A Quantum MMAS Based Algorithm for Multicast Routing Problem

Yalong Li¹, Wang Wei¹ *, Sun Jing² and Wan Jie²
Anhui Earthquake Agency, Hefei, Anhui, 230031, China
Anhui Mengcheng National Geophysical Observatory, Bozhou, Anhui, 233527, China
*Corresponding author’s e-mail: ww@aheq.gov.cn

Abstract. For solving the problem of multicast routing, ant colony algorithm (ACO) has insufficient optimization ability. The paper proposes a routing algorithm which combines quantum computing and max min ACO. The algorithm uses quantum bit probability amplitude to encode the link, and dynamically adjusts quantum revolving gate to update the quantum coding on the link, so as to meet the cost optimization under constraint conditions, combined with the maximum and minimum pheromone decision mechanism to find the optimal link path, effectively control the evolution speed and direction, and enhance the convergence performance of the algorithm. The simulation results show that the algorithm can effectively control the evolution speed and direction, and is better than ant colony algorithm in the optimization ability and convergence performance.

1. Introduction
The real-time streaming big data generated by earthquake early warning service have higher requirements for service quality (QoS) [1] of network parameters. Applying multicast technology to seismic information network system can reduce network load and alleviate network congestion. How to select the optimal cost (time) multicast routing under the condition of parameter constraints is the research content of multicast routing.

Constraint parameters [2] are important for solving multicast routing problem. Many scholars have applied various intelligent bionic algorithms to the routing problem solving process, and achieved certain results [3-5]. For example, document [6] presents a QoS Multicast Routing Algorithm Based on the fusion of evolutionary algorithm and ant colony algorithm, document [7] presents a swarming agent based intelligent algorithm to optimize the multicast tree. The optimized algorithm improves the performance of solving routing problems, but for solving large-scale QoS routing problems, the algorithm has more iterations and tends to converge prematurely.

In the 1980s, Quantum computing is more and more important. Shor proposed a large number factorization algorithm based on quantum computing in 1994. The algorithm is implemented in polynomial time on quantum computer, which makes NP problem evolve into P problem. In 2002, Kuk-Hyun Han quantum evolutionary algorithm is put forward, such as complete evolutionary search using quantum revolving door, with a small population size and does not affect the characteristics of the algorithm performance, in recent years, quantum computing with its unique computing performance in the tech world wide attention.

The paper proposes a quantum maximum and minimum ant colony algorithm, which uses the state vector in quantum computing to quantum code the links in the network topology, updates the
pheromone through the quantum spin entanglement property combined with the maximum and minimum test mechanism, and adds the quantum selection strategy in the "roulette" link selection, in the case of fitness were similar, effectively control the evolution speed and direction.

2. Quantum Max-Min Ant Colony Algorithm (QMMAS) for Seismic Multicast Routing Problem

The seismic multicast routing problem is to solve the optimal multicast tree problem in the simulated seismic information network topology, which satisfies the constraints of delay, bandwidth, packet loss rate and so on. That is to build a multicast tree to realize the high-speed transmission of seismic early warning data from point to multipoint efficient data transmission.

2.1. Quantum Coding

In QMMAS, using quantum bits of each link of information coding, quantum information coding path can be expressed as follows:

\[
Q_{bit} = \begin{pmatrix}
\alpha_1 & \beta_1 & ... & \alpha_n \\
\alpha_1 & \beta_1 & ... & \alpha_n \\
... & ... & ... & ...
\end{pmatrix}
\]

where \(n\) is the number of nodes in network topology, \((\alpha_{ij}, \beta_{ij})^T\) is the link quantum information between node \(i\) and node \(j\) for the said, and when \(i \neq j\), \(|\alpha_{ij}| + |\beta_{ij}| = 1\); When \(i = j\), \(|\alpha_{ij}| = |\beta_{ij}| = 0\) (1 ≤ \(i, j\) ≤ \(n\)). When the optimal ants through node \(i\) to node \(j\), the link quantum information value \(\beta_{ij}\) between node \(i\) and node \(j\) increases, the link is selected propensity to increase. On the other hand, the propensity to abate, selected the link the link on the value of quantum information \(\beta_{ij}\), quantum information update rules can be seen in section 2.4.

2.2. Probabilistic Decision Rule

Set \(m\) is the number of ants, \(n\) is the number of network nodes, \(C_{ij}\) is the cost between node \(i\) and node, \(\tau_{ij}\) is the pheromone on link \((i, j)\), \(P_{ij}^k\) is the probability of node \(j\) through node \(i\) as ants.

\[
P_{ij}^k = \begin{cases}
\frac{\tau_{ij}^{\alpha'} \eta_{ij}^{\beta'}}{\sum_{u \in N_i^k} \tau_{iu}^{\alpha'} \eta_{iu}^{\beta'}} & j \in N_i^k \\
0 & j \notin N_i^k
\end{cases}
\]

Ant \(k\) in node \(i\) can choose the nodes with said \(N_i^k\). Said pheromone accumulation degree of weight is \(\alpha'\), stimulating factor with said \(\eta_{ij}\), stimulating factor weights is \(\beta'\). \(\eta_{ij}\) inspired by the information Increase the propensity for attractive solution, used formula (3).

\[
\eta_{ij} = 1/C_{ij}
\]

See section 2.3 pheromone update way.

2.3. Pheromone Update Rule

When the ants reach the set end node, they need to update the pheromones on each link. The pheromone volatilization is calculated as follows:
\[ \tau_{ij} = (1 - \rho) \tau_y, \forall (i, j) \in E \tag{4} \]

Pheromone volatilization coefficient with said \( \rho \), \( 0 < \rho \leq 1 \), this parameter can effectively control the pheromone accumulation on the link. Selection of routing costs the least amount of ants to update global pheromone.

\[ \tau_y = \tau_y + \Delta \tau_y, \forall (i, j) \in E \tag{5} \]

Among them, \( \Delta \tau_y \) is to find the optimal path of ants to release the amount of pheromone it passes through the link \((i, j)\). \( \Delta \tau_y \) is defined as:

\[ \Delta \tau_y = \begin{cases} \left| \beta_y^t \right|^2 / C_{ij} & \text{if } (i, j) \in T_{best}(s, M) \\ 0 & \text{else} \end{cases} \tag{6} \]

One said to the quantum information on the link intensity is \( \beta_y \), \( |\alpha^t_y|^2 + |\beta^t_y|^2 = 1 \); For the node \( i \) to node \( j \) on the link between the weight of quantum information \( \beta_y \) is \( \gamma \).

After the completion of the pheromone update, the pheromone test is carried out. If it is greater than the maximum value \( \tau_{\text{max}} \), set it equal to \( \tau_{\text{max}} \); if it is less than the minimum value \( \tau_{\text{min}} \), set it equal to \( \tau_{\text{min}} \). \( \tau_{\text{max}} \) and \( \tau_{\text{min}} \) can be calculated by formulas (7) and (8).

\[ \tau_{\text{max}} = \frac{1}{\rho \star L_{\text{best}}} \tag{7} \]

\[ \tau_{\text{min}} = \frac{Q \star \tau_{\text{max}} (1 - P_{\text{dec}}) \star \tau_{\text{max}} (1 - \sqrt{P_{\text{dec}}})}{(\text{avg} - 1) P_{\text{dec}} = \frac{n - 2}{\sqrt{P_{\text{best}}}}} \tag{8} \]

the optimal cost for ant build path is \( L_{\text{best}} \), pheromones increase the relative coefficient is \( Q \), the ant search to find a single path is optimal probability is \( P_{\text{best}} \); \( P_{\text{dec}} \) is selecting the optimal solution of probability; \( \text{avg} \) is a number of optional path.

2.4. Quantum Update Rule

A matrix \( R \) of \( n \times n \) with \( m \) ants is a path from the starting point to the ending point in a network of \( n \) nodes. \( R[i, j] = 1 \) indicates that there is an edge from node \( i \) to node \( j \) in the path \( R \), and when \( i = j \), there must be \( R[i, j] = 0 \). The optimal solution obtained by the ants of the previous generation is denoted by \( R \), ,and the optimal solution obtained by the ants of this generation is denoted by \( R_{\text{best}} \). The quantum information in the network link is updated through Equation (9) using a quantum revolving door:

\[
\begin{pmatrix}
\alpha_{yi}^{t+1} \\
\beta_{yi}^{t+1}
\end{pmatrix} =
\begin{pmatrix}
\cos(\theta) & -\sin(\theta) \\
\sin(\theta) & \cos(\theta)
\end{pmatrix}
\begin{pmatrix}
\alpha_{yi}^{t} \\
\beta_{yi}^{t}
\end{pmatrix}
\tag{9}
\]

In the formula, \( i, j = 1, 2, 3 \cdots n \), the first \( t \) iteration between node \( i \) to node \( j \) quantum coding information on the link is \( \left( \alpha^t_y, \beta^t_y \right)^T \), link \( i \) to \( j \) quantum rotation Angle with \( \theta \) said.

2.5. QMMAS Algorithm Steps

Step 1 Initialization: randomly generated with parameters of the network topology, given the constraints of the various parameters in QoS routing, pretreatment of randomly generated network topology, setting does not meet the bandwidth of the link connection node inaccessible to each other.
**Step 2** Set the value of parameter $\alpha', \beta', \rho, P_{\text{best}}, Q, \gamma$, the number of ants for $m$, upper limit of the number of iterations for $\text{NMAX}$, starting point $s$, end node set $M$, end node number for $w$. Initialize the end node for $M(w), w = 1$. All $\alpha_i, \beta_i$ values of ant quantum pheromone encoding are $1/\sqrt{2}$.

**Step 3** If $w > W$, then turn to step 9, an ant or be placed in the starting point, initialize the tabu list and other constraint parameters, starting point will be added to the taboos in the table, according to the tabu table and information structure node and link parameters optional node set, using the greedy algorithm according to the end point $M(w)$, QoS constraints independent structure solution of $P(s, M(w))$. Equation (7) is used to obtain $\tau_{\text{max}}$ and initialize the pheromone $\tau = \tau_{\text{max}}$ in the link, and the current iteration number is $\text{count} = 1$.

**Step 4** $m$ ants are placed at the starting point, the tabu table and other constraint parameters are initialized, the starting point is added into the tabu table, and the optional node set is constructed according to the tabu table and node and link parameter information.

**Step 5** According to the optional node set, according to the type (2) establish a probability distribution, "roulette wheel selection method is adopted to define the next node $nc$ , if the current node and link between $nc$ binary code is 1, then the $nc$ from optional node set removed, otherwise separate" roulette wheel selection method is adopted to define the next node $nc$, and removed the $nc$ from optional node set. Update the optional node set, the cumulative path cost, delay the accumulate, delay jitter, packet loss rate is cumulative, if qualified, modify the current node for $nc$, if the ants to reach the end node $M(w)$ or search to a standstill, then find out the solution, otherwise, repeat the above steps.

**Step 6** If all the $m$ ants have completed the solution, Equation (9) is used to update the quantum coding information on the network link. Go to Step 7; otherwise, go to Step 5.

**Step 7** Equations (4) to (6) are used to update the pheromone on the link, and Equations (7) and (8) are used to check and update the pheromone on the link.

**Step 8** If $\text{count} \geq \text{NMAX}$, then $w = w + 1$, go to step 3, otherwise $\text{count} = \text{count} + 1$, go to step 4.

**Step 9** The optimal multicast tree is constructed according to the path of the ant from the starting point to all the end node points and output.

3. **Simulation Experiment and Analysis**

In this paper, the network topology to simulate seismic information network nodes randomly generated, in order to make clear the topology data, show only the part node parameter. In setting QoS delay constraint for $D = 165$, link bandwidth $B = 60$, delay jitter $Dj = 1000$, packet loss rate $Pl = 1000(10e^{-5})$, the rest of the parameter values for $\alpha' = 1, \beta' = 2, \rho = 0.02, \gamma = 2$, $P_{\text{best}} = 0.05, Q = 5, m = 50$, the largest evolution algebra $\text{NMAX} = 100$, respectively from the global search ability and convergence performance of the algorithm and the network scale from three aspects, the influence of the experiment of algorithm.
3.1. Global Searchability

Select 50 network nodes, network topology structure of randomly generated as shown in figure 1, using QMMAS algorithm for each route requests for 50 times separate experiments, recorded 50 times experiments to find the optimal solution, the costs, and the corresponding time delay and bandwidth. Figure 1 is the optimal multicast tree generated by solving the the routing request(3,\{2, 29,50\}).

3.2. Convergence Performance

Select 100 random topology network node to validate the performance of the proposed algorithm is convergent, constraint condition and algorithm parameters according to the initial setup, and will get the result of comparing with the traditional ant colony algorithm, aiming at the routing request (,59,90} \{2, 3\) experiment, two algorithms of iteration is shown in Figure 2.

By QMMAS and the experimental results show that the optimal cost multicast tree and convergence time is better than the ant colony algorithm, ant colony algorithm in the early convergence fast, slow convergence speed, late after 75 generations not convergence, get the effective solution in the range of solution for the local. The proposed algorithm effectively control the direction of the optimization, through quantum rotation early convergence speed, and in the global range constraint seismic for multicast routing problem solving effect is better.
3.3. Influence of Network Size on Algorithm

To study the effect of network size on the algorithm, in the experiments, constraint condition and algorithm parameters according to the initial setup, the initial network node number is 15, and in turn increase 10, maximum number of nodes is set to 100, at the same time using QMMAS and traditional ant colony algorithm for solving the comparison, the result is shown in figure 3.

Can be seen from the diagram, in the network node size is small (node number under 25), the effect of traditional ant colony algorithm and QMMAS algorithm of the match, with the increase of network nodes, QMMAS algorithm calculated the cost of the solution is always better than the traditional ant colony algorithm.

4. Conclusions

The simulation results show that the proposed algorithm can effectively control the evolution speed and evolution direction, the optimization ability and convergence performance is superior to the traditional ant colony algorithm. In the future work, the application of QMMAS algorithm in earthquake emergency rescue path planning will be further studied to solve more practical problems and expand the application field of the algorithm.

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