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Relay selection and Optimization algorithm of Power allocation based on Channel Delay for UWSN

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Abstract

In the light of the characteristics of random change that underwater sensor change by time, space and frequency, select the best relay node to improve communication quality and get the diversity gain. A new optimal relay selection method is proposed in this paper, by considering two indexes synthetically that channel gain and underwater acoustic communication long time delay to select the best relay node. Based on the best relay node and minimization of bit error rate to take optimal power allocation of source node and relay node to realize network error rate's reduction of 1.81 dB so then improve the overall performance of the network.

Keywords*: Underwater sensor network; Cooperation; Relay selection; Power allocation*

1. Introduction

UWSN (Underwater Sensor Networks) consist of the sensor laid in the water. In recent years, UWSN's application is more and more widely in marine data collection, pollution control, offshore exploration, disaster prevention, assistant navigation and tactical observation [1].Underwater communication technology is also increasingly valued. Due to the electromagnetic wave decays too fast in the water, acoustic wave is the most suitable energy form for human to be found so far.

Underwater communication environment is very complicated, acoustic channel parameters random change by the change of time, space and frequency. Unfavorable factor that underwater environmental noise is high, band width, large transmission time delay and so on will make the underwater communication transmission's high error rate and low rate difficult to solve. Although MIMO (multiple input multiple output) can improve the channel capacity and spectrum utilization significantly, due to the size of the restricted element, the underwater nodes can't install the multi antenna, we should use relay cooperative communication mode to make single antenna users can send information through relay nodes, it overcome the serious problem of channel fading and also get the diversity gain.

The selection of relay nodes is a key problem in cooperative communication. There are many relay node selection algorithms in wireless network [2], according to different objectives it can be divided into the following categories: Relay node selection algorithm based on channel state information, like the relay node selection algorithm based on channel capacity gain in literature [3] and a comparison relay selection algorithm for SNR threshold that put forward in literature [4]; Relay node selection algorithm based on utility function, this is a compromise between the throughput and the transmit power from the

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MAC layer, three relay selection methods are proposed in literature [5]: Maximum total utility, Minimum utility's maximization and maximum product utility; Relay node selection algorithm based on Cooperative Region, like the relay node selection algorithm based on pairwise error probability-ty that put forward in literature [6].

Although the relay selection algorithm has been used in terrestrial wireless communication, due to the particularity and complexity of underwater environment, many terrestrial wireless network technologies cannot be directly used in underwater environment, we need to consider in the original technology and add water environment particularity factor. On the one hand, the purpose of put relay coordination to use is to reduce the channel fading between the source node and destination node, therefore, the optimal relay node selection's primary standard is the channel characteristic of relay node; On the other hand, it should use sound wave to communicate in UWSN, and due to the speed of sound waves in the water is about 1500m/s, it has 5 orders of magnitude lower than the speed of electromagnetic waves in terrestrial radio networks, therefore, the transmission delay of underwater acoustic communication is not negligible, we also consider the time consuming problem caused by relay node when we choose relay node. The higher the time consuming, the higher the communication efficiency is.

2. UWSN Relay Cooperative Communication System Model

In cooperative communication systems, when the m relay node is involved in the cooperation, the m+1 signal is received at the receiving end. Take the m+1 signal to merging coherent, it can bring about the space diversity gain and also increasing the received SNR. When multiple relay nodes are available, we choose one of the best relay nodes to participate in the cooperation with the appropriate relay selection algorithm in order to reduce the collision in communication system. Although the destination node only has two signals, the optimal relay node is selected when choosing relay, this is equivalent to a selection merge when the diversity is combined. If the number of relay nodes is m, the diversity gain of destination node is m+1, instead of 2, the more relay nodes, the more performance improvement [7].

Parameter definition and settings as shown in Table 1:

Table 1. System Parameters Definition and Settings

Parameter	Definition
h_{sri}	The channel fading coefficient between the source node to the I relay node
l_{sri}	The distance from the source node to the I relay node
h_{rdi}	The channel fading coefficient between the I relay node to the destination node
l_{rdi}	The distance between the I relay node to the destination node
h_{sd}	Channel fading coefficient between source node and destination node
l_{sd}	Distance between source nodes and destination nodes

3. Relay Selection and Power Allocation Optimization Based On Channel and Delay in Underwater Sensor Networks

3.1. Optimal Relay Node Selection Method Based on Channel and Delay Synthesis Index

Consult cooperative relay node's selection algorithm of terrestrial wireless network and cognitive network, and then seriously consider the complexity and specificity of the underwater environment, the optimal relay node selection algorithm for underwater acoustic wireless sensor networks is proposed in this paper. The algorithm is improved and innovative base on relay node selection algorithm for channel state information. According to the literature's [8] optimal relay node selection method base on Harmonic average of Channel gain, it can work out the harmonic mean function of channel gain of relay nodes and then improve the defects in the underwater environment, put forward the best relay selection algorithm that combine channel state information and transmission delay as indicators. The selection of the relay node is determined by the relay node channel characteristic and the position of the relay node relative to the destination node.

Table 2. Relay Selection Algorithm Parameter Definition and Settings

Parameter	Definition	Formula
X	data packet	Including node sending time
v	Underwater acoustic velocity	v =1500m/s
h	Channel fading coefficient	$h = a(f)^{f/1000}$
α	Channel fading index	α Underwater environment take the value of 1.5
H	Channel gain	$H = hl^{-\alpha}$
$m_H(x, y)$	Harmonic mean	$m_H(x, y) = \frac{2}{1/x + 1/y} = \frac{2xy}{x + y}$

First consideration is the influence from Channel conditions for relay nodes to the selection of optimal relay node. Then we use source to relay, relay to destination channel's instantaneo-us power gain's normalized mean number to represent relay node channel performance evalu-ation criteria. The channel performance measure of the I relay node is:

$$\phi_{meani} = m_H(H_{rdi}, H_{sri}) = \frac{2H_{rdi}H_{sri}}{H_{rdi} + H_{sri}}, \tag{1}$$

Channel gain harmonic mean ϕ_{meani} reflect the instantaneous channel characteristic of rela- y node, the bigger the value, the better the channel performance. Normalize it in order to facilitate the formulation of the comprehensive assessment standards, $\psi_i = \phi_{meani} / H_1$, H_1 is the normalized standard value of the channel gain set by the system.

Secondly, the velocity of sound waves is 5 orders of magnitude lower than that of terrestrial electromagnetic waves in underwater acoustic sensor network environment, so tra-nsmission time can't be ignored. In the relay coordination, the cooperation process is divided into two stages, the first stage source node sends the information to the destination node and the relay node, second stage relay node sends the information to the destination end, so the information at the destination node to merge waiting time is the transmission delay for the second stage (Do not calculate the time of relay node to information processing).The distance between the i relay node and the destination node is denoted as l_{rdi}, then the destination node's waiting time is $\Delta t_i = l_{rdi} / v$ .The shorter the waiting time, the shorter the time consuming, the higher the overall communication efficiency of the system. To normalize the waiting time $\tau_i = \Delta t_i / T_1$, T_1 is the waiting time normalized standard values that set by system.

Put forward to comprehensive consideration about relay selection comprehensive assess-ent criteria $R_{besti} = \psi_i - \tau_i$ of the above two factors, this value is determined by the channel state of the relay node and the distance between the relay node and the destination node. By comparing the corresponding comprehensive evaluation values of each relay node, select the maximum relay node as the best relay node for the comprehensive evaluation.

Concrete steps are as follows:

(1) All relay nodes send packets X to the source node and destination node, the source node sends packets X to the destination node, the packets Include sending time t_1 , the packets X arrival receiving node in t_2 . Assuming global time synchronization and according to the arrival time (TOA), the communication distance between nodes is calculated, then feedback to the sending node.

(2) The candidate relay node calculates its channel fading coefficient h according to the distance between the nodes and the established communication frequency. The $a(f)$ in calculation formula is channel absorption coefficient [9]. Its solving empirical formula is:

$$10\log a(f)=0.11\frac{f^2}{f^2+1}+44\frac{f^2}{f+4100}+2.75\times10^{-4}f^2+0.003 \qquad (2)$$

(3) Then the channel gain H_{sri} and H_{rdi} between the relay node and the destination node is obtained by the relationship $H = hl^{-\alpha}$, and feedback the result to the source node finally.The channel characteristics of each relay node are calculated from the source node:

$$\phi_{meani} = m_H(H_{rdi}, H_{sri}) = \frac{2H_{rdi}H_{sri}}{H_{rdi} + H_{sri}} \qquad (3)$$

and its normalization $\psi_i = \phi_{meani} / H_1$.

(4) The i relay node computes the distance l_{rdi} between itself and the destination node to the source node. Source node according to formula calculation $\Delta t_i = l_{rdi} / v$ to calculate the time of the destination node for the information reached at the second stage of the i relay node and its normalized values $\tau_i = \Delta t_i / T_1$.

(5) The source node calculates the comprehensive evaluation values of the relay nodes according to (3) and (4) step calculation results $R_{besti} = \psi_i - \tau_i$, then select the maximum R_{besti} corresponding I relay node as the best relay for collaboration.

3.2. Power Allocation Optimization Algorithm Based On Optimal Relay

After selecting the best relay node, the best relay node can help source node to transmit information, but the new problem is that how to allocate the power of the source node and the relay node in order to make the receiving performance reach the best Power allocation optimization objective is under the condition of total power constraint, then according the source to the relay, the relay to the destination, the channel state between the source to the destination node and the power of the relay node to make the error rate of the final destination receiving node is the smallest. That means under the condition $Q = Q_1 + Q_2$, the symbol rate is the smallest.

In the selective decode and forward (DF) relay scheme, if the signal to noise ratio of the received signal of the relay node exceeds the threshold value, the relay node can decode the received signal and forward it to the destination node. Otherwise, if the source to the relay channel is severely fading, so that the received SNR is below the threshold, the relay node will not participate in the cooperation.

First, the source node broadcasts information to the destination node and the relay node, the power Q_2 will decode the symbol to the destination, otherwise the relay will not send or remain idle. Destination node to receive relay forwarding signal is:

$$y_{rd} = \sqrt{\tilde{Q}_2 H_{rd}}\, x + n_{rd}\ ,\ \tilde{Q}_2 = Q_2 \text{ or } \tilde{Q}_2 = 0 \tag{4}$$

Through the two links from the source node and the relay node, the destination node recei-ves two copies of the signal x, the optimal method of maximizing total SNR is the MRC (Maximal-Ratio Combining), MRC output SNR is equal to the sum of all branches SNR [10]. If the average energy of the emitted signal x is 1, the MRC output SNR is:

$$\gamma = \frac{Q_1 H_{sd} + \tilde{Q}_2 H_{rd}}{\delta_0^2} \tag{5}$$

From the literature [11] we can know that M-PSK bit error rate is :

$$P_{ser}(\gamma) = \int_0^{(M-1)\pi/M} \frac{1}{\pi} \exp\left(\frac{-C_1\gamma}{\sin^2\beta}\right) d\beta\ ,\quad C_1 = \sin^2(\pi / M) \tag{6}$$

Assuming that the source is M-PSK modulated signal, the probability of the relay decoding error is $P_{ser}\left(Q_1 H_{sr} \big/ \delta_0^2\right)$,the correct probability of decoding is $1 - P_{ser}\left(Q_1 H_{sr} \big/ \delta_0^2\right)$. Consider -ing that $\tilde{Q}_2 = Q_2$ or $\tilde{Q}_2 = 0$,the calculation formula of probability of error which based on con -ditional probability is :

$$P_{ser} = P_{ser}(\gamma)\Big|_{\tilde{Q}_2 = 0} P_{ser}\left(\frac{Q_1 H_{sr}}{\delta_0^2}\right) + P_{ser}(\gamma)\Big|_{\tilde{Q}_2 = Q_2}\left[1 - P_{ser}\left(\frac{Q_1 H_{sr}}{\delta_0^2}\right)\right] \tag{7}$$

When Q_1 / δ_0^2 and Q_2 / δ_0^2 is large enough, M-PSK modulation system SER can consider as:

$$\begin{cases} P_{ser} \approx \dfrac{(\delta_0^2)^2}{C_1^2} \times \dfrac{1}{Q_1 \delta_{sd}^2} \times \left(\dfrac{C_2^2}{Q_1 \delta_{sr}^2} + \dfrac{C_3}{Q_2 \delta_{rd}^2} \right) \\ C_2 = \dfrac{M-1}{2M} + \dfrac{\sin \frac{2\pi}{M}}{4\pi} \\ C_3 = \dfrac{3(M-1)}{8M} + \dfrac{\sin \frac{2\pi}{M}}{4\pi} - \dfrac{\sin \frac{4\pi}{M}}{32\pi} \end{cases} \quad (8)$$

Take $Q_2 = Q - Q_1$ to the type, the Q_1 derivative and the derivative is 0,the optimal power allocation ratio for Minimum bit error rate is:

$$\frac{Q_1}{Q_2} = \frac{C_3 \delta_{sr} + \sqrt{C_3^2 \delta_{sr}^2 + 8C_2^2 C_3 \delta_{rd}^2}}{2C_3 \delta_{sr}} \quad (9)$$

We can find that power allocation depends on the source to the relay, the relay to the destination channel condition whereas the channel condition is independent of the source to destination.

4. Experimental Results and Analysis

When simulate, the network model is shown in Figure 1.Assuming the channel is independent identically distributed Rayleigh flat fading channel, the next step is use the Matlab simulation software.

4.1. Selection of Optimal Relay Node Based On Channel and Delay Synthesis Index

If set $l_{sd} = 1000m$, the system carrier frequency is $f = 20KHz$. H_1 is set as channel gain when the distance is $l = 300m$ .T_1 is set as transmission delay when the distance is $l = 2000m$. There are 5 optional relay nodes, the distance of each relay node to the source node and destination node is set as follows:

Table 4. Distances among the Relay Node, the Source Node and the Destination Node

Numerical	$l_{sr}(m)$	$l_{rd}(m)$
1	500	800
2	600	600
3	800	500
4	1000	500
5	1300	450

The normalized values of the channel gain of each relay node are calculated by the formula and the time normalized value of destination node waiting for relay information, then, the comprehensive evaluation of the relay nodes is presented in this paper. The contrast is shown below:

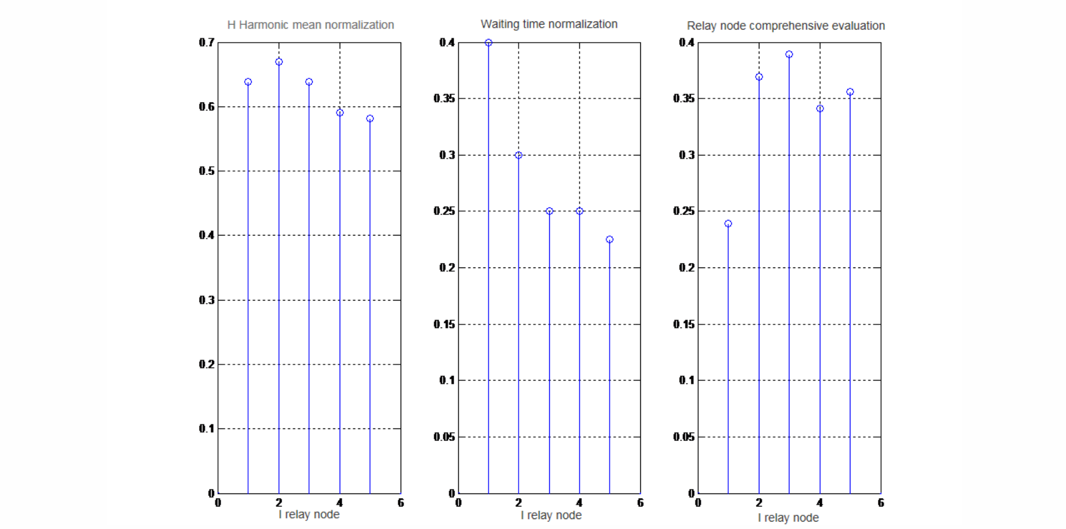

Figure 2. The Normalized Values of the Channel Gain of Each Relay Node

The first chart of the left is the normalized value of the channel gain of each relay node, it can be seen that the channel gain's Harmonic mean number of the second relay nodes is the largest and the channel characteristic is the best. The middle chart represents the normalized value of the transmission delay of each relay node in the second phase of cooperative communication, as the distance between the relay nodes to the destination node is shortened, the transmission delay is also reduced. Picture shows that the transmission delay of the first and the second relay nodes is much higher than other relay nodes, and reduce the overall communication efficiency. The right side of the diagram is the comprehensive performance evaluation of the relay nodes, it can be seen that the comprehensive evaluation of third relay nodes is the highest evaluate, it means the third relay nodes have achieved the best balance in channel performance and transmission delay two factors. Select the third relay nodes as the best relay node, for the channel characteristics of the best second relay nodes, the channel gain harmonic average only decreases the 4.5537% but transmission delay reduces 16.6667%. And for the transmission delay minimum 5 relay nodes, although the transmission delay normalized values increased 0.025, but channel gain harmonic mean normalized value grew 0.0579, so the third relay nodes of the comprehensive performance is the best.

4.2. Power Allocation Ratio Experiment Based On Optimal Relay

We should notice the relationship between bit error rate and power distribution ratio first. Even though asymptotically optimal power allocation is determined under the high SNR, they provide a good solution for the actual moderate SNR scenario. To the DF system for QPSK modulation under different fading scenarios, we will take SER as Q_1 / Q_2 function and draw it in the picture.

(1) $\delta_{sr}^2 = \delta_{rd}^2 = 1$, consider the channel quality of three different source to destination nodes: (a) $\delta_{sd}^2 = 0.1$; (b) $\delta_{sd}^2 = 1$; (c) $\delta_{sd}^2 = 10$, the optimal power allocation ratio in this case is $Q_1 / Q_2 = 1.681$ .Visible from the diagram, under different total transmit power $Q = 5W$、15W、20W and different channel variances δ_{sd}^2, $Q_1 / Q_2 = 1.681$ almost provide the best performance.

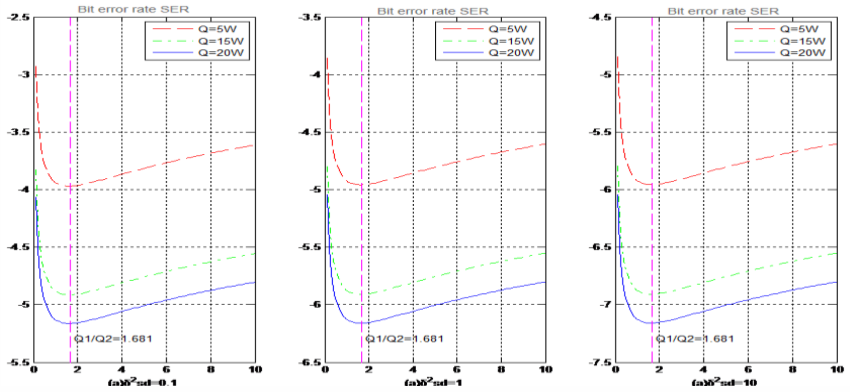

Figure 3. SER Performance of DF Cooperative System When $\delta_{sr}^2 = \delta_{rd}^2 = 1$ **, the Optimal Power Allocation Ratio Is** $Q_1 / Q_2 = 1.681$

(2) $\delta_{sr}^2 = 10, \delta_{rd}^2 = 1$, consider the channel quality of three different source to destination nodes: (a) $\delta_{sd}^2 = 0.1$; (b) $\delta_{sd}^2 = 1$; (c) $\delta_{sd}^2 = 10$, the optimal power allocation ratio in this case is $Q_1 / Q_2 = 1.1039$ .Visible from the diagram, under different total transmit power $Q = 5W$ 、15W、20W and different channel variances δ_{sd}^2 , $Q_1 / Q_2 = 1.1039$ almost provide the best performance.

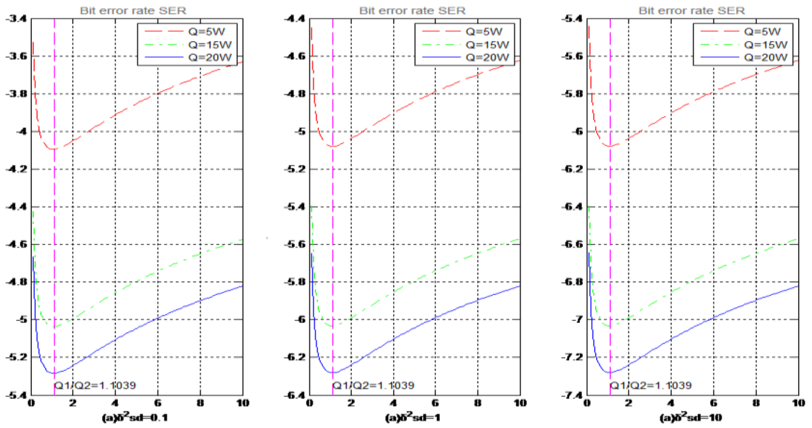

Figure 4. SER Performance of DF Cooperative System When $\delta_{sr}^2 = 10, \delta_{rd}^2 = 1$ **, the Optimal Power Allocation Ratio Is** $Q_1 / Q_2 = 1.1039$

(3) $\delta_{sr}^2 = 1, \delta_{rd}^2 = 10$, consider the channel quality of three different source to destination nodes: (a) $\delta_{sd}^2 = 0.1$; (b) $\delta_{sd}^2 = 1$; (c) $\delta_{sd}^2 = 10$, the optimal power allocation ratio in this case is $Q_1 / Q_2 = 3.9213$. Visible from the diagram, under different total transmit power $Q = 5W$ 、15W、20W and different channel variances δ_{sd}^2 , $Q_1 / Q_2 = 3.9213$ almost provide the best performance.

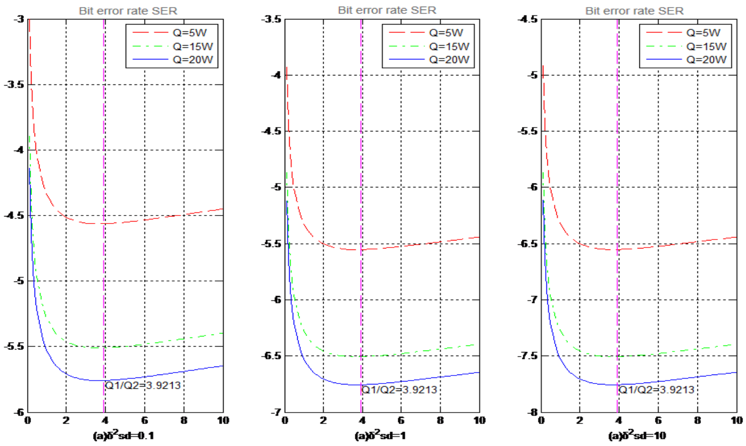

Figure 5. SER Performance of DF Cooperative System When $\delta_{sr}^2 = 1, \delta_{rd}^2 = 10$, the Optimal Power Allocation Ratio is $Q_1 / Q_2 = 3.9213$

5. Conclusion

In the light of the characteristics of underwater sensor network channel fading and using relay cooperative communication mode to reduce the impact of channel fading on communication quality. In this paper, a new optimal relay node selection method is proposed, which includes both the channel gain and the long delay problem in the underwater acoustic communication. According to this composite indicator, a balance point is taken from the channel condition and transmission delay, the next step is to choose the best relay node. This method can guarantee the communication quality and the communication efficiency. After choosing the best relay, according to the relay node channel and then allocating the power allocation of the source node and the relay node. This experiment proves that compared with equal power allocation algorithm, the method reduces the bit error rate of 1.81dB and improves the overall system's performance.

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