Relay selection scheme based on quantum differential evolution algorithm in relay networks

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Abstract—It is a classical integer optimization difficulty to design optimal selection scheme in cooperative relay networks considering co-channel interference. In order to attain optimal system performance of cooperative relay network, a novel quantum differential evolutionary algorithm (QDEA) is proposed to resolve the optimization difficulty of optimal relay selection, and the proposed optimal relay selection scheme is called as quantum differential evolutionary algorithm (QDEA) based optimal relay selection. The proposed QDEA combines the advantages of quantum computing theory and differential evolutionary algorithm (DEA) to improve exploring and exploiting potency of DEA. So QDEA has the capability to find the optimal relay selection scheme in cooperative relay networks. Simulation results indicate that the proposed relay selection scheme based on QDEA is superior to other intelligent relay selection schemes based on differential evolutionary algorithm, artificial bee colony optimization and quantum bee colony optimization in terms of convergence speed and accuracy.

Keywords—cooperative relay networks; multiple relay selection; quantum differential evolutionary algorithm; co-channel interference.

I. INTRODUCTION

Relaying is an emerging and effective communication technology which can overcome the limitation of cell coverage, cell edge users’ throughput and improve overall performance of wireless networks [1]. In the past, research efforts on relay selection schemes in multi-user networks are rather limited. In [2], for a multi-user network, a relay grouping algorithm is designed to maximize the minimum achievable rate among users or the network sum-rate. In [3-4], a relay selection method that maximizes the minimum achievable rate for all users is proposed. But it is assumed that there is no CCI between multiple users in [2-4]. So, in order to resolve the difficulty, multi-user relay selection method considering CCI between multiple users is proposed in [5]. However, only a sub-optimal solution for relay selection can be obtained.

For optimal relay selection problem of multiple relay selection is a typical integer optimization, and many previous continuous intelligent algorithms cannot be directly applied to solve this problem. Some intelligent algorithms are added post-processing of each iteration to resolve this problem, such as artificial bee colony (ABC) [6] and opposition-based quantum firework algorithm (OQFA) [7]. Although quantum bee colony optimization is designed in [8] for relay selection of multiple relay networks, it yet has the weakness of slow convergence rate and poor convergence value for complex relay selection problem.

In recent years, differential evolutionary algorithm (DEA) is an effective continuous optimization method, which is widely researched [9]. In this paper, we propose a novel intelligence algorithm which combines the DEA proposed in [9] with quantum evolutionary theory [7]. That is called as quantum differential evolutionary algorithm (QDEA), which has the advantage of both DEA and quantum evolutionary algorithm, and then has a better performance for the integer optimization of multiple relay selection. To our knowledge, no existing QDEA is proposed for integer optimization. So, it is the first time that QDEA is designed and applied to the relay selection problem of multi-user relay networks.

II. NETWORK MODEL OF MULTIPLE RELAY SELECTION

In this paper, a cooperative multi-user relaying system model is considered. N SNs have information to transmit to its own destination, thus formulating N SN-DN transmission pairs. Other M nodes are potential RNs. Usually M is larger than N [4]. Each SN-DN transmission pair can select one RN to help transmitting. Each RN can help at most one SN-DN transmission pair. There is only one available channel. A two-step decode-and-forward (DF) protocol is used to send information. Two time slots (TSs) are available, i.e., the SNs transmit in TS1 and the RNs transmit in TS2. The RNs can receive in TS1, while the DNs can combine the signals received from SNs and RNs in TS2. Maximum ratio combining (MRC) is used to combine the signals received from SNs and RNs. The transmissions from SNs and RNs are separated into two TSs, so the interference between SNs and RNs is avoided.

In TS1, the channel state information (CSI) from the ith SN to the ith RN is denoted as $G_{s_i, r_i}$ and the CSI from the ith SN to the ith DN is denoted as $G_{s_i, d_i}$. In TS2, the CSI from the ith RN to the ith DN is denoted as $G_{r_i, d_i}$. For each transmission, the power used at the ith SN and the ith RN are $P_s$ and $P_r$, respectively.

For DF relaying, the achievable data rate under the two-time-slot structure given by [8,10] is
where $W$ is the bandwidth of the available channel, $\gamma_i$ is the end-to-end signal-to-interference plus noise ratio (SINR) of SN-DN pair $i$, $\gamma_i^{(sr)}$ is the SINR of SN-RN pair $i$, $\gamma_i^{(rd)}$ is the SINR of SN-DN pair $i$, and $\gamma_i^{(ad)}$ is the SINR of RN-DN pair $i$. The objective is to maximize the total throughput of the network. The optimization problem of maximal sum rate can be formulated as

$$
\text{maximize } f(r) = \sum_{i=1}^{N} R_i = \sum_{i=1}^{N} \frac{1}{2} W \log_2(1 + \gamma_i)
$$

subject to $r_i \neq r_j, \forall i \neq j$

where $r = [r_1, r_2, \ldots, r_N]$ is the relay selection scheme, and constraint means that each RN can help at most one SN-DN transmission pair. Each element $r(i=1,2,\ldots,N)$ denotes the RN selected by SN-DN transmission pair $i$, so if RN $k(k=1,2,\ldots,M)$ is assigned to SN-DN transmission pair $i$, then $r_i = k$. In this paper, a novel intelligence algorithm, QDEA, is proposed to resolve this integer optimization problem.

III. RELAY SELECTION SCHEME BASED ON QUANTUM DIFFERENTIAL EVOLUTIONARY ALGORITHM

A. QDEA for integer programming

QDEA is a novel multi-agent optimization system modified by DE. There are $H$ quantum individuals in an $N$-dimensional space, where $N$ represents the maximal dimension of the optimization problem ($N$ represents the number of SN-DN transmission pair in the multi-user relay selection problem). Quantum individual is composed of quantum bits. The $h$th ($h=1,2,\ldots,H$) quantum individual is defined as

$$
\mathbf{x}_h = [x_{h1}, x_{h2}, \ldots, x_{hn}]
$$

where $n=1,2,\ldots,N$ and $0 \leq x_{hn} \leq 1$.

The quantum individual is mapped to definition domain, and the rule can be described as the following:

$$
\overline{x}_{hn} = l_h + x_{hn}(u_h - l_h),
$$

where $l_h$ is the lower bound of the $h$th dimension variable, and $u_h$ is the upper bound of the $h$th dimension variable. In the multi-user relay selection scheme, there are $M$ potential relays which can be chosen, so $l_h = 1$, $u_h = M$ for all $n=1,2,\ldots,N$.

Since the multi-user relay selection problem is an integer optimization problem, we should map the real number into integer number, the rule is as follow

$$
\text{round}(\overline{x}_{hn}) = \text{round}(\overline{x}_{hn}),
$$

where $\text{round}(\overline{x}_{hn})$ means rounding up to

$$
\overline{x}_{hn}, \overline{x}_{hn} = [\overline{x}_{h1}, \overline{x}_{h2}, \ldots, \overline{x}_{hn}].
$$

The fitness of the $h$th quantum individual is computed by

$$
f(\overline{x}_{h}) = \begin{cases} 
\overline{x}_{hn}^{(sr)} - \overline{x}_{hn}^{(rd)} (\forall i \neq n, i,n=1,2,\ldots,N) 
\end{cases}
$$

where $\overline{x}_{hn}^{(sr)}$ and $\overline{x}_{hn}^{(rd)}$ are the SINR of the $h$th quantum individual.

For the $h$th ($h=1,2,\ldots,H$) quantum individual, generate a uniform distributed random number $\xi_h$ from zero to one. When $\xi_h$ is less than 0.5, the $h$th quantum rotation angle and the $h$th quantum bit are updated as:

$$
\theta_{hn}^{(sr)} = \xi_h(x_{hn}^{(sr)} - x_{hn}^{(ad)}) + \frac{1}{2} \xi_h \cdot \text{sign}(f(\overline{x}_{h}) - f(\overline{x}_{h}))(x_{hn}^{(sr)} - x_{hn}^{(ad)})
$$

$$
p_{hn}^{(sr)} = \begin{cases} 
\text{abs}(x_{hn}^{(sr)} \cdot \cos \theta_{hn}^{(sr)} + \sqrt{1-(x_{hn}^{(sr)})^2} \cdot \sin \theta_{hn}^{(sr)}), & \text{if } \theta_{hn}^{(sr)} \leq 0.01 \\
\text{abs}(x_{hn}^{(sr)} \cdot \cos \theta_{hn}^{(sr)} + \sqrt{1-(x_{hn}^{(sr)})^2} \cdot \sin \theta_{hn}^{(sr)}), & \text{otherwise} 
\end{cases}
$$

where $\theta_{hn}^{(sr)}$, $\xi_h$ and $\theta_{hn}^{(sr)}$ are uniform distributed random numbers from zero to one, and sign() means sign function. $p_{hn}^{(sr)}$ is a Gaussian distributed random number with zero mean and unit variance, $a \in [1,2,\ldots,H]$ is a random integer.

When $\xi_h$ is no less than 0.5, the $h$th quantum rotation angle and the $h$th quantum bit of the $h$th quantum individual are updated as:

$$
\theta_{hn}^{(sd)} = (x_{hn}^{(sr)} - x_{hn}^{(ad)})
$$

$$
p_{hn}^{(ad)} = \begin{cases} 
\text{abs}(x_{hn}^{(sr)} \cdot \cos \theta_{hn}^{(ad)} + \sqrt{1-(x_{hn}^{(sr)})^2} \cdot \sin \theta_{hn}^{(ad)}), & \text{if } \theta_{hn}^{(ad)} \leq 0.01 \\
\text{abs}(x_{hn}^{(sr)} \cdot \cos \theta_{hn}^{(ad)} + \sqrt{1-(x_{hn}^{(sr)})^2} \cdot \sin \theta_{hn}^{(ad)}), & \text{otherwise} 
\end{cases}
$$

where $\theta_{hn}^{(ad)}$, $\xi_h$ and $\theta_{hn}^{(ad)}$ are Gaussian distributed random numbers with zero mean and unit variance, $b \in [1,2,\ldots,H]$ is a random integer, mutually different from $a$. $\xi_h$ is a uniform distributed random number from zero to one. $d \in [1,2,\ldots,H]$ is a random integer, $CR = 0.01 + (0.4t)/K$, and $K$ is the maximum number of iteration.
In each simulation, the path gain $G_{i,j}$ between two nodes is modeled as $G_{i,j} = d_{i,j}^{-3}$, where $d_{i,j}$ is the distance of the two nodes. Wireless links and nodes are uniformly distributed over a square field with $D \times D$ dimensions, in the simulation process, set $D=100m$. In each simulation, $N$ SNs are randomly generated and their corresponding DNs are generated around them in the area. The distance of the source node and destination node is uniformly distributed between $[d_{\text{min}}, d_{\text{max}}]$, so that they are not too far away from each other. In the simulation, $d_{\text{min}} = 25m$, $d_{\text{max}} = 35m$. Then $M$ candidate relays are generated in the area. The power of different SNs is the same, as well as the power of RNs. The power of the additive white Gaussian noise (AWGN) is $10^{-3}W$ at all nodes, i.e., $\eta = 10^{-3}W$. For QBCO, DEA, ABC and QDEA, the maximal iteration is set as 1000 and the population size $H$ is set as 20. For ABC, the parameter settings of ABC can refer to [6]. For DEA, the parameter settings can refer to [9]. For QBCO, the parameter settings of QBCO can refer to [8]. All results are averaged over 200 trials.

Fig. 1 considers the case where the total throughput varies with the iteration number for QBCO, DEA, ABC and QDEA when $N=10$, $M=20$, the SN power is 20W and the RN power is 18W. From Fig. 1, QDEA can obtain the result which is better than the results obtained by other algorithms. It is clear that the performance of QDEA is superior to QBCO, DEA and ABC.

**Fig. 1 Convergence curves of 4 different schemes with 20 RNs**

The total throughput varies with the RN number is considered. In the simulation, $N=10$ but $M$ varies from 20 to 35. The SN power is 20W while the RN power is 18W. Simulation results are shown in Fig. 2. It can be seen that the total throughput increases almost linearly with the RN number. From Fig. 2, it can also be seen that ABC performs worse than QDEA, QBCO and DEA, while QBCO performs better than DEA and ABC, but QDEA performs the best. The gain of QDEA is almost 3Mbit/s compared with QBCO.

**Fig. 2 Total throughput comparison of 4 schemes with different RN number**

Fig. 3 considers the case where the total throughput varies with the increasing power of RN when $N=10$, $M=20$ and the
SN power is 20W. From Fig. 3, QDEA can get the best performance. When the RN power is larger, the gains obtained by QDEA is much larger compared with QBCO, DEA and ABC. This means that QDEA has an excellent performance under different simulation conditions.

![Fig. 3 Total throughput of 4 schemes with different RN power](image)

Fig. 3 Total throughput of 4 schemes with different RN power

V. CONCLUSION AND FUTURE WORK

This paper has proposed QDEA based relay selection scheme considering CCI to other SN-DN transmission pairs in the cooperative relay networks. Compared with QBCO, DEA, and ABC based relay selection schemes, the proposed scheme has a much better performance on the total throughput target under different simulation scenarios. In the near future, we can design multi-objective QDEA for multi-objective relay selection method to resolve the tradeoff of reward and fairness of multiple users relay networks.

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VII. REFERENCES