# Fuzzy Probabilistic Topology Control Algorithm for Underwater Wireless Sensor Networks

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**Abstract.** Aiming at the problem that the underwater wireless sensor network is limited in energy and the underwater topology is susceptible to the dynamic environment, this paper designs an AUV-assisted fuzzy probability power topology control (FPPTC) algorithm by introducing AUV nodes and clusters generated by clustering. Head node communication reduces power consumption of low energy nodes. According to the data deviation value between the current data value of the AUV node and the target parameter, the adjustment probability of the transmission power is determined, and the transmission power of the AUV node is adjusted to an optimal value to reduce the underwater topology energy consumption, prolong the network life cycle, and improve the network. The purpose of communication quality. The simulation results show that the FPPTC algorithm can improve network coverage, slow down node failure speed and extend network life cycle.

**Keywords:** Underwater wireless sensor networks (UWSNs) · Topology control · Autonomous underwater vehicle (AUV) · Fuzzy power control

## 1 Introduction

The underwater world has a tremendous impact on the development of human beings. It is not only closely related to people's living environment, but also contains a large amount of minerals and natural resources under the water, which is also inextricably linked with economic development. With the emphasis on underwater environment and resources, underwater wireless sensor networks have been widely used in various fields such as underwater pollution monitoring, gas leakage monitoring and navigation [1].

The underwater wireless sensor network topology is mainly composed of a large number of wireless sensor nodes randomly scattered in the target water area. Unlike the

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terrestrial wireless sensor network, the underwater wireless sensor network is subject to more restrictions. The underwater node has limited energy and can't be charged, and its life is short. Because the Radio Frequency (RF) wave is seriously attenuated in the underwater environment [2], the communication quality is degraded. Therefore, in UWSNs, the underwater acoustic mode is mainly used for communication [3], The acoustic channel has limited bandwidth and is not suitable for large-scale communication. Secondly, the underwater node is easy to change with the influence of ocean currents and the like, and the topology is damaged.

Faced with the problems faced by the current underwater wireless sensor network topology, many solutions have been proposed, which can be mainly divided into two categories: node power control and cluster topology control [4]. Although traditional wireless sensor networks propose many topological control algorithms, their application to underwater environments is still limited. With the development of technology, AUV has been applied to underwater wireless sensor networks. As proposed in the literature [5], the AUV collaborative control strategy consists of multiple AUV nodes participating in the underwater network to improve network performance. However, AUV is costly and large-scale use is not realistic. In the traditional network topology control algorithm, when there is a deviation between the transmission power and the calculation power based on the optimal algorithm, the node needs to adjust the transmission power. This method is effective for network resource rich or static network, because the node energy is limited and topology in UWSN. The structure changes dynamically, and the effect of this method is not obvious. At the same time, in the AUV assisted underwater network topology, when there is a deviation between the AUV transmission power and the transmission power based on the optimal algorithm, adjusting the power may not be the best strategy, so consider balancing between network performance and network functions.

Aiming at the limitations of the above underwater wireless sensor network topology, this paper proposes a fuzzy probability power topology control (FPPTC) algorithm. Add AUV as a secondary node in UWSNs. On the basis of the residual energy of AUV node and ordinary node, the optimal algorithm based on factors such as transmission power and degree of enumerated list. Reference fuzzy logic control algorithm, In accordance with the current value and the deviation between the target parameters, output probability to adjust the parameters, such as transmission power, he greater the difference, the greater the probability of adjustment. The cluster head node is selected by the adaptive clustering method, and the AUV mainly exchanges data with the cluster head node to reduce the communication frequency of the low energy node. The mobility of AUV can realize dynamic link of underwater wireless sensor network, comprehensively consider parameters such as common node and AUV node transmission power, optimize network topology control, reduce energy consumption of underwater nodes, extend network life cycle, and improve communication quality.

## 2 Related Work

In recent years, many control algorithms have been proposed for underwater wireless sensor network topology. According to the underwater topology features, they are mainly divided into three categories [6]: energy control, mobile assisted technology and radio mode management. In the topology control process, based on different transmission power, it can be used to improve localization [7]. For dynamic topology control, AUV assistance or depth adjustment of some nodes can be used [8].

In the literature [9], two topology control algorithms, improved distributed topology control (iDTC) and power adjustment distributed topology control are proposed for underwater wireless sensor networks. These two methods can improve network communication capabilities while reducing energy consumption. The method mainly guarantees data transmission through the communication of geographic information opportunity routing. Then, according to the topology control strategy of complex network theory, a dual clustering structure is constructed, including two cluster head nodes, to ensure the coverage of the network connectivity nodes. However, in the underwater environment, it is not realistic to use the Global Positioning System (GPS) method. The wire is used to anchor the sensor node in the underwater environment, and the sensor node is offset around the anchor point, which causes the node to move in the horizontal direction. The node location is not accurate. In [10], an energy control underwater wireless sensor network topology control algorithm EFPC is proposed. This algorithm optimizes the node transmission power through a certain limited Nash equilibrium function to avoid underwater biological interference. It can better implement network topology, improve network performance, and avoid underwater biological interference. However, game theory equilibrium cannot fully guarantee network coverage and node connectivity, while other factors affecting energy consumption are not considered. In [11], the R-ERP$^2$R algorithm makes decisions based on the distance between nodes and residual energy, performs data transmission, and adds connection quality metrics and retransmission mechanisms to increase reliability.

## 3 FPPTC Algorithm

The FPPTC algorithm draws on the idea of fuzzy control theory to adjust the output power in FCTP [12] algorithm. Meanwhile, according to the fuzzy probability adjustment method, the transmission power of the AUV node is adjusted to ensure the underwater topological communication quality, and the average energy consumption of the node is reduced. The FPPTC algorithm is mainly composed of four stages: they are topological clustering, solving data deviation values, calculating power adjustment probability, and fuzzy power control.

### 3.1 Topological Clustering

The underwater wireless sensor nodes are randomly scattered in the target waters, and then the nodes are clustered. The selection of the cluster head node $N_i$ is mainly based on the residual energy of the underwater topology node. The time required for the topology to complete the clustering is $T_c$. The time interval for the next clustering process is $T_n$. The underwater topology triggers the cluster every $T_c + T_n$ seconds (this process is a network cycle), reselect cluster head, simultaneous multiple iterations in the clustering process. Set the initial cluster head percentage for all underwater topology nodes, i.e. $C_p$ (e.g. 6%), Where $C_p$ is limited to the notification of the initial cluster head, no direct influence on the formation of the final cluster. Set the node to cluster head probability to $CH_p$, as shown in Eq. (1):

$$CH_p = \frac{C_{p \times E_{residual}}}{E_{\max}} \tag{1}$$

Where $E_{residual}$ is the current remaining energy of the node, $E_{max}$ is the maximum energy of the node (generally the energy when the node is fully charged), However, the value of the node is not allowed to be lower than a certain value Pim (such as $10^{-4}$). The probability that a node is selected to be a cluster head is proportional to $E_{residual}$.

## 3.2 Solving Data Deviation Values

In order to realize UWSNs communication, there is a deviation between the current data of the AUV node and the target. According to this, the ratio of the difference between the data optimal solution and the current time parameter to the optimal solution is defined as the data deviation value. In order to ensure the communication quality and network connectivity of the underwater topology. In this paper, the data deviation analysis of the node's transmission power, neighbor node degree and residual energy value provides a reliable basis for AUV transmission power control.

According to the definition of the data deviation value above, the data deviation value is solved for the AUV transmission power, as shown in formula (2).

$$D_p = \frac{\left| \frac{\sum_{i=1}^{n} (P_a + P_{vi})}{n} - P^* \right|}{P^*} \tag{2}$$

The number of AUV communication nodes is n, $P_a$ is the current transmission power of the AUV node, $P_{vi}$ is the transmission power of the communication node, P* is the best transmission power of AUV when communication is realized, and $D_p$ is the data deviation value of transmission power. Similar to the transmission power, the data deviation value is calculated for the neighbor list degree (defined herein as the number of one-hop nodes in the AUV node communication range). Let the AUV node realize that the maximum neighbor node degree is Q*, and the current neighbor list degree of the AUV node is Q, then the neighbor node degree deviation value is as shown in formula (3):

$$D_Q = \frac{|Q - Q^*|}{Q^*} \tag{3}$$

For the residual energy deviation value, similar to the transmission power, not only the remaining energy of the AUV node but also the remaining energy of the cluster head node $V_i$ with the AUV communication. Let the total energy of the AUV node and the communication node be E*, the remaining energy of the AUV node be $E_a$, and the remaining energy of the communication node be $E_{vi}$, then the residual energy deviation value is as shown in formula (4):

$$D_E = \frac{\left| \frac{\sum_{i=1}^{n} (E_a + E_{vi})}{n} - E^* \right|}{E^*} \quad (4)$$

From the above definition of the data deviation value, the magnitude of the deviation value and the difference between the current value of the data and the optimal solution value are proportional to each other. The larger the difference, the larger the data deviation value.

### 3.3 Fuzzy Adjustment Probability

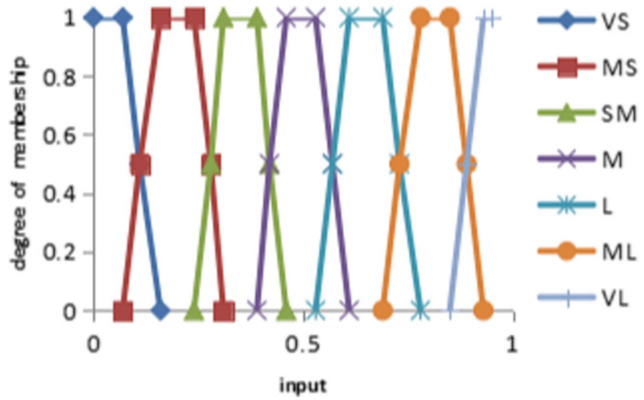
According to the data deviation value calculated in Sect. 3.2, the fuzzy logic algorithm is used to solve the adjustment probability of the transmission power. The larger the deviation, the greater the adjustment probability. However, there is no clear relationship between the data bias value and the adjustment probability. Therefore, in order to realize the correlation between them, this paper adopts the fuzzy logic algorithm to adjust them. According to the conclusions of the literature [10]. Using cross-layer parameters as the input value of the fuzzy logic system, i.e. the data deviation value. Give each cross-layer parameter a dynamic weight. The more fuzzy rules, the more output. Therefore, the accuracy is higher, the number of fuzzy rules set in this paper is 7, as shown in Table 1:

**Table 1.** The fuzzy rules

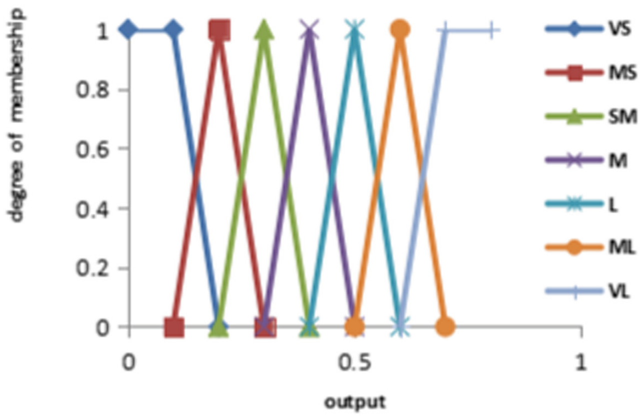
| Input | Output |
|---|---|
| Very Small (VS) | Very Small (VS) |
| Medium Small (MS) | Medium Small (MS) |
| Small (S) | Small (S) |
| Medium (M) | Medium (M) |
| Large (L) | Large (L) |
| Medium Large (ML) | Medium Large (ML) |
| Very Large (VL) | Very Large (VL) |

According to Table 1, the input and output membership function is shown in Fig. 1:

According to the above fuzzy rule input and output, the transmission power adjustment probability is proportional to the data deviation value. The data deviation values have been solved for AUV transmission power, neighbor list degree and residual energy respectively in Sect. 3.2. Three adjustment probabilities are output from the above fuzzy rules, respectively, the transmission power adjustment probability $\rho_P$, the adjustment probability of the neighbor list degree is $\rho_Q$, and the adjustment probability of the remaining energy is $\rho_E$. In order to improve network performance, it is necessary to determine the probability of adjusting the transmission power. Since the performance determined by a large deviation value cannot be guaranteed with a small probability,




(a)




(b)

**Fig. 1.** Input (a) and Output (b) membership function

the maximum adjustment probability should be selected. The AUV transmission power adjustment probability is shown in formula (5):

$$\rho = \max\{\rho_P, \rho_Q, \rho_E\} \tag{5}$$

Through Eq. 5, the adjustment probability of the transmission power is determined by the worst performance parameter, and the network performance can be improved by this method.

### 3.4 Power Control

When calculating the transmission power deviation, it is necessary to solve the optimum transmission power to determine the magnitude of the deviation. When the AUV needs to adjust the power, adjust it to the optimal transmission power. Therefore, the optimal transmission power plays a crucial role in the overall network topology.

In this paper, the calculation of the optimal transmission power is based on the FCTP algorithm proposed in [12]. Most nodes are between 4 and 7, with an average node degree of around 5.89.

This method is a power control method based on fuzzy logic. The power adjustment method uses closed-loop control, as shown in Fig. 2. Define Ed as the expected neighbor list degree, and Td as the current node degree of the AUV node. All nodes are running under the same rules. Closed-loop working mode: The AUV node has an initial power and the AUV node periodically broadcasts its uniquely represented message Msg. All cluster head nodes that receive Msg send a feedback confirmation message FBMsg to reply. Calculate the number of FBMsg received during the period before the node sends the next Msg. Its the Td of the current cycle, When there is a gap between Td and Ed, the TP value of the AUV is output through the fuzzy logic control algorithm. The fuzzy power control of the FPPTC algorithm based on the improved FCTP algorithm is shown in Fig. 2:

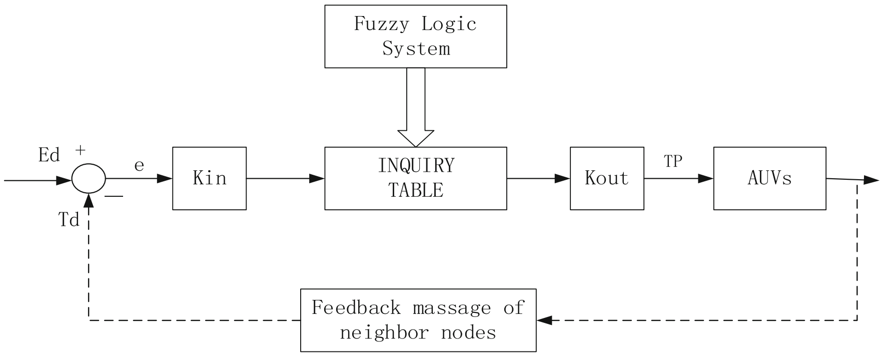



**Fig. 2.** Power control

## 4 Performance Analysis

FCTP algorithm is a traditional fuzzy logic topology control method. In order to verify the performance of the FPPTC algorithm, the simulation tool NS-3 was used to evaluate and compare with FCTP and R-ERP$^2$R under the same parameter settings. The simulation configuration parameters are shown in Table 2:

Figure 3 is a comparison of the coverage of underwater wireless sensor networks. as can be seen from the simulation results, compared with R-ERP$^2$R algorithm and FCTP algorithm, FPPTC algorithm coverage is higher. When the number of node failures is small (less than 20), the gap in network coverage is not obvious. As the number of failed nodes increases (when the failed node exceeds 61), network coverage declines faster. Due to the introduction of AUV node assistance in the underwater network topology, utilizing its autonomous mobility and expanding transmission

**Table 2.** Simulation configuration

| Parameter | Value |
|---|---|
| Simulation area | 300 m × 300 m |
| Number of nodes | 150 |
| Depth | 15 m |
| Sound speed | 1475 m/s |
| Communication radius | 30 m |
| Initial energy | 1000 J |
| Data rate | 2000 bit/s |
| Transmission power | 2.8 W |
| Receive power | 1.5 W |

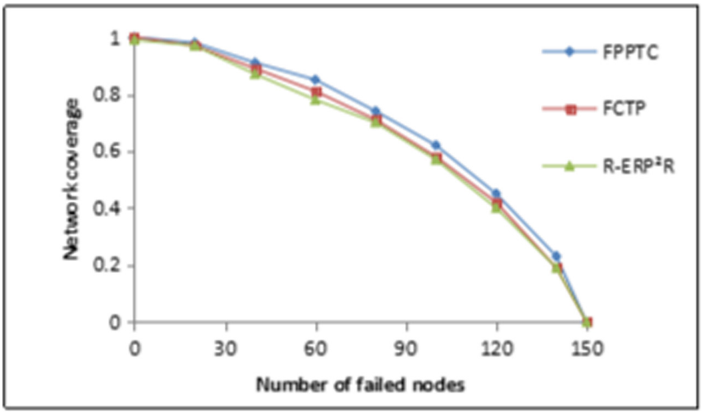



**Fig. 3.** Network coverage comparison chart

power, improve network coverage and communication quality of underwater acoustic networks.

Figure 4 shows the relationship between the operating cycle of the reaction node and the average remaining energy. As can be seen from the figure, the average residual energy of the FPPTC algorithm is slightly larger than the other two algorithms. Since the FPPTC algorithm needs to consume a certain amount of energy when initial clustering, the average energy of the node is slightly lower than the FTC algorithm when the number of running rounds is less than 10. As the number of running rounds increases, the average remaining energy is improved compared to the other two algorithms. This is because the FPPTC algorithm adjusts the AUV transmission power according to the probability, reduces the adjustment frequency (about 30%), and saves energy.

Figure 5 is a comparison of the number of algorithm nodes and the network life cycle of the three algorithms. As can be seen from the figure, as the number of deployed nodes increases, the FPTTC algorithm network lifetime is greater than the FCTP algorithm. This indicates that the FPTTC algorithm network runs more

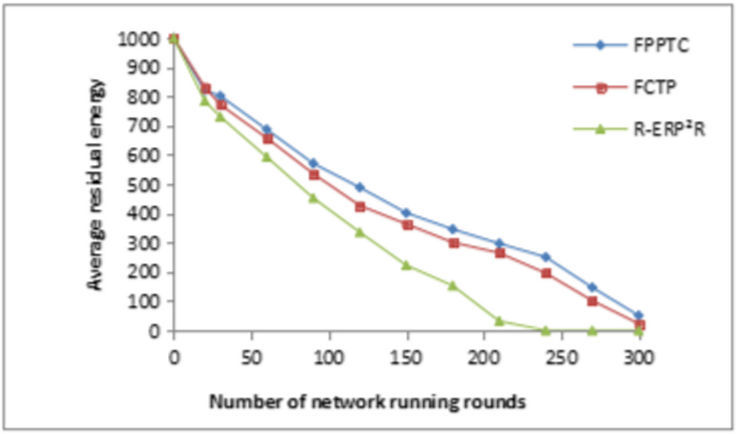



**Fig. 4.** Residual energy comparison chart

efficiently as the number of deployed nodes increases. Compared with R-ERP$^2$R, although the clustering process is carried out, the auxiliary of AUV significantly reduces the energy consumption of cluster head node communication. Thus extending the network life cycle.

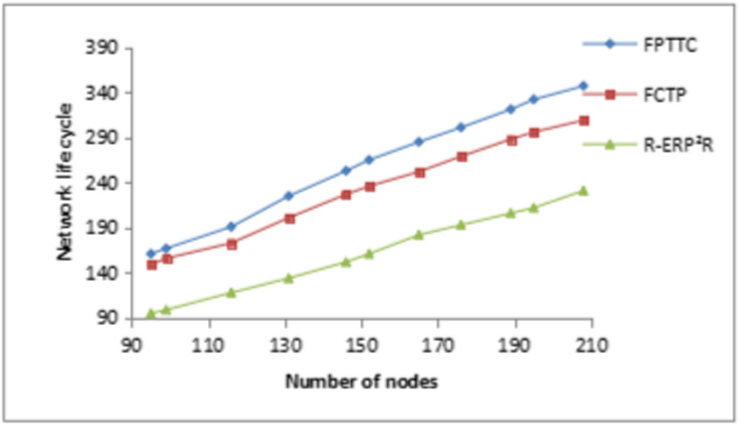



**Fig. 5.** Network life cycle comparison chart

## 5 Conclusion

Based on the FCTP algorithm, this paper proposes an AUV-assisted fuzzy probability power adjustment topology control algorithm. The FPPTC algorithm is characterized by the combination of AUV and underwater acoustic network topology. When the AUV transmission power and the optimal transmission power are not equal, it is determined according to the fuzzy rule whether the transmission power needs to be adjusted. This greatly reduces the power adjustment probability in the topology control algorithm. At the same time, the AUV mainly communicates with the cluster head node, which reduces the communication frequency of the low energy node and prolongs the network period of the node. Due to the complex underwater environment, the nodes fail to be irregular, which is easy to cause isolated nodes and difficult to repair the topology. How to heal the topology and improve the coverage will be further research directions.

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