverage. The nodes that are not scheduled are redundant nodes. To save the energy and reduce the monitoring network signal interference between nodes, the redundant nodes are in a dormant state under work environment, then the redundant node is defined as follows. If the sensing range of sensor node can be completely covered by at least one node which is different from itself, then the node is a redundant node, as shown in Figure 1.

2. Failure Analysis of PV Monitoring Network

2.1. Coverage Ratio Model of Monitoring Network. Coverage ratio of monitoring network refers to dividing all nodes’ sensing area on PV array by the area to be monitored. To facilitate the study, the PV array can be divided into pixels; that is, the region of PV array is firstly divided into \(j \times k\) small cells and then each cell is simplified by pixels. The perception situation of monitoring area can be equivalent to the perception situation of pixels. The actual nodes perception is not just constrained by the sensing radius of \(R_s\). Considering the effects of node sensing signals attenuation and obstacles in the work environment, the node perceptual model is available as shown in formula (1); the node perceptual model represents the sensing result of node \(s_i\) to pixel point \(g(x, y)\) [21, 22]:

\[
C_g(s_i, g) = \begin{cases} 
1, & d(s_i, g) \leq R_s - R_e \\
\exp \left( -\frac{\lambda_1}{\alpha_2^{\beta_1} + \alpha_2^{\beta_2}} \right), & R_s - R_e < d(s_i, g) < R_s + R_e \\
0, & \text{otherwise}.
\end{cases}
\]  

(1)

In formula (1), \(d(s_i, g)\) is the Euclidean distance between the sensor node \(s_i\) and the pixel \(g; R_s\) is the node reliability parameter, \(0 < R_s < R_e; \alpha_1, \alpha_2, \beta_1, \text{and} \ \beta_2\) represent the node characteristic parameters, among which \(\alpha_1 = R_e - R_s + d(s_i, g)\), \(\alpha_2 = R_e + R_s - d(s_i, g)\), and \(\beta_1, \beta_2\) take constant values; \(\lambda_1, \lambda_2\) are input parameters.

All pixels \(g\) are jointly perceived by all valid nodes with the following result:

\[
C_g(s, g) = 1 - \prod_{i=1}^{n} \left( 1 - C_g(s_i, g) \right). 
\]  

(2)

In this paper, one method of the coverage restoration is proposed through rational use of the redundant nodes.

![Figure 1: Redundant sensor node in WSN.](image-url)
when nodes failure occurs. In the situation of monitoring network failure, the number of remaining active nodes is supposed to be \( p \) and the number of redundant nodes involved in the network coverage restoration is supposed to be \( q \). \( s \) represents a node set \( \{s_1, s_2, \ldots, s_n\} \) and \( n \) is the total number of remaining active nodes in the monitoring network and nodes involved in the restoration of monitoring network, which can be called all active nodes. For the study of monitoring coverage restoration, the following assumptions should be made.

(1) Communication radius of each node is equal to twice the communication radius of node perception radius; that is, \( R_c = 2R_s \).

(2) There are three types of nodes in PV monitoring network: sink node, ordinary node, and cluster head node. The sink nodes are responsible for data processing, algorithm operation, and order transmission. Cluster head nodes in distributed systems are used for gathering data of ordinary nodes, data transmission, and data preprocessing; they can be selected from ordinary nodes. The main task of ordinary nodes is to gather information of PV system and to transmit data. The sink nodes and the cluster head nodes have their own and other nodes' position and energy information.

The photovoltaic system has a plurality of rectangular solar arrays, a certain number of nodes on PV arrays form a cluster, and each cluster comprises a cluster head node and a number of ordinary nodes. A sink node has more energy and greater ability of information processing than an ordinary one, and it can regain the boundary information of monitored region, based on which it can estimate the number of ordinary nodes.

The sink node should judge the boundary and the amount needs of nodes for the monitoring region [24]. Based on data quality analysis of sensor managements, one online node fault detection method is proposed in [25]. When the nodes failure occurs, the sink node firstly determines coverageratio of the monitoring network and then determines the amount of redundant nodes required to participate in coverage restoration of monitoring network. If the coverage ratio is \( \gamma \% \), then the monitoring network has an area of covering holes:

\[
S_{nc} = S_{all} (1 - \gamma \%) \tag{5}
\]

In formula (5), \( S_{all} \) represents the total area of PV monitoring area.

\( S_{nc} \) in formula (5) is the area of motoring coverage holes. In order to calculate the number of waken redundant nodes, \( S_{nc} \) can be equivalent to a square of the same \( d \times d \) area in Figure 2; the maximum number of required nodes participating in the monitoring network restoration can be calculated as shown in the following:

\[
i = \frac{d}{\sqrt{3}R_s} \tag{6}
\]

\[
n_{max} = \frac{2d^2 + 3i + 1}{2} \tag{7}
\]

There may be some small monitoring coverage holes; in this case, there is no need to wake up redundant nodes to cover. Therefore, \( n_{max} \) is the maximum value of redundant nodes. The minimum value of redundant nodes is limited to \( n_{max}/2 \) to ensure a sufficient amount of redundant nodes in monitoring network. Combining the upper limit and the lower limit, it is desirable to wake up certain redundant nodes with the number \( n_m \in \{ n_{max}/2, n_{max} \} \).

3. Coverage Restoration Algorithm of PV Monitoring Network

To solve the coverage decrease problem caused by the nodes failure of PV monitoring network, we use PSO algorithm with fitness function of the monitoring coverage model as shown in (4). The algorithm can determine the best locations of redundant nodes to wake up, improve coverage ratio of the monitoring network by waking up redundant nodes, and ultimately achieve the purpose of monitoring performance restoration.

3.1 Standard Particle Swarm Optimization. There are \( N \) particles in PSO algorithm and each particle has a \( m \)-dimension. The individual particle \( x_i \) updates the speed and the position in accordance with extreme global \( gB \) and individual extreme \( pB(i) \) as shown in

\[
\begin{align*}
\mathbf{v}^{i+1} &= \omega \mathbf{v}^{i} + c_1 r_1 ( p B_{i,j} - x_i^j ) + c_2 r_2 ( g B_{i,j} - x_i^j ), \\
x_i^{j+1} &= x_i^j + \mathbf{v}_i^{j+1} \quad j = 1, 2, 3, \ldots, m.
\end{align*}
\]

In the above two formulas, \( x_i \) represents the location of sensor nodes \( (x_{i1}, x_{i2}, x_{i3}, x_{i4}, \ldots, x_{im-1}, x_{im}) \), including the location information of all active nodes, which means that the redundant nodes participating in monitoring coverage restoration together with the remaining active nodes execute the position optimization. And \( N \) particles represent \( N \) different deployment scenarios of WSN nodes. \( t \) is the number of iterations, \( \omega \) is the inertia weight, \( c_1, c_2 \) are the learning factors.
of PSO, and \( r_1, r_2 \) are the uniformly distributed random numbers between [0, 1].

3.2. Hybrid Particle Swarm Algorithm of Unvalued Weights.

A large inertia weight \( \omega \) is conducive to jump out of local optima and easy for global search; the smaller \( \omega \) favors the convergence. Thus, the inertia weight is usually not a constant value. Under normal circumstances, PSO uses the method of linear decreasing weight or random weight [26].

Linear decreasing weight is as shown in the following formula:

\[
\omega = \omega_{\text{max}} - \frac{t (\omega_{\text{max}} - \omega_{\text{min}})}{t_{\text{max}}},
\]

(9)

In formula (9), usually take \( \omega_{\text{max}} = 0.9 \) and \( \omega_{\text{min}} = 0.4; \) \( t_{\text{max}} \) is the maximum number of iterations; \( t \) is the current number of iterations.

The random weight inertia obeys the standard normal distribution, as shown in formula (10). The method based on random weight can make the particles have a chance to get a larger or smaller weight during the early and later evolution period. Consider

\[
\omega = \mu + \sigma \cdot N(0, 1),
\]

\[
\mu = \mu_{\text{min}} + (\mu_{\text{max}} - \mu_{\text{min}}) \cdot \text{rand}(0, 1).
\]

(10)

In formula (10), \( N(0,1) \) represents the standard normal distribution; usually take \( \mu_{\text{max}} = 0.8, \mu_{\text{min}} = 0.5 \), and \( \sigma = 0.2 \).

For fast and effective restoration for the monitoring network, it is necessary to overcome the "premature" problem and the slow convergence problem of PSO algorithm. So this paper proposes the PSO algorithm based on natural selection. During the iteration period, the particle will be sorted according to the fitness value. The best alternative velocity of half the particles will take position of the worst half ones, preserving the best historical value of each individual.

3.3. Algorithm Flow. In the field of PV monitoring, sensor nodes can have the following power supply ways. (1) Powered up by the PV system with access to the underlying grid: this way has strong operability and sufficient energy supply but seriously affects the flexibility of nodes placement. (2) A solar panel or an induction device is installed in the node: because of the instability of the power supply, the allocation of a certain battery is required; thus, the total cost of a node increases. (3) Powered up by the battery alone: this way has been generally adopted; the battery can ensure sufficiently long lifetime [27]. After comprehensive consideration, the first power supply way is used for sink nodes and the third way is for ordinary nodes and cluster head nodes in this paper. In order to prevent the situation where redundant nodes with lower energy are awakened in the monitoring network, the energy threshold \( E_{th} \) is set to select redundant nodes with adequate energy [28]. If the redundant nodes do not meet the need of being waken up, they continue to sleep. Consider

\[
E_i \geq E_{\text{th}}.
\]

(11)

Since the photovoltaic system is composed of different PV arrays, the number of failed nodes will be different for different PV array. For this case, with the combination of formula (6), the number of involved redundant nodes for coverage restoration of monitoring network is different. Therefore, there is the need to limit the number of redundant nodes; namely,

\[
N_m \leq N_{\text{th}}.
\]

(12)

Basic steps of the hybrid PSO algorithm based on natural selection with the fitness function in formula (4) are as follows.

1. Random initialization of position and velocity of each particle swarm: the initialization scope of the position falls in PV monitoring area. The particle dimension initialization is referring to formulas (6) and (12); the dimension is twice the number of all active nodes; that is, if the number of remaining effective nodes is \( n_{\text{sta}} \), the dimension of particles will be \( 2(n_{\text{sta}} + n_m) \).

2. According to formula (4), calculation of the fitness value \( f(x) = C \) for each particle. Store the location of particle as well as the fitness value in individual extreme \( pB(i) \); store the location and the fitness values of all \( pB \)s in global extreme \( gB \).

3. Update the particles velocity and location according to formula (8), to obtain a new \( pB(i) \) and \( gB \).

4. Sorting of the updated particles depending on fitness value: replace the worst half of particles by the best half of particles (the related replacement of the location and velocity).

5. If the termination condition is satisfied, then exit. When \( f(x) \geq 1 + \eta \% \) or \( t \geq t_{\text{end}} \), the iteration is terminated. The former case means the monitoring coverage restoration is successful; the latter case means the restoration fails. \( \eta \% \) depends on the specific failure circumstances in monitoring network and \( t_{\text{end}} \) is set by the monitoring staff.

4. Simulations and Analysis

In this paper, the photovoltaic modules for distributed photovoltaic systems are constructed by Trina PCI4. The establishment of a \( d \times m \) square area in MATLAB R2013 represents the monitoring area of PV array. The photovoltaic systems have different sizes of photovoltaic arrays; namely, values of \( d \) will be different in the simulation. The node sensing radius \( R_s \) is 5 m, \( C_{th} = 0.9, \lambda_1 = 1, \lambda_2 = 0, \beta_1 = 1, \beta_2 = 1.5, t_{\text{end}} = 1500 \text{ s}, \) and \( \eta \% = 50\% \).

4.1. Analysis for Failure Conditions of PV Monitoring Network.

The distributed PV system has the feature of dispersion; failure situation will be different depending on different PV array. Therefore, to verify the effectiveness of the algorithm mentioned in this paper, in the following examples, the size of different PV array will be different and the number and location of failure nodes will also be different.
4.1.1. Situation of Regular Failure Region. For the PV array with \( d = 60 \) m, there are 27 remaining active nodes in the monitoring network. The coverage situation of network monitoring is shown in Figure 3. Inclement weather, human factors, and other external damage may lead to this kind of regular failure occurrence. In this failure case, the monitoring network cannot obtain information of region 1 on PV array in Figure 3. Applying formulas from (1) to (4), the coverage should be 43.29% after network nodes failure.

For all of the following simulation figures, “○” is on behalf of remaining effective monitoring network node and “●” is on behalf of awakened redundant nodes of monitoring network.

4.1.2. Situation of Irregular Failure Region. For the PV array with \( d = 50 \) m, there are 35 remaining active nodes in the photovoltaic monitoring network. The coverage situation of network monitoring is shown in Figure 4. In Figure 4, regions 1, 2, 3, and 4 are the monitoring failure areas when the nodes failure occurs. Applying formulas from (1) to (4), the coverage ratio should be 51.94%.

4.2. Coverage Restoration for Monitoring Network. In the case where there are a large number of failure nodes appearing, it is usually considered to redeploy new nodes in order to rebuild the monitoring network; this paper will not consider this situation. This paper makes the following assumption: if the coverage ratio of monitoring network can be increased by 50% on the basis of coverage ratio of the current failure network, then monitoring network performance will be restored.

Aiming at the regular failure situation, \( i = 5.21 \), \( n_{\text{max}} = 35.46 \), \( E_{\text{th}} = 0.5 \) J, and then \( n_m = 18 \).

In order to improve coverage of the monitoring network, run the PSO algorithm of natural selection based on random weight. The result is as shown in Figure 5; when 21 iterations end with a time of 147.70 s, the coverage ratio reaches 65.61%; from \( (65.61\% - 43.29\%)/43.29\% = 0.5156 \), we can know that the monitoring network coverage is improved by 51.56%, meeting the performance restoration requirements for monitoring network. Because the sensor nodes are used by a jointly perceptual model, the monitor network coverage is not just calculated in accordance with perception of a circle of radius \( R_s \). Therefore, not all of redundant nodes awakened fall in region 1; meanwhile, the redundant nodes in the figure that falls in other regions will achieve the effect of improving the monitoring network coverage.

For the irregular failure situation, \( i = 4.0 \), \( n_{\text{max}} = 22.5 \), \( E_{\text{th}} = 0.5 \) J, and then \( n_m = 15 \).

Run the PSO algorithm of natural selection based on random weight. The result is as shown in Figure 6; when
Table 1: Comparison of operating time.

| Iterations | 20     | 50     | 150    | 300    |
|------------|--------|--------|--------|--------|
| Random PSO | 94.57  | 210.67 | 563.85 | 1121.15|
| Random hybrid PSO | 81.29  | 180.48 | 545.80 | 1104.79|
| Linear PSO | 107.76 | 222.75 | 649.49 | 1242.67|
| Linear hybrid PSO | 87.31  | 209.16 | 590.42 | 1117.50|

Table 2: Comparison of time for monitoring network restoration.

|                | Random PSO | Random hybrid PSO | Linear PSO | Linear hybrid PSO |
|----------------|------------|-------------------|------------|-------------------|
| Iterations     | 36         | 32                | 46         | 42                |
| Coverage ratio | 78.04%     | 78.11%            | 78.66%     | 78.08%            |
| Coverage increase | 50.25% | 50.39%            | 51.44%     | 50.33%            |
| Running time (s) | 149.20   | 117.33            | 204.14     | 200.22            |

Figure 6: Restoration in irregular failed situation.

31 iterations end with a time of 116.58 s, the coverage ratio reaches 78.05%; from \((78.05\% - 51.94\%)/51.94\% = 0.5026\), we can know that the monitoring network coverage is improved by 51.56%, meeting the performance restoration requirements for monitoring network.

4.3. Consuming Time of Coverage Restoration for the Monitoring Network. Coverage of photovoltaic monitoring network has to be restored quickly; the equipped computer has the Core Duo with a processing frequency 2 GHz, and the simulation is run on the MATLAB platform. Therefore, under the same configuration conditions of running computer, we should choose the algorithm with a less computing time.

Obviously, since the irregular failure simulation can represent the random node failure situation of PV array, it has a more general applicability. The algorithm running time for the case of irregular failure is as shown in Table 1. From Table 1, for either the random weight method or the linear weight method, the PSO based on natural selection takes shorter time than the standard PSO; for either the PSO or the hybrid PSO, the random weight method takes shorter time than the linear weighting method; for these four methods, the natural selection PSO based on random weight takes the shortest time.

After having run 1000 times for all above algorithm methods, the results of comparing the average running time of the above four kinds of methods are shown in Table 2. The results show that PSO algorithm of natural selection based on random weight can recover the monitoring network coverage with the fastest speed.

5. Conclusion

In this paper, aiming at the coverage decrease problem of PV monitoring network based on WSN due to sensor nodes failure, the particle swarm optimization of natural selection based on random weight is firstly proposed. Combining the different failure conditions for different PV array monitoring network, simulation analysis for the coverage restoration of monitoring network is executed. Results show that the PSO of natural selection based on random weight can quickly find the best position needed to arouse the redundant nodes. After the nodes’ participation in the restoration process, the monitoring network coverage can be improved; as a result, the monitoring network performance can be restored.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

This work is supported by the National Natural Science Foundation of China (no. 51307044) and the Natural Science Foundation of Jiangsu Province of China (no. BK2012409).

References

[1] J. Su, L. Zhou, and R. Li, "Cost-benefit analysis of distributed grid-connected photovoltaic power generation," Proceedings of the Chinese Society of Electrical Engineering, vol. 33, no. 34, pp. 50–56, 2013.
[2] S. Chen, H. Bao, C. Wu, D. Zhang, and Y. Han, “Direct grid-tie power control method for distributed photovoltaic generation,” *Proceedings of the Chinese Society of Electrical Engineering*, vol. 31, no. 10, pp. 6–11, 2011.

[3] W. Chen, X. Ai, T. Wu, and H. Liu, “Influence of grid-connected photovoltaic system on power network,” *Electric Power Automation Equipment*, vol. 33, no. 2, pp. 26–39, 2013.

[4] Z. Fu and K. You, “Optimal mobile sensor scheduling for a guaranteed coverage ratio in hybrid wireless sensor networks,” *International Journal of Distributed Sensor Networks*, vol. 2013, Article ID 740841, 11 pages, 2013.

[5] B. Andò, S. Baglio, A. Pistorius, G. M. Tina, and C. Ventura, “SENTINELLA: A WSN for a smart monitoring of PV systems at module level,” in *Proceedings of the 2nd IEEE International Workshop on Measurements and Networking (M and N’13)*, pp. 36–40, October 2013.

[6] Y. Zuo, H. Wang, X. Xu et al., “Solar photovoltaic power generation wireless monitoring system,” *Solar Energy*, vol. 1, pp. 29–32, 2011.

[7] F. Senel, M. Younis, and K. Akkaya, “A robust relay node placement heuristic for structurally damaged wireless sensor networks,” in *Proceedings of the IEEE 34th Conference on Local Computer Networks (LCN’09)*, pp. 633–640, Zurich, Switzerland, October 2009.

[8] F. Senel, M. F. Younis, and K. Akkaya, “Bio-inspired relay node placement heuristics for repairing damaged wireless sensor networks,” *IEEE Transactions on Vehicular Technology*, vol. 60, no. 4, pp. 1835–1848, 2011.

[9] V. Coskun, “Relocating sensor nodes to maximize cumulative connected coverage in wireless sensor networks,” *Sensors*, vol. 8, no. 4, pp. 2792–2817, 2008.

[10] H. Zhang and J. C. Hou, “Maintaining sensing coverage and connectivity in large sensor networks,” *Ad Hoc & Sensor Wireless Networks*, vol. 1, pp. 89–87, 2005.

[11] G. L. Xing, X. R. Wang, Y. F. Zhang, C. Lu, R. Pless, and C. Gill, “Integrated coverage and connectivity configuration for energy conservation in sensor networks,” *ACM Transactions on Sensor Networks*, vol. 1, no. 1, pp. 36–72, 2005.

[12] T. A. Wettergren and C. M. Traweek, “The search benefits of autonomous mobility in distributed sensor networks,” *International Journal of Distributed Sensor Networks*, vol. 2012, Article ID 797040, 11 pages, 2012.

[13] H.-C. Shih, J.-H. Ho, B.-Y. Liao, and J.-S. Pan, “Fault node recovery algorithm for a wireless sensor network,” *IEEE Sensors Journal*, vol. 13, no. 7, pp. 2683–2689, 2013.

[14] J. Li, L. L. H. Andrew, C. H. Foh, M. Zukerman, and H.-H. Chen, “Connectivity, coverage and placement in wireless sensor networks,” *Sensors*, vol. 9, no. 10, pp. 7664–7693, 2009.

[15] W. N. W. Muhamad, N. H. Rodzi, N. M. Isa, and N. A. Wahab, “Efficient network coverage for wireless sensor networks,” in *Proceedings of the IEEE Region 10 Conference (TENCON ’10)*, pp. 240–244, November 2010.

[16] J. Chen, S. Li, and Y. Sun, “Novel deployment schemes for mobile sensor networks,” *Sensors*, vol. 7, no. 11, pp. 2907–2919, 2007.

[17] X. Wang, S. Wang, and J. Ma, “Dynamic deployment optimization in wireless sensor networks,” in *Intelligent Control and Automation*, vol. 344 of *Lecture Notes in Control and Information Sciences*, pp. 182–187, Springer, Berlin, Germany, 2006.
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