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Joint Relay Selection and Power Allocation Algorithm with Trust Parameter in an Underwater Cognitive Acoustic Cooperative System

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We investigated the problem of joint relay selection and power allocation in underwater cognitive acoustic networks (UCANs). A selection and allocation strategy based on the achieved this system was applied to maximize system throughput without affecting the quality of service of the primary system. In view of the harsh underwater environments, the trust parameter was first developed to overcome the imperfect spectrum sensing and improve the underwater cognitive acoustic system performance. The optimal approach of system throughput is difficult to obtain because of the non-constant definition of the mis-detection probability. Thus, we proposed a suboptimal approach based on cross-over iteration and sub-gradient (CISG) method to achieve maximum system throughput. Simulation results show that the proposed approach achieved better system throughput than other cooperative methods without trust parameter.

Keywords: Underwater cognitive acoustic networks (UCANs), relay selection, power allocation, trust parameter, mis-detection probability

1 INTRODUCTION

Given the advancements in acoustic technology, underwater acoustic communication has received considerable interest from both the academe and the industry, leading to the development of various aquatic applications, such

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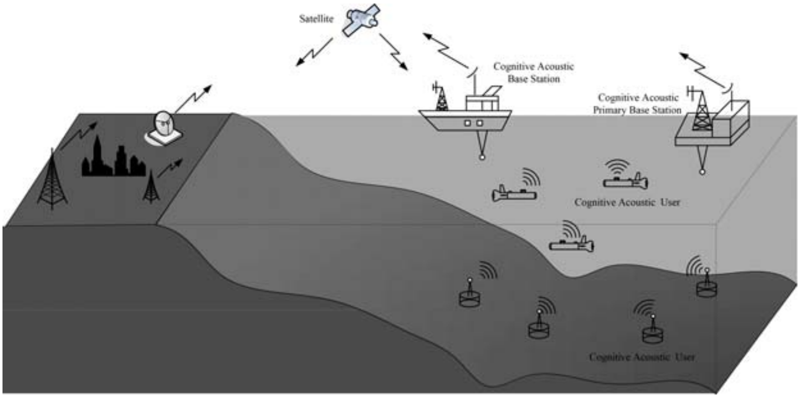

FIGURE 1
Underwater cognitive acoustic networks.

as mineral exploitation, environmental monitoring, disaster prevention, military surveillance, and coastline protection [19]. However, communication in aquatic environments is characterized by limited bandwidth, severe fading, and complex noise, all of which impede reliable underwater acoustic communication [6, 8].

Some of the unique features of underwater acoustic system include low data rate, long propagation delay, and time-varying fading. In view of the frequency-dependent attenuation, limited communication frequencies are available in water and usually range from tens of hertz to hundreds of kilohertz [3, 15]. Cooperative relaying techniques are gaining recognition as potential strategies for improving the performance of underwater acoustic communication [1, 9]. The scarce spectrum resource has become heavily shared by underwater acoustic systems as a result of the growth of underwater application networks, as is shown in Figure 1. In [2], dynamic spectrum sharing based on cognitive radio (CR) was applied to UCANs, this technique can reach higher capacities than traditional spectrum approaches. [11] pointed out that underwater acoustic environments usually comprise many acoustic systems, such as marine mammals and sonar users, and that underwater cognitive acoustic techniques can potentially develop an environmentally friendly underwater acoustic network with high spectrum utilization. Therefore, it is necessary for underwater acoustic network to introduce the cognitive technology [23].

Recent studies on UCANs have explored underwater acoustic cooperative transmission to implement spatial diversity and address the effects of fading. In [7], by taking advantage of the characteristics of UCANs, the author designed a new underwater cooperative transmission scheme that is focused mainly on improving channel capacity. As in the radio frequency(RF) scenario, selection and resource allocation issues must also be considered in underwater acoustic cooperative communication [14]. In [20], a reliable and energy-efficient relay selection scheme was proposed to minimize packet transmission delay. [25] proposed a new power-control transmission scheme that can guarantee certain end to-end packet error rate while achieving a good balance between the overall energy efficiency and the end-to-end packet delay. In [17], an energy-efficient relay selection scheme based on restless multi-armed bandit theory was proposed. [18] proposed a power-efficiency resource allocation scheme in a MIMO-OFDM cooperative system, and in [22], the Doppler compensation was considered during power allocation. However, limited studies have been conducted the joint relay selection and power allocation in UCANs, although this topic has been extensively investigated in radio communication [10]. Meanwhile, the development of cooperative transmission in cognitive scenarios is still in its infancy, despite its wide use in radio communication. In [13], an efficient spectrum management system was examined in UCANs to significantly improve the performance by a collaboration of the physical layer and the media access control (MAC) layer. [12] proposed an environmentally friendly cooperative transmission strategy that avoids interference with marine animals. In [21], we have studied a channel state information feedback scheme based on limited feedback in an underwater cognitive scenario. However, imperfect spectrum sensing was not considered in these studies. Moreover, given the transmission decline and the uncertainty caused by marine animals, a constant definition of the mis-detection probability i.e. in [10], is unsuitable for underwater environments. Furthermore, as in [11], the effects of the characteristics of underwater environments on underwater cognitive acoustic communication transmission were disregarded.

In this paper, we developed the trust parameter to evaluate the communication environment and overcome the imperfect spectrum sensing. We then discussed how a joint relay selection and power allocation with trust parameter can be realized under the constraints of the interference threshold and the total transmit power of cognitive nodes. To reduce the complexity, a cross-over iterative method was proposed, and sub-gradient method was utilized. Simulation results showed that the proposed algorithm has better performance and is more suitable for underwater cognitive acoustic cooperative systems than a joint relay selection and power allocation scheme without trust parameter.

The paper is organized as follows. In Section 2, the system model is introduced. Section 3 describes the problem of relay selection and trust parameter in underwater cognitive acoustic cooperative system. In section 4, the method of CISG for relay selection and power allocation with trust parameter is

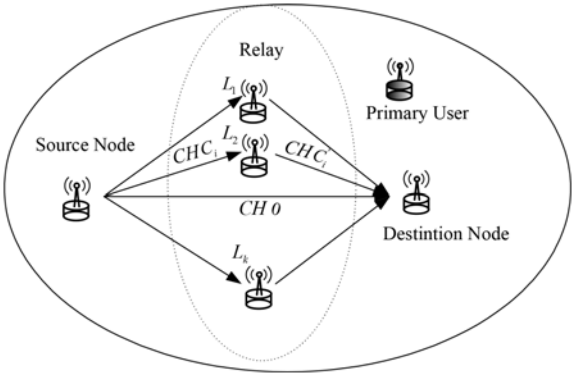

FIGURE 2
Underwater cognitive acoustic cooperative system.

proposed to solve the problem. The simulation results are given in section 5, and finally section 6 contains the conclusion.

2 SYSTEM MODEL

2.1 Network Model

As is shown in Figure 2, this study considered an underwater cognitive acoustic cooperative system consisting of a primary user(PU) and one underwater cognitive acoustic system, which includes one source node, one destination node, and multiple relay nodes. We used amplify-forward(AF) relaying protocol, indicating that the relay only amplified the signal from the source node and then sent the processed signal to the destination node. The cognitive nodes shared spectrum with the PU and used transmit/receive antennas. Underlay spectrum sharing was used in underwater cognitive acoustic system transmission.

2.2 Channel Model

As transmission media, underwater acoustic is complex and changeable, and the average sound velocity is approximately 1500 m/s. Seawater is not a loss-free medium. During underwater sound propagation, the signal energy will gradually become weakened. Underwater communication channels are mainly affected by spreading loss and absorption loss. The attenuation $A(l,\ f)$ as described by Urick [16] can be calculated as following:

$$A(l,\ f) = l^k a(f)^l, \tag{1}$$

where k is the spreading factor ($k = 1$ is cylindrical, $k = 2$ is spherical, and $k = 1.5$ in practical spreading), l is the distance in kilometers between these locations. The absorption coefficient $a(f)$ can be expressed by Thorps formula [16]:

$$10loga(f) = \frac{0.11 f^2}{1 + f^2} + \frac{44 f^2}{4100 + f^2} + \frac{2.75 f^2}{10^4} + 0.003, \tag{2}$$

where f is the sound frequency in kilohertz.

The ambient noise in the ocean can be modeled using four sources: turbulence (N_t), shipping (N_s), waves (N_w) and thermal noise (N_{th}), which can be described by the Gaussian statistics and a continuous power spectral density (PSD). The power spectral densities of the four noise components (in dB re ÂfÃ Pa per Hz) as modeled in [5]:

$$10logN_t(f) = 17 - 30logf, \tag{3}$$

$$10logN_s(f) = 40 + 20(s - 0.5) + 26logf - 60log(f + 0.03), \tag{4}$$

$$10logN_w(f) = 50 + 7.5\sqrt{w} + 20logf - 40log(f + 0.4), \tag{5}$$

$$10logN_{th}(f) = -15 + 20logf, \tag{6}$$

where s is the shipping activity factor, $0 \leq s \leq 1$, and w is the wind speed in m/s. Then, the overall ambient noise is:

$$N_f = N_t(f) + N_s(f) + N_w(f) + N_{th}(f). \tag{7}$$

3 PROBLEM FORMULATION

In UCANs, the signal transmitted between the source node and the destination node is divided into two time slots. We assumed that these three nodes use orthogonal channels. In the first time slot, the source node simultaneously sends data to the destination node and to the relay nodes through orthogonal channels, channel CH 0 and CH C_i, respectively. In the second time slot, the selected relay amplifies and forwards the data received from the source node to the destination node through CH C_i'. In the first time slot, the signal received at relay node i is depicted as:

$$y_{s,r_i} = \sqrt{P_{2,i}} h_{s,i} x + \sigma_{s,i}, \tag{8}$$

Also, the signal received at destination node is:

$$y_{s,d} = \sqrt{P_1} h_{s,d} x + \sigma_{i,d}, \tag{9}$$

where P_1 and $P_{2,i}$ denote the transmission powers from the source node to the destination node and to the relay node i respectively. $h_{s,d}$ and $h_{s,i}$ are the channel gains between the source node and destination node, and the source node and relay node i respectively. $\sigma_{s,i}$ and $\sigma_{i,d}$ denote noise. x is the signal from source node. During the first time slot, θ_1 and θ_2 are acceptable interference powers of the primary user over CH 0 and CH C_i, respectively, which are donated as follows:

$$P_1 |h_{s,p,d}|^2 \leq \theta_1, \tag{10}$$

$$P_{2,i} |h_{s,p,i}|^2 \leq \theta_2, \tag{11}$$

where $h_{s,p,d}$ and $h_{s,p,i}$ are the channel gains between the source node and the PU for CH 0 and CH C_i, respectively.

In the second time slot, the selected relay transmits the signal by AF protocol to the destination node, so the received signal at the destination node can be expressed as:

$$y_{r_i,d} = \sqrt{P_{3,i}} h_{i,d} y^*_{s,r_i} + \sigma_{s,d}, \tag{12}$$

where $P_{3,i}$ is the transmission powers of the relay node i to the destination node. $h_{i,d}$ is the channel gain between the relay node and the destination node. we assumed that ${\sigma_{s,d}}^2 = {\sigma_{s,i}}^2 = {\sigma_{i,d}}^2 = N_f$, N_f is represented by σ^2 in the following, and y^*_{s,r_i} is the normalization of y_{s,r_i}, which is donated as:

$$y^*_{s,r_i} = \frac{y_{s,r_i}}{\sqrt{P_{2,i} |h_{s,d}|^2 + \sigma^2}}, \tag{13}$$

In the second time slot, the transmission between the relay node and destination node also causes interference to the PU, the acceptable interference power limit expressed as θ_3 is shown as follows:

$$P_{3,i} |h_{i,p}|^2 \leq \theta_3, \tag{14}$$

where $h_{i,p}$ is the channel gain between relay node and PU for CH C_i'. The transmission powers at the source and relay are also constrained by the battery capacity, in the underwater cognitive node transmission, the limits of the source node and the relay node are donated as:

$$P_1 + P_{2,i} \leq P_{total}, \tag{15}$$

$$P_{3,i} \leq P_3, \tag{16}$$

where P_{total} is the overall transmission power limit for the source. P_3 is the maximum transmission power allowed by each relay. We can calculate the received powers of signal $P_{s,i}$ and noise $P_{n,i}$ at the destination node from relay node as:

$$P_{s,i} = \frac{P_{3,i} P_{2,i} |h_{s,i}|^2 |h_{i,d}|^2}{P_{2,i} |h_{s,i}|^2 + \sigma^2}, \tag{17}$$

$$P_{n,i} = (\frac{P_{3,i} |h_{i,d}|^2}{P_{2,i} |h_{s,i}|^2 + \sigma^2} + 1)\sigma^2, \tag{18}$$

Finally the received signal to noise ratio (SNR) at the destination node from the selected relay's channel can be donated as:

$$SNR_i = \frac{P_{s,i}}{P_{n,i}} = \frac{P_{3,i} P_{2,i} |h_{s,i}|^2 |h_{i,d}|^2}{(P_{3,i} |h_{i,d}|^2 + P_{2,i} |h_{s,i}|^2 + \sigma^2)\sigma^2}, \tag{19}$$

Then the system throughput T is given as follows:

$$\begin{aligned} T &= (1 - \beta_i) \log_2(1 + \frac{P_1 |h_{s,d}|^2}{\sigma^2}) \\ &+ (1 - \beta_i) \log_2(1 + \frac{P_{3,i} P_{2,i} |h_{s,i}|^2 |h_{i,d}|^2}{(P_{3,i} |h_{i,d}|^2 + P_{2,i} |h_{s,i}|^2 + \sigma^2)\sigma^2}), \end{aligned} \tag{20}$$

where β_i is mis-detection probability of each relay node.

The mis-detection probability β_i is generally set as a constant in radio scenarios, However, in real underwater acoustic environments, uncertainty, such as schools of fish, affects the performance of CSI based cooperative relay selection algorithms. Seawater is not a loss-free medium. Thus, a longer propagation distance corresponds to a more severe signal attenuation. The mis-detection probability is often determined by two factors: delay and channel environment. β_i changes with sensing distance, channel situation, and so on. When the selected relay is nearer to the source node, it can be easily detected by the source node, resulting in a lower value of the mis-detection probability β_i. Thus, the mis-detection probability β_i was not set as a constant in this paper. A new trust parameter was proposed to optimize the mis-detection probability β_i, that is, to make β_i more portable and reasonable. This trust parameter mainly reflects the influence of the speed of sound and the complex channel condition on the systems. The trust parameter is defined as:

$$\eta_i = a \cdot \exp(-\|d_i\|) + b \cdot SNR_i + \delta, \tag{21}$$

where d_i is the distance between the source node and relay node i, which is assumed as a different constant value defined by different relay nodes. With the increase of distance, the trust parameter of the relay will be reduced. δ is the factors that can reflect other aspect on the trust parameter. SNR_i is the signal-to-noise radio received by the destination node from the selected channel in formula (19). a and b is the weighting factor of each part, and let $a + b = 1$, $a > 0$, $b > 0$. Different a and b can reflect the importance of distance and SNR_i respectively. Finally, the trust parameter is normalized as:

$$\eta_i' = \frac{a \cdot \exp(-\|d_i\|) + b \cdot SNR_i + \delta}{\Sigma_{i=1}^{L} \eta_i}, \tag{22}$$

In an actual underwater cognitive acoustic transmission, if cognitive nodes have higher levels of trust, the system throughput will be higher. What's more, it means that the system has a low mis-detection probability of the selected cognitive node. So there exists a relationship between the trust parameter and the mis-detection probability β_i.

$$\beta_i \propto \kappa \cdot (1 - \eta_i'), \tag{23}$$

κ is constant, and without loss of generality, let $\kappa > 0$.

4 OPTIMAL RELAY SELECTION AND POWER ALLOCATION

Relay selection and power allocation can be formulated as the maximization of system throughput. The performance of the underwater cognitive acoustic cooperative system can be reflected by system throughput. According to the previous discussion, maximization of system throughput can be formulated as:

$$\arg \max_{P_1, P_{2,i}, P_{3,i}, \beta_i} T(P_1, P_{2,i}, P_{3,i}, \beta_i), \tag{24}$$

$$\begin{aligned} T(P_1, P_{2,i}, P_{3,i}, \beta_i) &= (1 - \beta_i)\log_2(1 + \frac{P_1|h_{s,d}|^2}{\sigma^2}) \\ &+ (1 - \beta_i)\log_2(1 + \frac{P_{3,i}P_{2,i}|h_{s,i}|^2|h_{i,d}|^2}{(P_{3,i}|h_{i,d}|^2 + P_{2,i}|h_{s,i}|^2 + \sigma^2)\sigma^2}), \end{aligned}$$

Subject to

$$P_1 + P_{2,i} \leq P_{total},$$
$$P_{3,i} \leq P_3,$$
$$P_1|h_{s,p,d}|^2 \leq \theta_1,$$
$$P_{2,i}|h_{s,p,i}|^2 \leq \theta_2,$$
$$P_{3,i}|h_{i,p}|^2 \leq \theta_3,$$

After the formula of probability of mis-detection is obtained, we come up with the second step, the system throughput problem can be expressed as:

$$\begin{aligned} T &= [1-\kappa\cdot(1-\eta_i')]\cdot\log_2(1+\frac{P_1|h_{s,d}|^2}{\sigma^2}) \\ &+ [1-\kappa\cdot(1-\eta_i')] \\ &\cdot \log_2(1+\frac{P_{3,i}P_{2,i}|h_{s,i}|^2|h_{i,d}|^2}{(P_{3,i}|h_{i,d}|^2+P_{2,i}|h_{s,i}|^2+\sigma^2)\sigma^2}), \end{aligned} \tag{25}$$

Namely

$$\begin{aligned} T &= (1-\kappa\cdot(1-\frac{a\cdot\exp(-\|d_i\|)+b\cdot SNR_i+\delta}{\Sigma_{i=1}^L\eta_i}))\cdot \\ &[\log_2(1+\frac{P_1|h_{s,d}|^2}{\sigma^2}) \\ &+\log_2(1+\frac{P_{3,i}P_{2,i}|h_{s,i}|^2|h_{i,d}|^2}{(P_{3,i}|h_{i,d}|^2+P_{2,i}|h_{s,i}|^2+\sigma^2)\sigma^2})], \end{aligned} \tag{26}$$

Let

$$T = (1-\beta_i)\cdot(T_i'), \tag{27}$$

$$1-\beta_i = 1-\kappa\cdot(1-\frac{a\cdot\exp(-\|d_i\|)+b\cdot SNR_i+\delta}{\Sigma_{i=1}^L\eta_i}), \tag{27-a}$$

$$\begin{aligned} T_i' &= \log_2(1+\frac{P_1|h_{s,d}|^2}{\sigma^2}) \\ &+\log_2(1+\frac{P_{3,i}P_{2,i}|h_{s,i}|^2|h_{i,d}|^2}{(P_{3,i}|h_{i,d}|^2+P_{2,i}|h_{s,i}|^2+\sigma^2)\sigma^2}). \end{aligned} \tag{27-b}$$

In this paper, a cross-over iteration and sub-gradient method (CISG) is proposed to obtain the solution of the problem, we set the optimal problem into three main steps:

(1) We use $(1-\beta_i)$ and T_i' to simplify the expression in (24). Due to the difficulty of solving the optimal problem simultaneously, we can obtain the

optimal solution of $(1-\beta_i)$ and T_i' separately. $(1-\beta_i)$ is a increasing function of $P_{2,i}$ and $P_{3,i}$. Because the partial derivative of $P_{2,i}$ and $P_{3,i}$ is greater than 0, we first obtain the optimal value of $P_{3,i}'$, set $P_{3,i}' = \min\{\frac{\theta_3}{|h_{i,p}|^2}, P_3\}$, and there is no direct link between the mis-detection probability of β_i and P_1, so the value $P_{2,i}'$ can be expressed as $P_{2,i}' = \min\{\frac{\theta_2}{|h_{s,p,i}|^2}, P_{total}\}$. Finally the optimized value of $(1-\beta_i)_1^*$ is obtained when $P_{2,i}'$ and $P_{3,i}'$ is used in (27-a).

(2) Since T_i' increases with $P_{3,i}$, $P_{3,i}' = \min\{\frac{\theta_3}{|h_{i,p}|^2}, P_3\}$, Using the Lagrange multiplier method, we have the Lagrange function for (24):

$$\begin{aligned} &L(P_1, P_{2,i}, \lambda_i, \mu_i, \nu_i) = -(1-\beta_i)_1^* \log_2(1+\frac{P_1|h_{s,d}|^2}{\sigma^2}) \\ &-(1-\beta_i)_1^* \log_2(1+\frac{P_{3,i}P_{2,i}|h_{s,i}|^2|h_{i,d}|^2}{(P_{3,i}|h_{i,d}|^2+P_{2,i}|h_{s,i}|^2+\sigma^2)\sigma^2}) \\ &+\lambda_i(P_1+P_{2,i}-P_{total})+\mu_i(P_1|h_{s,p,d}|^2-\theta_1) \\ &+\nu_i(P_{2,i}|h_{s,p,i}|^2-\theta_2), \end{aligned} \tag{28}$$

where $(1-\beta_i)_1^*$ is a constant, λ_i, μ_i, ν_i are the Lagrange multipliers. Employing the Karush-Kuhn-Tucher (KKT) conditions, where $[\cdot]^+$is defined as $\max\{x, 0\}$. In the iterative process, all the power levels should not be less than zero. If the power level is less than zero, it will be set to zero. we obtain:

$$P_1'' = [\frac{(1-\beta_i)_1^*}{\lambda_i+\mu_i|h_{s,p,d}|^2\ln 2} - \frac{\sigma^2}{|h_{s,d}|^2}]^+, \tag{29}$$

$$\begin{aligned} P_{2,i}'' = [&\frac{\sqrt{{P_{3,i}'}^2|h_{i,d}|^4+4P_{3,i}'|h_{i,d}|^2\frac{K}{\ln 2(\lambda_i+\mu_i|h_{s,p,i}|^2)}}}{2|h_{s,i}|^2} \\ &-\frac{P_{3,i}'|h_{i,d}|^2+2\sigma^2}{2|h_{s,i}|^2}]^+, \end{aligned} \tag{30}$$

where $K = \frac{(1-\beta_i)_1^*}{(\lambda_i+\nu_i|h_{s,p,i}|^2)\ln 2}$. The dual problem can be successfully reached by using sub-gradient method in [24] [4],which updates the Lagrange multipliers as follows:

$$\begin{aligned} &\lambda_i(t+1) = [\lambda_i+\rho(t)(P_1(\lambda_i(t), \mu_i(t), \nu_i(t)) \\ &+P_{2,i}(\lambda_i(t), \mu_i(t), \nu_i(t))-P_{total})]^+, \end{aligned} \tag{31}$$

$$\begin{aligned} &\mu_i(t+1) = \\ &[\mu_i+\rho(t)(P_1(\lambda_i(t), \mu_i(t), \nu_i(t))|h_{s,p,d}|^2-\theta_1)]^+, \end{aligned} \tag{32}$$

$$\nu_i(t+1) = \\ [\nu_i + \rho(t)(P_{2,i}(\lambda_i(t), \mu_i(t), \nu_i(t))|h_{s,p,i}|^2 - \theta_2)]^+, \tag{33}$$

where t is the iteration index and $\rho(t)$ is the step size. Finally the algorithm of T_i' is summarized as follows:
Initialization: $\lambda_i(0) > 0$, $\mu_i(0) > 0$, $\nu_i(0) > 0$ $\forall i$
Repeat: for $t = 1 : L$
1) Calculate the optimal power value through (29), (30).
2) Update the Lagrange multiplier λ_i, μ_i, ν_i according to (31)-(33). At last, the optimal value $(T_i')^*$ of T_i' is achieved by P_1'', $P_{2,i}''$, $P_{3,i}'$.
3) Finally, the iteration method is proposed to achieve the suboptimal system throughput T_i.

After obtaining the optimal values of P_1'' and $P_{2,i}''$ in step (2), we input the optimal values of P_1'' and $P_{2,i}''$ into (27-a) to obtain another optimal value $(1-\beta_i)_2^*$ of $(1-\beta_i)$ and substitute $(1-\beta_i)_1^*$ in (28). We then used the same approach to obtain P_1''' and $P_{2,i}'''$ in step (2) and regain $(1-\beta_i)_3^*$ in step (1). This procedure was repeated n times until the values of P_1'' and $P_{2,i}''$ were stable. Finally, the suboptimal result of system throughput with trust parameter was determined by the optimal value of $(1-\beta_i)_n^*$ and $(T_i')_n^*$. By Repeating this procedure at all relays, we found the relay with the maximum throughput through (24).

In the process of proposed algorithm, we carry out L iteration to obtain the power value, and then repeat n times the above procedures until the value of P_1 and P_2 is stable. Thus, the computational complexity of our proposed method is $o(nL)$.

5 SIMULATION RESULT

In this section, the benefits of CISG method in section 4 was compared with advantages of the method in [10] and [19], random relay selection with power allocation, and random relay selection with equal power allocation. The characteristic of underwater communication environment is obtained by World Ocean Simulation System (WOSS) and Bellhop model. In our simulation study, we consider a location in the Qinhuangdao with latitude 39.4 degrees north latitude and longitude 119.4 degrees east longitude. Acoustic users are placed in the geographic area that simulation database covers. The acoustic spectrum of the available channels ranged from 1 kHz to 40 kHz. For simplicity, we set the sound speed in an underwater environment to a normal value of 1500 m/s. The acoustic loss was modeled using practical spreading, $k = 1.5$, and the noise is that obtained for moderate shipping activity $s = 0.5$, and

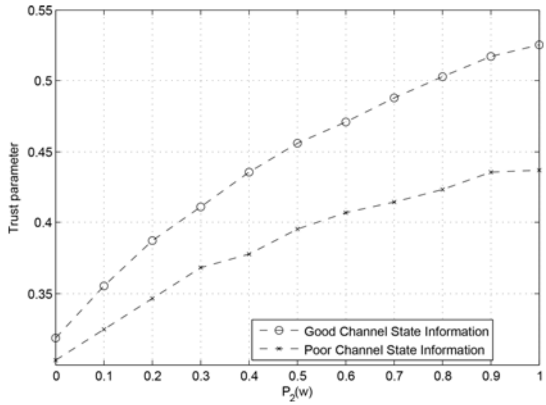

FIGURE 3
Trust parameter of relay with P2.

wind speed $w = 0$. We define the interference limits $\theta_1 = \theta_2 = \theta_3 = 10^{-4}W$. It is assumed that all the channel fading coefficients follow a Rayleigh distribution and are orthogonal. All relays between the source and destination nodes were available, indicating that any of the relays can be selected to cooperate.

Figure 3 provides the values of the relays' trust parameter in different channel states when $P_3 = 0.4W$. The trust parameter was significantly different for different values of P_2, because the sensing ability of the relay that was selected to cooperate in the system is decided by P_2. If the transmit power of the source is high, the relay can make better use of the channel to transmit the signal to destination node, that is, the selected relay had a higher trust rank by the source node, and the mis-detection probability would be lower. For this reason, the mis-detection probability was not constant for different values of P_2.

Figure 4 shows the mis-detection probability of relay for different sensing distances with maximum transmission power allowed by each relay $P_3 = 0.4W$ when $P_2 = 0.5W$. The mis-detection probability rapidly changed with the sensing distance. In a real cooperative sensing scenario, if the channel state information is good, then the relay has greater chances of participating in the PU spectrum. Thus, the selected relay has a lower value of mis-detection probability, and the system throughput is better than that obtained by other approach without trust parameter, in which the mis-detection probability is a constant parameter.

Figure 5 describes the power allocation process of the relay i. The convergence of our method was analyzed by performing a simulation experiment. The picture on the left shows the interference limited conditions,

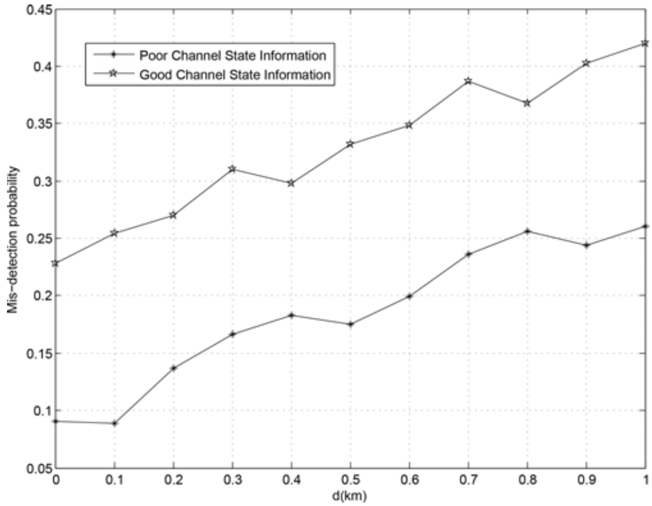

FIGURE 4
Mis-detection probability of relay with distance.

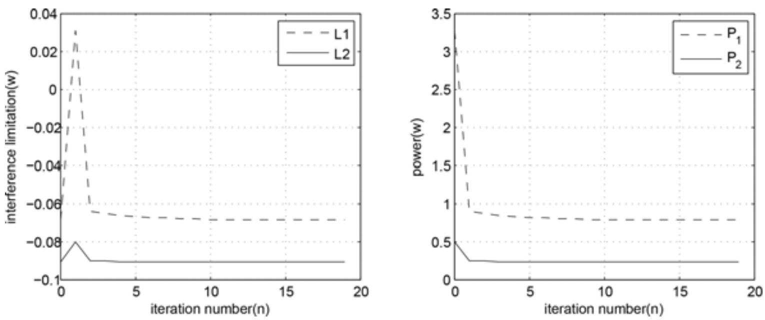

FIGURE 5
The power allocation process of the relay i.

which are expressed in (10) and (11),where $L1 = P_1|h_{s,p,d}|^2 - \theta_1$, $L2 = P_{2,i}|h_{s,p,i}|^2 - \theta_2$. To prevent the interference to the primary user, the interference limited conditions $L1$ and $L2$ should be less than 0. As is shown in Fig.5, at the beginning stage, the curve displays a large fluctuation, and then gradually tends to converge. After several iterations, P_1 and P_2 tend to stabilize within the limits of interference. Finally, we obtained the optimized power allocation results.

Figure 6 shows the changes in system throughput as P_3 increases. The total power of the source node was fixed as $P_{total} = 0.5W$ and the relay number is 10. All known parameters were assumed the same when using different

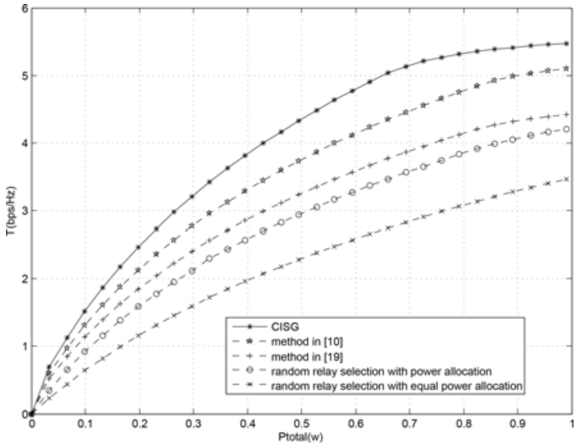

FIGURE 6
System throughput with transmission power limit of relay.

methods. Compared with other schemes,CISG method offers obvious advantages over the other schemes. A better system throughput was achieved by our proposed suboptimal approach. The system throughput attained by the other two methods presented a distinct advantage over random relay selection with equal power allocation. In cooperative communication, it is difficult to obtain accurate channel state information. By introducing the trust parameter in the relay selection, the relay selection and power allocation became more reasonable. Compared with the method in [10], our scheme can obtain a higher channel capacity in Fig 6. As the value of P_3 increases, the system throughput by our proposed algorithm exhibits a faster ascendance. That is, if relay i is closer to the source node and destination nodes, it will have a higher SNR, In turn, we can obtain a low mis-detection probability, which is calculated from the trust parameter. Thus, the system throughout is more reflective of the real scenario.

Figure 7 shows the benefits of the proposed algorithm when $P_3 = 0.4W$. As regards the relay's trust parameter, the system throughput grows rapidly with P_{total}. However, regardless of the selected relay is, the actual situation of the relay must be considered to make the system throughput more representative of the real scenario. In the low P_{total} region, the system throughput increased rapidly with trust parameter, whereas in high P_{total} region, the system throughput with trust parameter is limited by the interference limits and is higher than in other schemes. Moreover, the other two methods can achieve a much higher value of system throughput than random relay selection with equal power allocation.

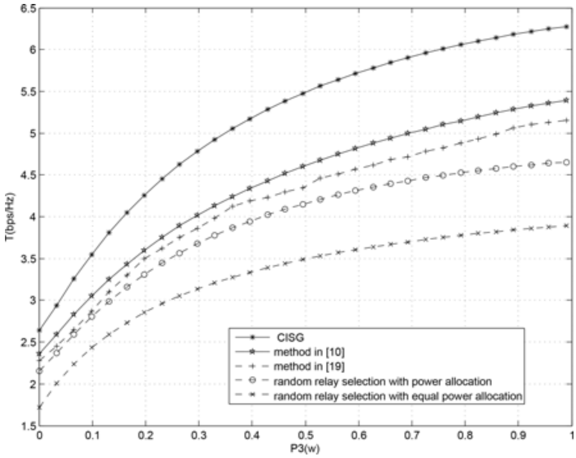

FIGURE 7
System throughput with transmission power limit of CR source node.

6 CONCLUSION

In this paper, a joint relay selection and power allocation algorithm with trust parameter scheme was first proposed to maximize the system throughput with limited interference to primary users. The trust parameter was introduced to make relay selection and power allocation more practical in marine environment. Simulation results showed that the proposed scheme is superior to the approach without trust parameter and other methods, such as random relay selection with equal power allocation. Moreover, the system throughput model with trust parameter is more adaptive and practical in actual UCANs.

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