An Optimized Approach to Solving Ad Hoc QoS Routing with GPS Location

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Abstract: - The Ad Hoc network has attracted more and more attention with its good performance and special application. Many transactions, such as real-time multimedia and audio-video transmission have strict demand for QoS parameters, which requires that we find a QoS routing in multi-constrained conditions. Generally, multiconstrained QoS routing is an NP-Complete problem. The drawbacks of the ad hoc network—poor quality of network links, frequent topology change and low capacity, make it more complicated for the QoS guarantee because the time and information needed for the algorithm to search path is relatively limited. We propose a modified ant colony algorithm based on the orientation factor to solve multi-constrained QoS routing problem by recurring to GPS location. This algorithm employs the orientation factor to adjust the search act of ants and update pheromones according to objective function values, thus guaranteeing the speed and effeciency of the search， and avoiding falling into local optimization. Simulation results indicate that the algorithm proposed in this paper has good performance in computing speed and reduction of control information amount.

Key-Words: - Ad Hoc; QoS Routing; Ant colony algorithm; GPS Location; Optimization; Orientation Factor

1 Introduction

The Ad Hoc network is a type of wireless network without a center which can be organized quickly. Its good performance has wide application in civil and military communications domains. Many transactions demand strict QoS guarantee. For example, real-time audio-video transmission requires the network provide QoS guarantee. Many transactions require that we find a QoS routing in multi-constrained conditions. Generally, multi-constrained QoS routing is an NP-Complete problem[1]. Meanwhile, QoS study contributes to the increase of network efficiency and lower network cost. Although many studies have been made on QoS guarantee most of the schemes are designed in terms of the features of fixed networks and cannot be directly applied to ad hoc networks.

The features of ad hoc dynamic topology structure, time variation link capacity and power limit have made the QoS guarantee problems more complicated. The ant colony algorithm was adopted to solve the problem[2] . On one hand in large scale optimization this algorithm has the shortcomings of slow convergence speed, weak local search capacity and stagnation[3] . On the other hand, the development of GPS technology makes it possible for GPS receiver with low cost to install in movable nodes. The node itself can know its geographical location[4] , which reduces bandwidth waste as compared with adopting flooding mechanism. On this basis, many researchers proposed a variety of protocols such as LAR(location aided routing), GLS (grid location service), GPSR(greedy perimeter stateless routing) [4, 5] . Those protocols have better expandability and adaptability, but they did not solve the multi-constrained QoS routing problem. This paper puts forward a new ant colony algorithm based on the orientation factor. This algorithm adjusts the search direction of ants by recurring to the geographical information obtained through GPS, and thus speeding up convergence of multi-constrained QoS ant colony algorithm. Simulation results indicate this modified algorithm is effective.

The rest of this paper is organized as follows. The notation of QoS routing for the ad hoc network is introduced in Section 2. Section 3 describes the basic ant colony algorithm and its modification. Section 4 explains the realization of ant colony algorithm based on the orientation factor for Multi-constrained QoS routing optimization. Simulation results and discussion are given in Section 5. Section 6 concludes the paper.

2 Notation of QoS routing for the ad hoc network

We model the Ad Hoc network by a weighted undirected graph $G(V, E)$. The node in the graph denotes network device, and the edge denotes the communication link connecting nodes in the network. V denotes the set of nodes in the network and E denotes the set of links in the network. Let $p = p(s,d)$ represent a path from source node s to destination node d. Let e denote a link on the path p, i.e. $e \in p$. We define several commonly used QoS parameters.

(1) delay: delay on link e; $delay(p) = \sum_{e \in p} delay(e)$, $delay(e)$ is delay on link e;

(2) cost: $\cos t(p) = \sum_{e \in p} \cos t(e)$, $\cos t(e)$ is cost on link e;

(3) packet loss rate: $loss(p) = 1 - \prod_{e \in p}(1 - l(e))$, $l(e)$ is packet loss rate on link e;

(4) bottleneck bandwidth: $bandwidth(p) = \min\{b(e)\}$, $b(e)$ is bottleneck bandwidth on link e.

The objective of solving multi-constraint QoS problem is to find a path $p(s,d)$ that satisfies the following condition:

$$delay \le D \,\&\&\, \cos t \le C \,\&\&\, loss \le L \,\&\&\, bandwidth \ge B \quad (1)$$

Where D, C, L and B respectively denotes delay constraints, cost constraints, packet loss rate constraints, and bandwidth constraints of QoS constraints.

For multi-constrained routing problems optimization is not easy for every parameter to achieve owing to the lack of consistent metrics among objectives. Therefore the common practice is to find satisfactory solutions by considering as many objectives as possible.

3 Basic ant colony algorithm and its modification

3．1 Basic ant colony algorithm(ACA)

The basic ant colony algorithm in the case of solving the shortest path problem is briefly described in the following.

(1) Transition probability. Given all the sets of ants $\{a_1, a_2, ..., a_m\}$. In every search period, every ant randomly selects a path from the source node to the destination node according to the select probability of the path. When all the ants have completed a path search, the algorithm is said to have a search period. In the t-th search period, the select probability $p_{ij}^{\ k}(t)$ of the path from node i to node j is defined as

$$p_{ij}^{\ k}(t) = \begin{cases} \dfrac{[\tau_{ij}(t)]^{\alpha}[\eta_{ij}(t)]^{\beta}}{\sum_{s \in allowed_k} [\tau_{is}(t)]^{\alpha}[\eta_{is}(t)]^{\beta}} & j \in allowed_k \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Where the set $allowed_k = \{0,1,...,n-1\} - tabu_k$ denotes the node set of next allowed selection of K-th ant. $tabu_k (k = 1,2,...,m)$ represents the node set of passed nodes in this cycle by K-th ant. This node set adjusts dynamically with the evolution process. $\tau_{ij}(t)$ denotes the pheromone on (i, j) between node i and node j in the t-th search period, representing the optimization tendency. $\eta_{ij}(t)$ is heuristic function: $\eta_{ij}(t) = \frac{1}{d_{ij}}$. To K-th ant, the smaller d_{ij} is, the bigger $\eta_{ij}(t)$, and the bigger $p_{ij}^{\ k}(t)$.

Obviously, this heuristic function indicates the degree of expectation of the ant from node i to node j. α denotes the comparative importance of the track, reflecting the effect of accumulated information of the ant in the course of movement when the ant moves. The bigger the value of α, the more inclined the ant is to select the path taking by other ants, and the higher coordination among ants. β represents the comparative importance of visibility, reflecting the degree of recognition of heuristic factor in selecting path in the course of movement. The bigger its value is, the more close the transition probability is to greedy algorithm[6].

(2) Local update: Local update is conducted by every ant to set up a solution. With the passing of time, the pheromone left before disappears gradually. After h moments, the number of local pheromones between two nodes should be adjusted according to the following formula

$$\tau_{ij}(t+h) = (1-\zeta)\cdot\tau_{ij}(t) + \zeta\cdot\tau_0 \quad (3)$$

$$\tau_0 = \frac{1}{n l_{\min}} \quad (4)$$

Where $\zeta \in [0,1]$, $l_{\min}$ denotes the shortest distance between two nodes in the set C.

(3) global update: Only the ant which generates the global optimization has the opportunity of making global adjustment. The rule of global adjustment is

$$\tau_{ij}(t+n) = (1-\rho)\cdot\tau_{ij}(t) + \rho\cdot\Delta\tau_{ij}(t) \quad (5)$$

$$\Delta\tau_{ij}(t) = \sum_{k=1}^{m}\Delta\tau_{ij}^{k}(t) \quad (6)$$

$$\Delta\tau_{ij}^{k}(t) = \begin{cases} \frac{Q}{L_k} & \text{When } k-th \text{ ant} \\ & \text{passes } (i,j) \text{ in this cycle} \\ 0 & \text{Otherwise} \end{cases} \quad (7)$$

Where ρ is evaporation coefficient, $\rho\in[0,1]$. $\Delta\tau_{ij}(t)$ denotes the increment of the number of pheromones on the path (*i,j*) of the cycle. $\Delta\tau_{ij}^{k}(t)$ denotes the number of pheromones left by k-th ant on the path (*i,j*) in the cycle. Q is constant . L_k represents the length of the path covered by k-th ant in the cycle. The initial time $\Delta\tau_{ij}(t)=0$, $\tau_{ij}(0)=A$, $(i,j=0,1,...,n-1)$.

3.2 Modification of the algorithm

3.2.1 Causes of modification

Although strict proof of algorithm convergence in some basic conditions has been given in [7],drawbacks of the basic ant colony algorithm still exist. For one thing, the major reason for the slow initial convergence of ant colony algorithm lies in the blindness of search direction, because according to Formula (2), in the condition of the sameness of initial pheromone intensity, the search of ant colony may be poles apart. For another, from Formula (3), local updating of pheromones is required according to every candidate solution. But in fact, the candidate solutions are not necessarily good solutions. The result is that computing the increment of pheromone will lead to erroneously directed information, thus causing a large quantity of search without progress. So we introduced the orientation factor to modify the basic ant colony algorithm.

3.2.2 Features essential for the orientation factor

1) Increase the probability of selection of the directed edge orienting towards the destination node(The orientation is defined as vector d.) as compared with the basic ant colony algorithm. With the increase of the difference between direction and d, the probability of the directed edge being selected becomes smaller, i.e. the orientation factor is strictly non-increasing function of angle θ, such as θ, －θ.

2)Influence the choice of rather than decide next hop in case of falling into local optimization.

3)The ideal orientation factor should be able to vary with real situations. For instance, when the pheromone can fully decide next hop, the orientation factor must play a subordinate role. When the pheromone cannot validly decide next hop, the orientation factor can play a major role.

3.2.3 Realizability of the orientation factor in application

The key to obtaining the orientation factor is to acquire geographical information of each node, which can be achieved by using GPS[8] . GPS is the most sophisticated and practical global satellite navigation and positioning system, able to provide real-time three-dimensional navigation and positioning service on the sea, land and in the sky. Connecting with a GPS receiver, the moving node can obtain the current geographical information. In ad hoc networks it is a mature technology, out of which have developed Location-Aided Routing(LAR) protocols. LAR is the typical representative. In LAR protocols, the node can acquire its own position through GPS. Position service enables the obtaining of the position of node.

3.3 Scheme of modification On the basis of the above analysis, we proposed the following measures of modification.

(1) The orientation factor is employed to direct the ant colony to search path. After many times' experiments, we select the orientation factor as $\eta = 2+\cos\theta$. Every time the ant selects the next node, increase the probability of moving towards the destination node so that a lot of unnecessary invalid search can be reduced. The modified formula is described as follows.

$$p_{ij}^{k}(t) = \begin{cases} \dfrac{[\tau_{ij}(t)]^{\alpha}[\cos_{ij,it}(\theta)+2]^{\beta}}{\sum_{s\in allowed_k}[\tau_{is}(t)]^{\alpha}[\cos_{is,it}(\theta)+2]^{\beta}} & j\in allowed_k \\ 0 & \text{otherwise} \end{cases} \quad (8)$$

$$\cos_{ij,it}(\theta) = \frac{\vec{ij}\bullet\vec{it}}{|\vec{ij}|\bullet|\vec{it}|} \quad (9)$$

Where θ is the angle between vectors $\vec{ij}$ and $\vec{it}$, $\cos_{ij,it}(\theta)$ denotes the cosine value of the angle of the two directions between the current node i to next node j and the current node i to destination node t. In ad hoc networks, it is easy to determine geographical information through GPS to obtain this orientation factor.

(2) In every cycle, only the local optimization in the cycle is selected to update pheromones. At an interval of fixed generations global optimization is employed to update pheromones. To avoid local optimization, an upper bound and a low bound are set for the pheromone intensity on the link [9] . Therefore, it will not happen that the pheromone intensity on certain path is larger than that of other paths.

4 Ant colony algorithm based on the orientation factor(OACA) for Multi-constrained QoS routing optimization

In order to map the QoS routing problem to the model of the above mentioned modified ant colony algorithm OACA, we number all the nodes of the network 1, 2, …, n. Objective function is $y(p)=\sum_{i=1}^{m} w_i f_i(p)$, where p is the path passed in this search cycle. f_i is QoS constrained function, such as bandwidth, delay etc. w_i is the weight of every QoS constraint. This paper took account of the routing optimization of four QoS constraints including bandwidth, delay, cost and packet loss rate, i.e. to find a route, whose objective function value is minimal on condition of satisfying the four QoS constraints. The objective function is defined as:

$$y(p)=w_d \cdot delay(p)+w_c \cdot \cos t(p)+ w_l \cdot loss(p)+w_b \cdot bandwidth(p) \quad (10)$$

Where w_d, w_c, w_l, w_b denote the weight of bandwidth, delay, cost and packet loss rate respectively.

The process of solving the multi-constraint routing problem by using ant colony algorithm based on orientation factor is as follows.

Step 1: delete the link of the network which does not satisfy $f_i(e) \le \delta_i$ *(e.g. delete the link which does not satisfy the smallest bandwidth in the network), then a new network topology* G_1 *will be obtained. Start to search on the basis of* G_1.

Step 2: (initialize) set $r=0$. *Give initial values of pheromones on all the links. Set* $\tau_{ij}(0)=A$, *(* A *is a constant). Given the maximum number of search cycle* R, *the fixed generations i, the number of ants* n, *and the maximum time limit of one search cycle* T. *The optimization objective function value* Y *is infinite. Let the solution set be null.*

Step 3: Set the time function t *of this search cycle as 0 and start timing.* n *ants, from the source node, randomly moves independently. They select the next node according to the probability in Formula (8), until all the ants finish searching paths and reach the destination node, or the search time* $t=T$.

Step 4: Compute the objective function value of the path passed by all the ants in this cycle.

Set $y(p^k)=\sum_{i=1}^{m} w_i f_i(p^k), k=1,2,...,n$. p^k *is the path passed by the* k *-th ant from the source node to the destination node in the cycle. If in this cycle the* k *-th ant does not reach the destination node, or if it reaches the destination node, but does not satisfy* $f_i(p^k) \le \alpha_i \quad i=1,2,...,m$, *set* $y(p^k)$ = *infinite,* $k=1,2,...,n$.

Step 5: Solve $\min_p\{y(p^k)\}$. *If* $\min_p\{y(p^k)\}<Y$, *then set* $Y=\min_p\{y(p^k)\}$. *So far if the generations of ants are the integer times of the fixed generations i, global optimal path is used to update the solution set; otherwise, choose the minimum path which is obtained through objective function value, and update the solution according to this minimum path.*

Step 6: Set $r=r+1$. *If* $r<R$, *go to step 3, and proceed to next cycle of search. Or end the algorithm.*

Step 7: Output the path of solution set, i.e. the optimal path satisfying QoS requirements. If Y *is infinite, then the path required by QoS does not exist.*

5 Simulations

The proposed algorithm was simulated in the environment of VC++ 6.0. Figure 1 is a topology graph of program operation. There are 25 nodes. Set the source node at 23(shown in black solid square), the destination node at 22(shown in black solid circle). The property of the link is described in a quadruple (delay, cost, bandwidth, packet loss rate). A path from node 23 to node 22 that satisfies multi-constraint Qos should be solved. The requirements of QoS are: delay≤ 50, cost ≤ 200, bandwidth $\ge$ 80000 , packet loss rate $\le$ 0.002. According to the formula (10), set the weight value of w_d, w_c, w_l, w_b as $0.01, 0.47, 0.51, 0.01$ respectively, the number of ants is 10.

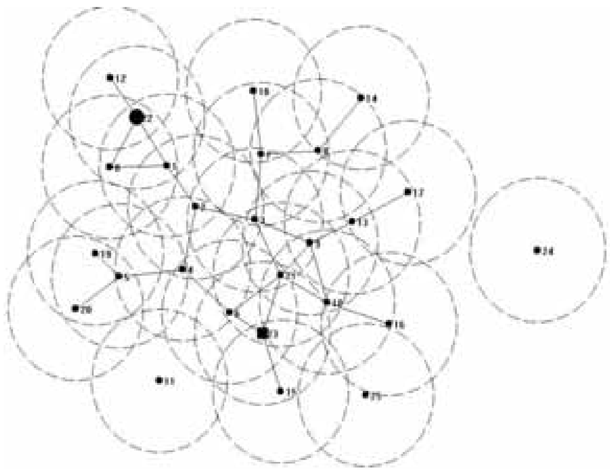

Fig1. Simulation network topology

Table 1. Sequence change of the path

Sequence change of the path	cost	delay	Bottleneck bandwidth	Packet loss rate	Objective function value y (p)	Generations of ants
23->21->3->2->1->8->22	243	69	155200	0.001356	14.56	1
23->21->3->2->1->22	127	52	84678	0.000851	6.34	7
23->6->4->2->1-22	109	47	92680	0.001076	4.95	13
23->6->4->2->1-22	109	47	92680	0.001076	4.95	13
23->6->4->2->1-22	109	47	92680	0.001076	4.95	14
23->6->4->2->1-22	109	47	92680	0.001076	4.95	15
23->6->4->2->1-22	109	47	92680	0.001076	4.95	16

The result of the simulation is as follows:

Table 1 shows the sequence change of path when the algorithm is working. It can be seen that the objective function value of the path decreases with the increase of the ant generations. When the generation of ants reaches 13 the best optimal solution is obtained

We compare OACA and ACA by simulation. Figure 2 indicates that both algorithms converge to the best solution. But the former takes shorter time to converge, leading to higher search efficiency.

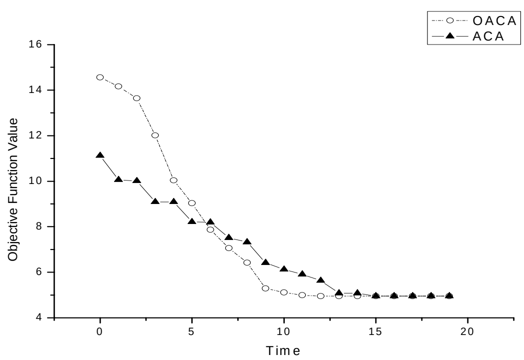

Fig. 2 Comparison of convergence time

We do further simulation by expanding the scale of network to compare the average searching speed and power consumption. The more time the algorithm takes to operate, the more packets are transmitted, and the more power the system consumes. For the ad hoc system whose battery capacity is limited, the operation time and number of transmitted packets are important factors to be considered. The generation number of the modified ant colony algorithm does not increase greatly with the expansion of the network. Meanwhile, the convergence speed and power consumption of OACA are better than ACA.

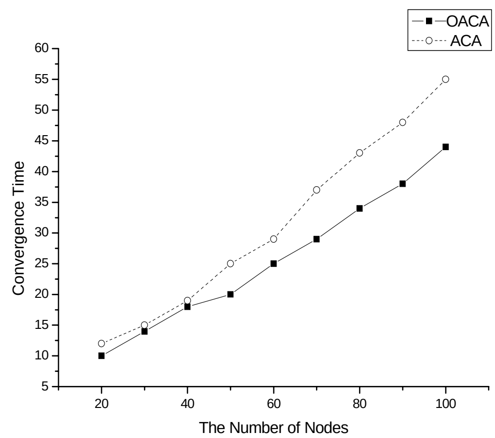

Fig. 3 Comparison of expandability and convergence speed

When the scale of topology is bigger the differences between the two algorithms become obvious because in such case the ant has more choices in selecting paths. With the guidance of the orientation factor, OACA enables the ant at the initial stage to move in the direction of the destination node, thus finding some good paths. In contrast, the ant in ACA blindly searches the path at the initial stage. As a result, many of the paths found at the initial stage are not good enough, and some ants cannot arrive at the destination node and "die" halfway. Pheromones left by them have unfavorable effect on the ants following. Good paths mean a relatively small number of control packets are replicated and forwarded, while poor paths mean amount of the replication of control packets increases greatly.

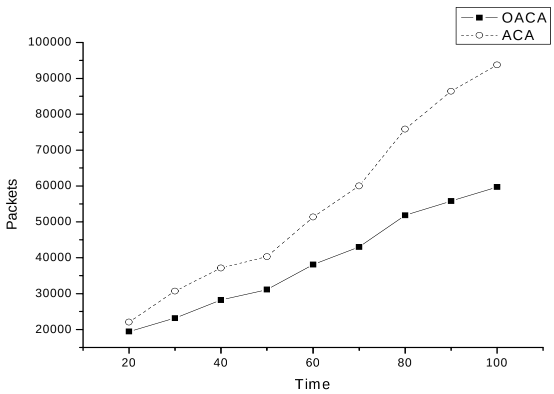

Fig. 4 Comparison of information amount

6 Conclusion

A novel ant colony algorithm based on the orientation factor was proposed to solve multi-constrained QoS routing optimization in terms of the features of ad hoc networks. This algorithm makes use of GPS technique to obtain geographical information of nodes, thus reducing blindness of search and power consumption. The simulation results indicated improvements in search efficiency of the ant colony optimal performance of the algorithm. We are going to perfect this algorithm to improve the adaptability of it to network topology variation in the future research.

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