WUJNS
Wuhan University Journal of Natural Sciences

Vol.9 No.4 2004 449-453

Article ID: 1007-1202(2004)04-0449-05

Ant Colony Algorithm for Solving QoS Routing Problem

SUN Li-juan, WANG Liang-jun, WANG Ru-chuan

Department of Computer Science and Technology, Nanjing University of Posts and Telecommunications, Nanjing 210003, Jiangsu, China

Abstract: Based on the state transition rule, the local updating rule and the global updating rule of ant colony algorithm, we propose an improved ant colony algorithm of the least-cost quality of service (QoS) unicast routing. The algorithm is used for solving the routing problem with delay, delay jitter, bandwidth, and packet loss-constrained. In the simulation, about 52.33% ants find the successful QoS routing, and converge to the best. It is proved that the algorithm is efficient and effective.

Key words: ant colony algorithm; QoS; unicast routing

CLC number: TP 393

Received date: 2004-04-09

Foundation item: Supported by the National Natural Science Foundation of China(60173037 and 70271050); the Natural Science Foundation of Jiangsu Province(BK2003105)

Biography: SUN Li-juan(1963-), female, Associate professor, Ph. D candidate, research direction: the optimization theory and its application, computer network. E-mail: sunlj@njupt.edu.cn

0 Introduction

The aim of QoS routing problem is to find out a path that satisfies certain requirements of applications such as delay, delay jitter, bandwidth, packet loss rate, and cost, which are the characteristics of network transmission. It's well known that, if QoS contains at least two additive metrics or the combination of additive and multiplicative metrics, the routing problem becomes NP-complete problem. At present, scholars usually use the heuristic algorithm, such as genetic algorithm, neural networks and etc. to solve NP problems[1-3]. But these algorithms have some limitations that cannot be overcome by themselves.

In the 90s of 20th, Italian scholar M. Dorigo put forward a new heuristic algorithm—ant colony algorithm (ACA), which simulates the routing behavior of natural ants[1,5]. The advantages of algorithm are distributing computation, positive feedback, and constructive greed heuristic[4-10]. These features can help to find solution of NP-complete problem.

This paper describes an optimization method of unicast multi-constrained QoS routing problem, which is based on the ant colony algorithm. Experimental results show that this algorithm can solve the QoS routing problem effectively and efficiently.

1 Theory of Ant Colony Algorithm (ACA) in QoS Unicast Routing

1.1 Basic Theory of ACA

Ant colony algorithm is based on bionics, which simulates the ant colony behavior. In the nature, ants can accomplish complex tasks by exchanging information and collaborating with each other. For example, real ants are capable of finding the shortest or near shortest path from a food source to their nests. By observing and studying, it is known that a kind of substance called pheromone plays an important role in path finding. While walking, ants deposit pheromone on the ground, and follow, in probability, pheromone previously deposited by other ants. For a link, the more ants visit it, the more pheromone is deposited on it. Conversely, the more pheromone on it, the larger of the probability it can be chosen by offspring. Thus, the process is characterized as a positive feedback loop. By many generations routing cycle, more ants converge on the shortest path finally.

Informally, in ant colony algorithm, the ants work as follows[1-5]: each ant finds its tour according to the state transition rule, and each ant can find the shortest path rapidly by applying the local updating rule and the global updating rule.

1.1.1 The State Transition Rule

While building a tour, ant k positioned on node r chooses its next node s to move to by applying the rule given by formula (1) and (2).

$$s=\begin{cases} S, & \text{otherwise} \\ \arg\max\{[\tau(r,u)]\times[\eta(r,u)]^{\beta}\}_{u\in J_k(r)}, & \text{if } q\leqslant q_0 \end{cases} \tag{1}$$

$$p_k(r,s)=\begin{cases} \dfrac{[\tau(r,s)]\times[\eta(r,s)]^{\beta}}{\sum\limits_{u\in J_k(r)}[\tau(r,u)]\times[\eta(r,u)]^{\beta}}, & \text{if } s\in J_k(r) \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

where q is a random number uniformly distributed in $[0,1]$, q_0 is a constant parameter between 0 and 1. The parameter q_0 determines the relative importance of exploitation and exploration. Firstly, q is created randomly. If $q\leqslant q_0$, the best edge, whose function value is the maximum, is chosen. Else, if $q>q_0$, the ant will build a random number p, which is uniformly distributed between $[0,1]$, then compare p and $p_k(r,s)$ to choose the next nodes according to the formula (2).

$\tau(r,s)$ is the pheromone level of the link connecting node r and s. τ is updated by rules 1.1.2 and 1.1.3. $\eta(r,s)=\dfrac{1}{\text{cost}(r,s)}$, is the inverse of the $\text{cost}(r,s)$, which is the cost between node r and s. β (>0) is a parameter which determines the relative importance of pheromone versus cost. $J_k(r)\subset\{0,1,2,\cdots,n-1\}$, is the set of nodes that remain to be visited by ant k in node r.

1.1.2 The Local Updating Rule

For the kth ant, it visits edges and changes to get the value of pheromone on them when building a tour. If r,s are two adjacent nodes connected together on the chosen path, the amount of pheromone on the path is modified by the following:

$$\tau(r,s)\leftarrow(1-\rho)\times\tau(r,s)+\rho\times\Delta\tau(r,s) \tag{3}$$

Otherwise, the values of pheromone on other paths should not be adjusted.

In the formula (2), $\rho(0<\rho<1)$ is the decay parameter and means that the pheromone on link (r,s) decreases based on this multiplicative modulus. $\Delta\tau(r,s)$ is the increment of pheromone on (r,s). According to Ref. [5], in ACA $\Delta\tau(r,s)=\tau_0$ as the initial pheromone level. In the Ant-Q algorithm[11], $\Delta\tau(r,s)=\gamma\times\max\limits_{z\in J_k(s)}\tau(s,z)$. Experiments show that the ACA requires less computation than Ant-Q in local updating rule, but two algorithms can receive a similar performance. So the former is chosen in this paper and $\Delta\tau(r,s)=\tau_0$ is set as a constant.

1.1.3 The Global Updating Rule

When all m ants complete the tour successfully for one time, we choose the globally best ant in current iteration, whose value of objective function is considered the best. This measure makes the best result kept down, which can affect the behavior of offspring. If r,s are two adjacent nodes and there is a connect between them, the amount of pheromone on it would be modified according to formula (4).

$$\tau(r,s)\leftarrow(1-\alpha)\tau(r,s)+\alpha\times\Delta\tau(r,s) \tag{4}$$

where

$$\Delta\tau(r,s)=\begin{cases}(Q/L_{\text{best}}), & \text{if } (r,s)\in \text{global-best-tour} \\ 0, & \text{otherwise}\end{cases}$$

$0<\alpha<1$ is pheromone decay parameter. In our paper, we set $\alpha=\rho$. And L_{best} is the best value of the objective function. Global-best-tour is the path of the best ant. Formula (4) indicates that only those edges belong to the best tour in current iteration can be enhanced. The pheromone on other edges will be weakened. Q is a constant, which is used to adjust the value of pheromone (τ).

1.2 Description on QoS Routing

The aim of QoS routing is to supply the service quality guarantee of unicast. The dominating guideline of quality includes delay, delay jitter, bandwidth, packet loss rate, and cost. These four characters make up the constraints of QoS. The algorithm in this paper, aims at looking for the route, which meets four constraints with minimum cost.

The communication network can be modeled as graph $G=(V,E)$, where V presents a set of nodes in network (e.g. switcher, router, and host computer) and E is a set of edges between two direct connecting nodes. In this paper, the network model is symmetrical. Node $S\in V$ is the source node, and node $M\in\{V-\{S\}\}$ is the destination. There are four QoS measures associated with each link ($e\in E$): delay(e), delay_jitter(e), cost(e), bandwidth(e). Similarly, for each node $n\in V$ in the network, the four measures can be denoted as: delay (n), delay_jitter (n), cost (n), packet_loss (n). Given a source node $S\in V$ and a destination M, the following relationship exists in the tree $T(S,M)$ involving node S and M[12].

① $$\text{delay}(T(S,M)) = \sum_{e\in T(S,M)} \text{delay}(e) + \sum_{n\in T(S,M)} \text{delay}(n)$$

② $$\text{cost}(T(S,M)) = \sum_{e\in T(S,M)} \text{cost}(e) + \sum_{n\in T(S,M)} \text{cost}(n)$$

③ $$\text{bandwidth}(T(S,M)) = \min\{\text{bandwith}(e), e\in T(S,M)\}$$

④ $$\text{delay\_jitter}(T(S,M)) = \sum_{e\in T(S,M)} \text{delay\_jitter}(e) + \sum_{n\in T(S,M)} \text{delay\_jitter}(n)$$

⑤ $$\text{packet\_loss}(T(S,M)) = \prod_{n\in T(S,M)} (1-\text{packet\_loss}(n))$$

The QoS unicast routing problem can be described as follows: in the topological graph of network $N(V,E)$, given the source S and the destination M, we must find out a route $T(S,M)$, which meets the following condition[12]:

① delay constraint:

$$\text{delay}(T,(S,M))\leqslant D;$$

② bandwidth constraint:

$$\text{bandwith}(T,(S,M))\geqslant B_w;$$

③ delay jitter constraint:

$$\text{delay\_jitter}(T,(S,M))\leqslant D_j;$$

④ packet loss constraint:

$$\text{packet\_loss}(T,(S,M))\leqslant P_l;$$

⑤ Cost constraint: under the condition of meeting the above four constraints, cost($T,(S,M)$) is the minimum.

Where B_w, D, D_j, and P_l represents the bandwidth, delay, delay jitter, and packet loss restriction respectively. The QoS routing in this paper includes four irrelevant measures, which is an NP-complete problem[12].

1.3 QoS Routing Optimization Algorithm Based on Ant Colony Algorithm

It is necessary to simplify the topology of network before routing, which can reduce the difficulty of design and optimize the capability of algorithm. In this paper, we remove the links with bandwidth less than the bandwidth requirement, thus we filter the topology into a new network, which will satisfy the bandwidth constraint very well. If the source node and the destination node are laid on the connecting Steiner tree, this topology is regarded as the platform to simulate the algorithm (Then the ACA is adapted to solve the minimal unicast tree with the constraints of delay, delay jitter, and cost. If the network cannot meet the bandwidth constrained, we should release the constraint and reduce the topology again).

In this paper, we import the QoS restrictions while doing the global updating. That is to say, whether the tour meets the constraints or not decides the value of the punish-gene and the objective function. This measure aims at modifying the value of $\tau_{ij}(t+\Delta t)$. After m ants' routing for one repetition, we count their objective function $L_k(k=1,2,\cdots,m)$, which is decided by the following equations[12]:

$$L_k = \frac{1}{\text{cost}(T(r,s))}(Af_d + Bf_{dj} + Cf_{pl}) \tag{5}$$

$$f_d = \Phi_d\{\text{delay}(T_k(r,s)) - D\}$$
$$f_{dj} = \Phi_{dj}\{\text{delay\_jitter}(T_k(r,s)) - D_j\}$$
$$f_{pl} = \Phi_{pl}\{\text{packet\_loss}(T_k(r,s)) - P_l\}$$

$$\begin{cases} \Phi_d(Z) = \begin{cases} 1, & Z\leqslant 0 \\ r_d, & Z>0 \end{cases} \\ \Phi_{dj}(Z) = \begin{cases} 1, & Z\leqslant 0 \\ r_{dj}, & Z>0 \end{cases} \\ \Phi_{pl}(Z) = \begin{cases} 1, & Z\leqslant 0 \\ r_{pl}, & Z>0 \end{cases} \end{cases} \tag{6}$$

where A, B, C are the corrective-gene of f_d, f_{dl}, f_{pl} respectively and denote the relative importance of delay, delay jitter, and packet loss rate in the objective function. The values of them can be set according to the actual requirement.

$\Phi_d(Z)$ is set to be the punishment function of delay. If the tour meets the delay constraint, $\Phi_d(Z)=1$; otherwise, $\Phi_d(Z)=r_d(0<r_d<1)$. Similarly, $\Phi_{dj}(Z)$ figures the punishment gene of delay jitter, whose value is 1 (meeting the inequality delay_jitter ($T_k(r,s))\leqslant D_{dj}$) or

r_{dj} ($0 < r_{dj} < 1$) (otherwise condition). $\Phi_{pl}(Z)$ is the packet loss punishment gene, whose value is 1 or r_{pl} ($0 < r_{pl} < 1$) . The values of r_d, r_{dj}, r_{pl} decide the degree of punishment. In this paper, we set $r_d = r_{dj} = r_{pl} = 0.5$. Comparing the value of L_k ($1 \leqslant k \leqslant m$) and identifying the maximum L_{best}, the pheromone level of each link can be adjusted based on formula (4).

In this paper we modify the basic ant colony algorithm with MMAS (max-min ant system)[13]. The concrete steps of the constructed algorithm are given as follows:

① Initialize parameters: There are Itera (a constant) sets of ants, each set consisting of m ants different with each other, and n nodes. The values of every node is (d, d_j, p_l, c), which represent the values of delay, delay jitter, packet loss rate, and cost of every node respectively. And the values of every edge parameters are given as (d, d_j, b_w, c), the elements in which mean delay, delay jitter, bandwidth, and cost. The values of constraint D, D_j, B, and P_l are set based on the concrete service.

② Simplify the topology of network into a new one by cutting down the links with bandwidth smaller than the requirement.

③ Initialize the pheromone level of each link with τ_0 = const, and position a set of m ants on the source node s.

④ Let every ant choose its next node by applying formula (1) and (2). When an ant finds its next node successfully, the pheromone on this link will be modified based on formula(3). If an ant cannot find appropriate next node before it reach the destination node, it will be denounced that this ant is killed.

⑤ Repeating the step ④ for all m ants, until all m ants find their paths from the source to the destination or die.

⑥ Calculate the objective function L_k, then choose the max objective function L_{best}, and then find best tour T_{best}. Renew the pheromone level of all links by using the global updating rule formula (4).

⑦ Repeating the steps ④-⑥, until all Iter sets of ants complete the route searching.

2 Simulations and Result

In this simulation, the network topology is depicted in Fig. 1. Every node in the network is defined with parameters (d, d_j, p_l, c). Each link is denoted by (d, d_j, b_w, c). The cost in the topology means the distance between two nodes, so it can be measured by length.

The elements in this simulation are set to the following values[11]: $m=10$, Iter$=30$, $\rho=0.2$, $q_0=0.7$, $\beta=2$. The pheromone of all links can be initialized to be uniform, $\tau_0=10$, $Q=1\ 000$. Applying MMAS (max-min ant system) to restrict τ within $[\tau_{min}, \tau_{max}]$, where the value of τ_{min} and τ_{max} are suggested in Ref. [13].

At the beginning of the simulation, the original topology Fig. 1 is modified into Fig. 2 according to the bandwidth requirement.

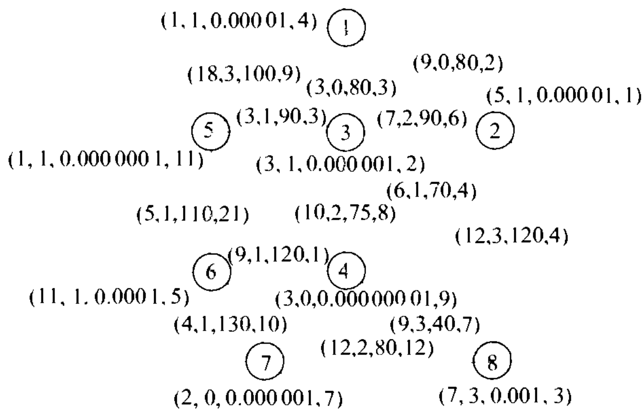

Fig. 1 Topology of simulation network (8 nodes)

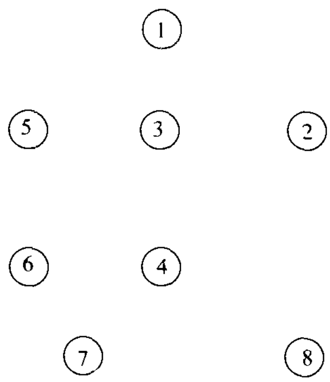

Fig. 2 Simplification of Fig. 1 according to bandwidth

The QoS requirements are considered as[15]: $D=46$, $D_j=10$, $P_l=0.001$, $B_w=70$. The source is node 1, and the destination is node 7. The value of A, B and C are determined by concrete requirement. In this experiment, $A=B=C=1$, which means the cost is the most important parameter and the others affect the service in the same way.

After 20 ants finish the routing for 20 iterations, we obtain the routing result as shown in Table 1 (All the ants finished the searching work except one was killed).

We denote the successful routing as follows : the

Table 1 The result of (1.7) QoS routing

The number of tour	The list of nodes in a tour	Delay s	Delay jitter s	Cost	Times of appearance
1	1-2-8-7	45	9	29	146
2	1-5-6-7	42	7	63	11
3	1-2-4-6-7	47	5	39	46
4	1-2-3-5-6-7	48	9	61	1
5	1-5-3-4-6-7	62	11	65	22
6	1-5-3-2-8-7	68	17	58	32
7	1-5-6-4-2-8-7	92	17	87	12
8	1-5-3-2-4-6-7	70	13	68	19
9	1-5-6-4-3-2-8-7	106	21	99	6
10	1-3-5-6-4-2-8-7	83	16	86	4

path can meet the QoS requirements being proposed in this paper (delay, delay jitter, packet loss, and bandwidth). The route 1, 2 are regard as successful. Then, the costs of these routs become the decisive ingredient. According to Table 1, about 52.33% ants find the successful QoS routing, and converge to the best route step by step. At last, 48.67% ants choose the best route: 1-2-8-7. While the appearance of route 3, 4, 5, 6, 7, 8, 9 and 10 denotes that the process is a global searching. In this simulation, MMAS confine the pheromone of all links and avoid their misdirection, which makes the ants' plunge into the local best solution.

3 Conclusion

In this paper, a heuristic algorithm-improved ant colony algorithm is introduced. It explains how an ant find the shortest route between food and nest by releasing the pheromone on the path. ACA is a dynamic distributed algorithm. A route search with delay, delay jitter, bandwidth, and packet loss-constrained is regard as an NP-complete problem. A proposal applying improved ACA to solve the QoS unicast routing is set up. The simulation results indicate that the method is effective and efficient: it can arrive at global search and converge the global best solution gradually.

References

[1] Feng X, Liu J Z, Wang J Y, *et al*. QoS Routing Based on Genetic Algorithm. *Computer Communications*, 1999, **22**(15): 1394-1399.

[2] Mustafa K, Mehmet A, Faouzi K. Neural Networks for Shortest Path Computation and Routing in Computer Networks. *IEEE Trans on Neural Networks*, 1993, **4**(6): 941-954.

[3] Wang Z, Shi B. Solution to QoS Multicast Routing Problem Based on Heuristic Genetic Algorithm. *Journal of Computer*, 2001, **24**(1): 55-61(Ch).

[4] Dorigo M, Maniezzo V, Colorni A. The Ant System: Optimization by a Colony of Cooperating Agents. *IEEE Transactions on Systems, Man, and Cybernetrics*, 1996, **26**(1): 1-13.

[5] Dorigo M, Gambardella L M. Ant Colony System: A Cooperative Learning Approach to the Traveling Salesman Problem. *IEEE Transactions on Evolutionary Computation*, 1997, **1**(1): 53-66.

[6] Li S, Liu Z, Zhou Z. An Ant Algorithm Based VC Routing Method in ATM Networks. *Journal of Communication*, 2000, **21**(1): 22-28(Ch).

[7] Zhang J, Gao Q, Xu X. A Self-Adaptive Ant Colony Algorithm. *Control Theory and Application*, 2000, **17**(1): 1-3 (Ch).

[8] Lu G Y, Zhang S B, Liu Z M. Distributed Dynamic Routing Using Ant Algorithm FOR telecommunication Networks. *http://www.ifip.or.at/con2000/contents/icct2000/icct-con21.htm*. Fer, 2002.

[9] Colorni A, Dorigo M. Distributed Algorithm by Ant Colonies. *Proc First Europ Conf Artificial Life*. Paris, France: Elsevier, 1991. 134-142.

[10] Dorigo M, Caro G D. Ant Algorithms for Discrete Optimization. *Artificial Life*, 1999, **5**(3), 137-172.

[11] Gambardella L M, Dorigo M. Ant-Q: A Reinforcement Learning Approach to the Traveling Salesman Problem. *Proceedings of ML-95 Twelfth Intern Conf on Machining*. Tahoe: Morgan Kaufmann, 1995. 252-260.

[12] Wang Z, Shi B. Solution to QoS Multicast Routing Problem Based on Heuristic Genetic Algorithm. *Journal of Computer*, 2001, **24**(1): 55-61 (Ch).

[13] Stutzle T, Hoos H H. MAX-MIN Ant System. *Future Generation Compter System*, 2000, **16**(8): 889-914.

[14] Pilat M L, White T. Using Genetic Algorithm to Optimize ACS-TSP. *Proceedings of the 3rd International Workshop on Ant Algorithms*. Brussels: Springer, 2002. 12-14.

[15] Zhang S, Liu Z. A QoS Routing Algorithm Based on Ant Algorithm. *http://csdl.compater.org/comp/proceedings/lcn/2000/0912/00/09120574abs.htm*. Dec, 2000.

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