Journal of Physics: Conference Series



# Charging path planning algorithm based on multi-parameters in underwater wireless rechargeable sensor network

# Charging path planning algorithm based on multi-parameters in underwater wireless rechargeable sensor network

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**Abstract**. UWSN (Underwater wireless sensor network) is a significant part of marine environment stereo monitoring system, and the energy problem has always been an important constraint and challenge that limits its wide application. Due to the development of wireless charging technology and intelligent mobile nodes, the energy problem in UWSN has been solved. The underwater sensor network using wireless charging method is called UWRSN (underwater wireless rechargeable sensor network). In wireless rechargeable sensor networks, one of the core issues is the design of the charging planning. In this paper, a charging path planning algorithm based on multi-parameters is proposed for the on-demand charging system of UWRSN. The algorithm plans the charging path for the underwater MC (mobile charger) according to the parameters such as the remaining power, position, and power consumption speed of the underwater sensor node, so as to minimize the number of network dead nodes, improve network energy efficiency, and extend life of the network. Simulation results show that the algorithm has good performance in terms of charging efficiency, extending network life and other performance indicators.

## 1. Introduction

With the deepening of human understanding of the strategic position of the ocean, the development of marine resources, and the value of marine scientific research, all countries in the world have increased their attention to the ocean to an unprecedented strategic height [1]. UWSN mainly uses sound waves as the physical carrier for wireless transmission. It collects information through various static dynamic sensor nodes scattered in wide waters, and integrates data acquisition, transmission, processing, and fusion functions. It is a distributed intelligent network system [2]. The traditional wireless sensor nodes are mostly powered by batteries, which seriously limits the work of UWSN and brings great inconvenience to the application of UWSN. The breakthrough of WPT (Wireless Power Transmission) is crucial to the development of UWSN. WPT uses inductive coupling, electromagnetic radiation, magnetic coupling resonance and other technologies to wirelessly transmit the energy of the charger to the sensor node, providing the sensor node with a permanently controllable energy source, thereby solving the charging, energy renewal and life extension of different network devices and other issues [3]. WPT based on magnetic coupling resonance provides the possibility of energy supply in the underwater environment. Therefore, the research on UWRSN's energy supply problem will shift from how to reduce node power consumption to how to formulate a feasible and efficient charging path planning algorithm to reduce node mortality and extend the life of the network.

NJNP (Nearest-job-next with preemption) [4] strategy and ERS (Emergency Recharge Scheme) are two kinds of benchmark energy scheduling schemes in WRSN [5]. The NJNP strategy first charges the nearest node, but ignores the important parameter of the remaining power of the node, thereby increasing the node mortality of the network and reducing the network life. ERS uses the minimum charge node priority charging algorithm, which plans the path according to the remaining power of the node. The smaller the remaining power, the higher the position of the node in the charging list. The algorithm does not consider the position of the node, the charging distance of the MC is greatly increased, thereby increasing the energy consumption of the network.

In order to reduce network energy consumption and increase network life, the focus of this work is to propose an active UWRSN charging path planning algorithm based on multi-parameters. A path planning function is introduced by measuring factors such as the remaining power, location, and power consumption rate of the sensor node, to plan the charging path for the MC; finally, through simulation, the algorithm is compared with the traditional NJNP algorithm and ERS to verify the superiority of the algorithm.

The structure of this article is as follows. The second part gives the problem statement and solution in related work. The third part introduces the UWRSN model designed in this paper. In the fourth part, the algorithm proposed in this paper is described in detail. In the fifth part, the proposed algorithm is simulated and analyzed. Finally, the sixth part summarizes the full text and gives the conclusion.

## 2. Related Work

Underwater wireless sensor networks will have important applications in marine data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation, and tactical surveillance [6]. The breakthrough of WPT technology makes the charging scheduling problem an important research direction of UWRSN. J. Manikandan et al. [7] designed an autonomous underwater wireless charging station to charge underwater wireless sensor networks. Liguang Xie et al. [8] used magnetic coupling resonance technology to charge wireless sensor networks for the first time, and proposed a basic framework for charging scheduling. Wang et al. [9] designed a model framework that fully exploited the advantages of multi-hop energy transmission using magnetically coupled resonant repeaters.

Wireless charging technology is the physical basis for building rechargeable sensor networks, and charging plan design is the theoretical core to solve the energy shortage of sensor nodes. Zhang et al. [10] first proposed a multiple mobile charging device collaborative algorithm, aiming at maximizing the energy use efficiency, configuring multiple mobile charging devices and allowing energy transfer between devices. Liu et al. [11] divided the wireless rechargeable sensor network into several subnets, and used MC to periodically and orderly charge each subnet, focusing on the charging time distribution of each subnet. Wang et al. [12] studied two on-demand charging strategies, nearest-charger-first scheduling and recent-rarest-charger-first scheduling, and assigned the generated charging requests to the corresponding MCs. Sheikhi, Marzieh et al. [13] proposed LKC (Limited Knowledge Charging) that adapts to changes in network conditions to extend network life by balancing energy in the network area. Chi et al. [14, 15] proposed a HOCS (Hybrid Optimal Charging Scheme), which divides charging robot mules into common mules and emergency mules, these two mules respectively charge ordinary nodes and nodes with low power. In addition, the author also proposed the TSCA (A Temporal-Spatial Real-Time Charging Scheduling Algorithm) that removes low-efficiency charging nodes from the basic charging path to maximize network charging efficiency. The design of charging plans in wireless rechargeable sensor networks is essentially to improve the performance of the network while minimizing the cost of charging.

## 3. Preliminaries

This section mainly introduces UWRSN's evaluation index and network distribution model, and makes relevant preparations for later work.

### 3.1. Problem description

In this paper, the state of the sensor node is defined as three types, which are “normal ( $N$ )”, “to be charged ( $W$ )”, and “dead ( $D$ )” The definition of the node state $S(i).type$ is as shown in Equation 1.

$$S(i).type = \begin{cases} N & S(i).E > T_1 \\ W & T_2(i) \le S(i).E \le T_1 \\ D & S(i).E < T_2 \end{cases} \tag{1}$$

Where, threshold $T1$ is a constant, and threshold $T2$ is defined as Equation 2:

$$T_2(i) = \frac{\mathrm{d}(i, MC)}{V_{mc}} * S(i).V \tag{2}$$

$T_2(i)$ is related to the distance $d(i,MC)$ between the node and the MC, the navigation speed of MC $V_{MC}$ and the energy consumption speed of the node $S(i).V$, that is, when the remaining power of the node is not enough to maintain the node until the mobile charging node navigates to the node position, the node will be considered the dead node.

This article sets up multiple evaluation indicators to measure the performance of the charging algorithm, including node mortality $R_{dn}$, MC charging efficiency $\eta$, MC's driving power consumption $E_{\mathrm{d}}$ and node average waiting time $T_W$, defined as Equation 3-6:

$$R_{\mathrm{dn}} = \frac{N_D}{N} \tag{3}$$

$$\eta = \frac{\sum E_C(i)}{\sum E_C(i) + \sum E_d(ij)} \tag{4}$$

$$E_d = \sum E_d(ij) \tag{5}$$

$$T_W = \frac{\sum T_W(i)}{N'} \tag{6}$$

Where, the node death rate $R_{dn}$ refers to the ratio of the number of dead nodes $N_D$ to the total number of nodes $N$ in the sensor network; $T_W(i)$ is the waiting time of the node to be charged with id $i$, $N'$ is the number of nodes to be charged, the waiting time $T_W$ of each node is the sum of the voyage time of MC and the charging time of the node before node $i$.

### 3.2. Model of network distribution

The entire UWRSN includes a number of rechargeable sensor nodes, a number of MCs (mobile chargers), a number of SSs (service stations), and a BS (base station). Among them, the sensor node and BS form the sensor network, SS and MC form the charging system. Sensor nodes are randomly deployed in the wireless sensor network area, they send charging request to MC in a hop-by-hop manner, which includes the location coordinate node id, remaining power and power consumption speed of the node. After each MC receives the charging request, it departs from the SS, moves in the network according to the planned path, and stays at the charging residence point to charge the surrounding nodes. After charging, MC returns to SS to replenish its own energy.

## 4. Implementation

Considering that node's location, node's remaining power, and node's power consumption rate will affect the performance of the charging plan, therefore, a path planning function is introduced to assist the MC in charging path planning when path planning is performed. The path planning function is defined as Equation 7:

$$K(i)=\begin{cases}\alpha * D_{nor}(i,\ p)+\beta * E_{\mathrm{nor}}(i)+\gamma * 1/V_{nor}(i) & S(i).E>0 \\ \alpha * D_{nor}(i,\ p) & S(i).E=0\end{cases} \tag{7}$$

Where, *α, β, γ* are the weight coefficients of the node's position, remaining power, and power consumption rate factors in the path planning function, it satisfying 0<α<1,0<β<1,0<γ<1 and α+β+γ=1. Because the location of nodes, remaining power, and power consumption rate have different dimensions and orders of magnitude, the levels between factors differ greatly, in order to facilitate calculation, these data have been standardized by min-max. $D_{nor}(i,p)$, $E_{nor}(i)$ and $V_{nor}(i)$ are respectively the distance between the node and previous hop node, the remaining power and the power consumption rate of the node $i$ after standardization.

The charging planning algorithm based on multi-parameters is described in *Algorithm 1*. First, $S_C$ is defined as the current node, the distance between the nodes in the list $C$ to be charged and the node $S_C$ is calculated, the value $K(i)$ of the path planning function is calculated, and then select the node $i$ with the smallest $K(i)$ as the charging node for the next station. Simultaneously, adding node $i$ to the charging sequence $R$ and deleting node $i$ from the list $C$ to be charged. This process loops until the number of nodes in list $C$ is zero.

## 5. Simulation analysis

In this section, Matlab is used to simulate the charging process of CPMP (Charging path planning algorithm based on multi-parameters), ERS and NJNP charging schemes under the same initialization conditions, and evaluate the performance of the multi-parameter UWRS charging path planning algorithm.

### *5.1. Simulation settings*

N sensor nodes S are randomly deployed in the square wireless sensor network area. The SS is located in the center of the network. All underwater MCs start at the speed of 1m/s from the location of the SS they belong to, consume 8J energy per meter, and charge the sensor node at 4W after reaching the node. The initial energy of the node is 500J, and the energy consumption rate of each node varies from 0 to 0.2.

### *5.2. Path planning simulation of three algorithms*

Fig. 1 depicts the driving path of underwater MC in a certain period under different algorithms. It can be seen from the figure that the charging path under the NJNP scheme is the shortest, while the charging driving path of the MC under the ERS scheme has a redundant route. The length and redundancy of the charging driving path of the MC under the CPMP scheme are between the above two schemes.

**Algorithm 1** Recharging scheme based on multiple parameters

```
Input: Charging candidate list C
Output: Recharging node sequence R
Initial: Sc← MC
for i=1 to num do
    Calculate Min_E, Max_E, Max_V, Min_V, Min_dis, Max_dis
end for
for i=1 to num do
    Calculate Dnor(i, Sc, Enor(i), Vnor(i)
    if S(i).E≤T2 then
        K(i) ← α*Dnor(i, p)+1
    else
        K(i) ← α*Dnor(i, Sc)+β*Enor(i)+γ*1/Vnor(i)
     end if
    Find a node i with minimum K(i) in R
    R←R∪{i}, Sc←i
   C←C/{i}, num←num−1
end for
Return: R
```

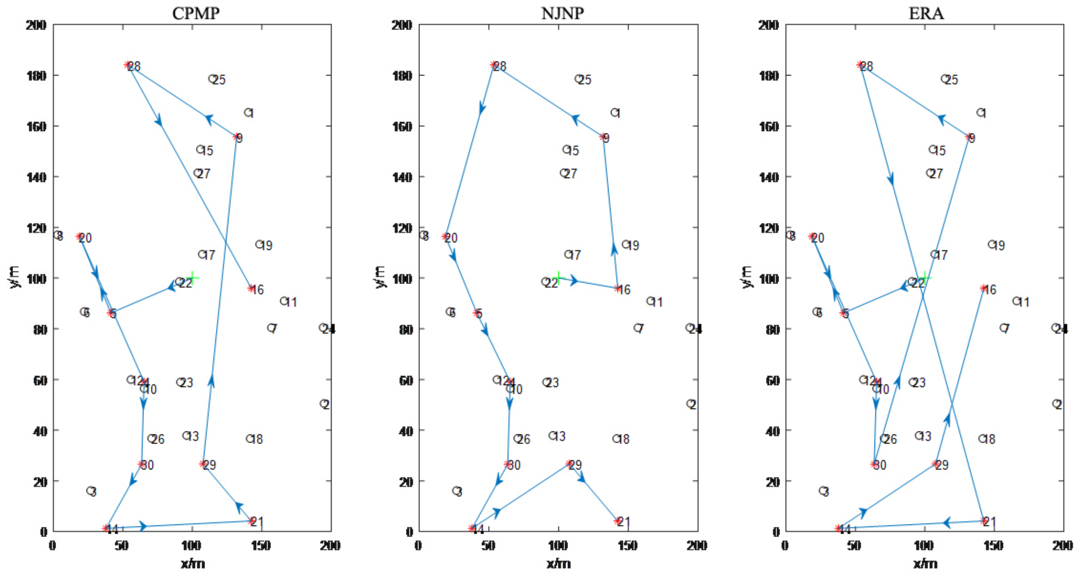


**Figure 1** The driving path of a certain period under different algorithms

### *5.3. Performance comparison*

*5.3.1. Rate of dead nodes.* Node mortality is an important factor to measure the performance of underwater wireless sensor networks. This paper first compares the ratio of network dead nodes under three charging schemes of ERS, NJNP and CPMP in each charging cycle of the network. As shown in Fig. 2, as the network's working time increases, the rate of dead nodes is increasing, but the rate of death nodes of CPMP is always lower than NJNP and ERS. The reason is that NJNP does not consider the problem of emergency nodes, causing the nodes with less energy to die, and ERS only focuses on the nodes with the least energy, causing the nodes at long distances to die. In CPMP, the driving cost, the remaining power of nodes and the average power consumption rate of nodes are taken into account, so the death rate of the node is reduced, which reflects the superiority of CPMP performance.

*5.3.2. Charging efficiency.* The charging efficiency of the network refers to the ratio of the energy supplied by the MC to the node and the total energy consumed by the MC in each charging round. Fig. 3 and Fig. 4 show the comparison of network charging efficiency and MC driving energy consumption of three algorithms under different charging rounds. It can be seen that the charging efficiency of CPMP is slightly higher than that of ERS. Although the charging efficiency of CPMP is lower than that of NJNP, the driving energy consumption of MC in CPMP is the lowest, indicating that the algorithm proposed in this paper can guarantee the lowest Charging for driving energy consumption, and charging efficiency has also been improved compared to ERS.

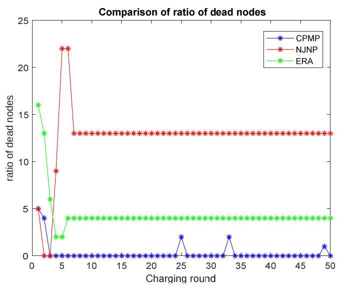


**Figure 2** Comparison of node mortality

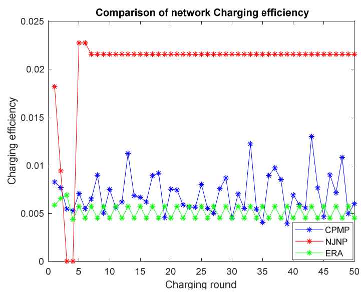


**Figure 3** Comparison of charging efficiency

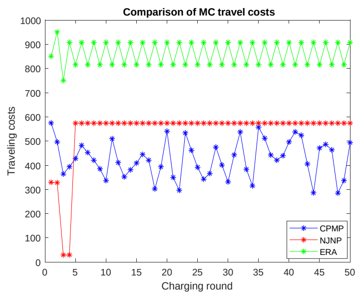


**Figure 4** Comparison of driving energy

*5.3.3. Average waiting time.* It can be seen from Fig. 5 that the average charging delay keeps changing as the network charging time increases. Among them, the average waiting time of CPMP is the shortest, followed by NJNP, and the average waiting time of ERS is the longest. The reason is that ERS is the first to charge the node with the lowest amount of electricity. The charging time is longer and the MC travels longer, thereby extending the average waiting time of other nodes to be charged. In NJNP, irrespective of the remaining power of the node, the first node that issued the charging request may not be able to get a response for a long time due to location factors, so the average waiting time will increase.

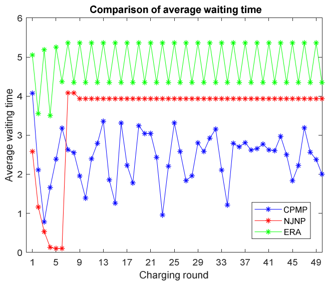


**Figure 5** Comparison of average waiting time of nodes

## 6. Conclusion

UWRSN, which introduces wireless energy transmission technology, is a brand new method to solve the energy problem of UWSN. In order to ensure the long-term operation of UWRSN, it is very important to design and plan the charging path. This paper proposes a new charging path planning scheme for UWRSN. Firstly, according to the relationship between the energy consumption of the node and the navigation speed of the underwater wireless MC, a threshold method is designed to select the node to be charged. Then CPMP algorithm is proposed to improve the survival rate of network nodes. In order to evaluate the performance of the charging scheme, we simulated and compared two typical charging schemes. We have concluded that, compared to the classic scheme, CPMP can make the UWRSN network live longer and the MC's driving energy consumption is the lowest.

## 7. Acknowledgments

This work was supported in part by the Key R & D projects of Shandong Province (2019JMRH0109) and the National Natural Science Foundation of China (61972367).

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