A Wireless Charging Vehicle on-demand scheduling algorithm based on entropy weight method

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Abstract. The energy of the sensor node (SNs) is always an important factor restricting its long-term stable operation. In order to ensure that the sensor node has a stable energy supply and prolong its working life, a charging scheduling algorithm based on the entropy weight method is proposed to reasonably schedule the wireless charging vehicle (WCV) and improve charging effectiveness. In the proposed algorithm, the concept of node network attributes is first proposed, and the entropy weight method evaluation model is introduced, and then the entropy weight method is used to comprehensively evaluate the network attributes of the nodes, and the scores of each node after the evaluation are arranged in descending order to obtain the charging plan. WCV carries multiple detachable charging devices to charge the nodes according to the charging plan. Finally, the proposed algorithm is simulated, and the result shows that the proposed algorithm is significantly higher than the existing FCFS and NJNP algorithms in terms of charging delay and node survival rate.

1. Introduction

The working life of the traditional wireless rechargeable sensor network (WRSN) is often limited by the electrical energy carried by the node itself [1]. Although many researchers have made great efforts in energy saving, limited energy is still the bottleneck of WRSN’s long-term operation. In order to extend the effective life of SNs, the existing research mainly considers the use of wireless energy transmission methods to supplement the energy of wireless sensor nodes [2]. The main idea of wireless energy transmission is to use electromagnetic effect or magnetic resonance coupling to charge SNs. Charging schemes based on wireless energy transmission are mainly divided into two categories, namely periodic charging schemes [3] and on-demand charging schemes [4]. Periodic charging schemes are divided into two categories, namely single-node charging schemes [5] and multi-node charging schemes [6]. In the single-node charging scheme, WCV only charges one node at a time. In the multi-node scheme, WCV can charge all nodes within its charging radius at the same time. Because the charging time delay of the multi-node charging scheme is lower, it is better than the single-node charging scheme. In the literature [7], the author used the concept of Smallest Enclosing Disk (SED) to determine the mobile charger (MC) moving path. The stay point of MC is the overlapping area of concentric circles obtained by drawing. Also in the literature [5], using the idea of SED, a distributed charging scheme was developed to minimize the charging delay of the wireless rechargeable sensor network. In [8], nodes with energy lower than a certain value are identified as target charging nodes, and the charging time is allocated proportionally according to the energy requirements of the nodes to maximize energy utilization. Lin et al. proposed a dual alarm threshold for dual preemptive charging, using dual thresholds to adjust different charging priorities, which has improved the charging
throughput of the network and the charging efficiency of WCV \cite{9}. Literature \cite{10} studied an on-demand energy replenishment problem and formulated it as an optimization problem with the purpose of maximizing the number of sensors per trip. In this case, He et al. \cite{11} proposed the First Come First Serve (FCFS) algorithm to schedule MC in WRSNs. Here MC provides services for incoming charging requests in the order of their arrival, that is, the charging schedule is only determined according to their time characteristics. However, the MC may have to move back and forth in its spatial domain because its charging scheme is to request the location of the SN by ignoring the geographic location. And this may increase charging delay and reduce network life. In order to overcome the shortcomings of the FCFS algorithm, He et al. proposed the nearest-job-next with preemption (NJNP) algorithm \cite{12-13}. In this solution, the MC already has the ability to switch to the requesting node adjacent to the nearest requesting node. Generally, after fully charging the SN and receiving a new SN charging request, the MC will re-select a new node for charging according to the request and based on the geographic location of the requesting node. By introducing the idea of preemption in the charging process, the shortcomings of FCFS are successfully solved. However, the preemption process may cause new defects, that is, the running time of MC is divided into several time slots, and each time slot can perform a preemption operation, so it is likely to be executed frequently, which leads to large-scale WRSNs charging the scheme became inefficient. In addition, when the time slot is small, the system will become unstable, and due to frequent preemption operations, nodes far away from the MC still face death, thereby reducing the life cycle of the network. Although the NJNP scheme is still very popular, it is still necessary to develop a new charging scheduling scheme to restore the energy of SNs. In this paper, considering the remaining energy, space, and energy consumption rate of the node, an on-demand charging scheme for WCV scheduling is designed. Taking the time delay generated during the charging process and the number of dead nodes as evaluation indicators, using the entropy weight method as the basic evaluation model, a charging scheduling algorithm based on the entropy weight method is constructed. Finally, a single WCV carries multiple detachable charging devices to charge the nodes according to the generated charging plan.

2. System Model

2.1 WRSN Network Models

Assume that the WRSN network model consists of sensor nodes randomly distributed in space, and the base station is located in the center of the network for receiving and processing data. WCV carries multiple low-cost detachable charging devices to drive in the area. According to the service plan, the charging device is placed or recycled for the requested node. WCV only executes the placement or recycling action, and continues to drive after the execution is completed to achieve multiple locations for the node Concurrent charging. Each detachable charging device carries a certain amount of energy. One of the detachable charging devices can only charge one node at a time, and sends a recovery request to the base station when the charging is completed, and then is recovered by the passing WCV. If the electric energy carried by this device is enough to charge the next requesting node, it will be placed next to the next requesting node, otherwise the WCV that travels with it will eventually return to the base station to supplement energy. Assuming that each SNs has the same specifications and is in a static state after deployment, the distance between nodes is called Euclidean distance. The energy consumption of nodes in different working situations is different (for example, when transmitting data and receiving data respectively). Therefore, the node energy consumption in a certain period of time is also different \cite{14}. When the energy of each node is lower than a given threshold, the node sends a service request to the base station. After the base station receives the service request, it sends the prepared service plan together with the location of the node to the corresponding WCV. The WCV starts from the base station and follows the plan to serve the nodes in turn. The WRSN network model uses a model similar to that in the literature \cite{15}, which is expressed in mathematical formula(1) and (2):
\[
C_r = \frac{\theta}{\text{dist}(s_i, W) + \beta^2} \quad (1)
\]
\[
\beta = \frac{G_x G_y \omega}{L_p} \left( \frac{e}{4\pi} \right) P_s \quad (2)
\]

Where \( P_s \) is the transmit power of the energy transmitted by the charging device, \( C_r \) is the power of the node receiving energy, \( \text{dist}(s_i, W) \) represents the Euclidean distance from node \( s_i \) to WCV, \( G_x \) is the gain of the transmitting module, \( G_y \) is the gain of the receiving module, and \( L_p \) is the pole The loss, \( E \) is the signal wavelength, \( \omega \) is the rectifier efficiency, and \( \beta \) is the adjustable parameter in the Friesian transmission equation.

2.2 Sensor node attribution

Residual energy: Residual energy is an important parameter, which is determined by the node's energy consumption rate and charging threshold. Each node will record the remaining energy in real time. When the node's remaining energy is lower than or equal to the charging threshold, it will send a charging request to WCV. When WCV receives the charging request, it will move to the node to charge it. The node to be charged is represented as the set of \( i \) is defined as \( N \), and the remaining energy is defined as \( e_{\text{remain}} \).

Distance: The distance here is the Euclidean distance between the current position of the WCV \((x_{\text{WCV}}, y_{\text{WCV}})\) and the node to be charged \((x_i, y_i)\). The formula is as follows:
\[
d_{\text{WCV,i}} = \sqrt{(x_{\text{WCV}} - x_i)^2 + (y_{\text{WCV}} - y_i)^2} \quad (3)
\]

Energy consumption rate: The energy consumption rate reflects the importance of the node in the network to a large extent, because the higher the energy consumption rate of the node means the more transmission tasks it undertakes. The energy consumption rate is defined by the formula:
\[
E = \frac{e_{\text{t},r} + e_{\text{t},s}}{t} \quad (4)
\]

The energy consumption of a sensor node consists of three parts, sending data, sensing data and receiving data, where \( e_{\text{t},r} \), \( e_{\text{t},s} \) represent these three parts respectively, where \( e_{\text{t},t} \) and \( e_{\text{t},r} \) include the following: (1) The energy consumption of sending and receiving data by its own node (2) In a multi-hop relay wireless sensor network, transmitting and receiving adjacent nodes The energy consumption generated by the data, in a period of time \( t \) the energy consumption rate of the node can be expressed by the formula (4).

3. Charging scheduling algorithm based on entropy weight method

We propose a charging scheduling algorithm based on entropy weight method\(^\text{[16]}\). The steps for establishing the entropy method model are as follows:

Step1: Establish an initial decision matrix. We first establish an initial decision matrix list for the m network attributes of n nodes to be charged. The establishment of the initial matrix \( X = [x_{ij}] \) is as follows:
\[
X = \begin{bmatrix}
x_{11} & x_{12} & \cdots & x_{1m} \\
x_{21} & x_{22} & \cdots & x_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
x_{n1} & x_{n2} & \cdots & x_{nm}
\end{bmatrix} \quad (5)
\]

Here, \( x_{ij} \) represents the network attribute value of the \( i \)th node to be charged.

Step2: Normalize the initial decision matrix. Since different network attributes have different quantification standards, simple weighting operations will destroy the objectivity of the indicators. We use the vector normalization method to normalize the decision matrix. For positive indicators, the normalization formula is:
\[
x_{ij} = \frac{x_{ij} - \min\{x_{1j}, x_{2j}, \ldots, x_{nj}\}}{\max\{x_{1j}, x_{2j}, \ldots, x_{nj}\} - \min\{x_{1j}, x_{2j}, \ldots, x_{nj}\}} \quad (6)
\]
For negative indicators, the normalization formula is:

\[ x_{ij} = \frac{\min\{x_{1j}, x_{2j}, \ldots, x_{nj}\} - x_{ij}}{\max\{x_{1j}, x_{2j}, \ldots, x_{nj}\} - \min\{x_{1j}, x_{2j}, \ldots, x_{nj}\}} \]  

(7)

In this paper, distance is a negative indicator and energy consumption rate is a positive indicator.

Step3: Calculation of the index entropy and weight of the charging node. Since the various network attributes of the node to be charged are unpredictable, we use the feature ratio, which represents the

\[ w_e(j) = \frac{d_j}{\sum_{j=1}^{m}(d_j)} \]

(8)

Finally, according to the weight of each network attribute, the final score of each node can be calculated, and the final charging plan can be generated according to the score of the node. Define the charging scheduling plan as \( c_{\text{schedule}} \), and the charging scheduling algorithm based on the entropy weight method is described as the algorithm:

**Algorithm 1 Charging scheduling algorithm based on entropy weight method**

Input: \( e_{\text{remain}}, d_{\text{wcv},i}, E \),  
Output: \( c_{\text{schedule}} \)

1: Initialize the network  
2: for \( i \leftarrow 1 \) to \( n \) do  
3: calculate \( E \) as equation  
4: Build the decision matrix \( X \) by inserting \( E, e_{\text{remain}}, d_{\text{wcv},i} \)  
5: Normalize the decision matrix \( X \) as Eqs6 and 7  
6: Evaluate entropy weights by Normalized matrix \( X \) and EVM computations  
7: calculate the final score of each sensor node by entropy weights  
8: end for  
9: sort nodes \( \leftarrow \) sort the nodes score according to ascending order  
10: \( c_{\text{schedule}} \leftarrow \) sorted nodes  
11: return \( c_{\text{schedule}} \)

4. Simulation

In this paper, a rigorous simulation of the proposed algorithm is carried out to prove its effectiveness. Mainly use MATLAB2019a to complete the simulation, the system environment is Core i7 (64-bit) processor, running memory 8GB, operating system MacOS10.14. Multiple static sensor nodes (300-700) are randomly deployed in an area of 220×220m, the communication range of the node is 50m, the charging threshold is 0.5J, and the driving speed of the WCV is 2m/s. The paper uses charging delay as the standard to measure the performance of the algorithm. The charging delay includes the time that the node waits for the WCV to charge it and the time that the WCV charges it. For any charging scheduling algorithm, this indicator directly reflects the charging efficiency. The lower algorithm is considered the better. The simulation results are the average of 20 simulations under the same conditions. The specific simulation parameters are shown in Table 1.

| Parameter               | Value      |
|-------------------------|------------|
| Number of nodes         | 300-700    |
| SNs communication range | 50m        |
| Speed of WCV            | 2m/s       |
| Charging radius of WCV  | 5m         |
| SNs initial energy      | 2 J        |
| Charging threshold      | 0.5J       |
| Round                   | 4s         |
| Network working time    | 5000 rounds|

Table 1. Network parameter
It can be seen from Figure 1 that as the number of nodes increases, the charging delay of the three algorithms also increases. Since the FCFS algorithm only considers the time factor, as the network density increases, the charging delay of the FCFS algorithm increases significantly. Due to the introduction of the idea of "preemption" in the NJNP algorithm, the charging request has been optimized, and the charging delay and the proposed algorithm have become stable. Among them, the charging delay of this algorithm is the lowest.

![Fig.1 Charging delay under different number of nodes](image1)

![Fig.2 Number of dead nodes under different number of nodes](image2)

It can be seen from Figure 2 that as the number of nodes increases, the number of requesting nodes also increases accordingly. Therefore, as the simulation progresses, the dead nodes of the three algorithms are increasing. When the number of nodes is small, there is little difference in the number of dead nodes among the three algorithms. When the number of nodes gradually increases, the number of dead nodes in the FCFS algorithm and the NJNP algorithm increases significantly, and the number of dead nodes in the proposed algorithm remains low. The growth trend is always lower than the other two algorithms.

5. Conclusion
This paper studies the WCV scheduling problem in the on-demand charging situation, and proposes a charging scheduling algorithm based on the entropy weight method. First, the concept of node network attributes is proposed, which makes the charging demand of nodes have a precise quantification standard. The charging scheduling algorithm based on entropy weight method is used to make on-demand planning for WCV scheduling, which effectively extends the network life. Finally, the proposed algorithm is simulated and compared with the existing FCFS algorithm and NJNP algorithm. Experimental results show that compared with the existing algorithms, the proposed algorithm significantly reduces the charging delay and improves the network life. Therefore, the scheme proposed in this paper has greater practical significance and reference value.

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