Performance Analysis of Routing Algorithms Based on Intelligent Optimization Algorithms in Cluster Ad Hoc Network

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Abstract. In this paper, a mobile cluster Ad Hoc network model is presented for scenarios with large nodes number and high mobility. Intelligent optimization algorithms perform better than traditional routing algorithms in such scenarios but papers about performance comparison of these algorithms are rare. So we pick the most widely used intelligent optimization algorithms ACO, PSO and GA and describe the routing search process of these three algorithms in detail. Then we analyze performance of them together with AODV for comparison. Simulation results show that ACO, PSO and GA algorithms perform better than AODV in average throughput, packet loss rate, success link rate and average link hop.

Keywords: Ad Hoc network · Intelligent optimization · Cluster · Performance analysis

1 Introduction

Mobile Ad Hoc networks, where users can communicate with each other directly when infrastructures are unavailable, were proposed for military purpose in 1970s and 1980s. Since 1990s Ad Hoc networks were adopted widely in emergency communications, commercial and civil communications [1, 2]. Ad Hoc networks have some significant characteristics [2]: Ad Hoc networks have dynamic topology; nodes in the network are self-organized and can have various functions; communication links between nodes are multi-hop, etc.

The topology of Ad Hoc network is dynamic and generally can be divided into two types: flat and hierarchical structure [3], according to whether there is logic hierarchical relationship among nodes. All the nodes in the flat structure have equal status, and every node needs to know the information of all the other nodes in the network. For small and medium-sized network, it's easy to manage and maintain network in the flat structure. However, when there is a large amount of nodes, especially when nodes have

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high mobility, the control overhead becomes severe and routing interrupts frequently; management and control of the network become difficult, too. So for scenarios of large node number and high node mobility, the hierarchical structure is usually adopted. In the hierarchical structure nodes will be divided into several clusters [4] and each cluster has one cluster head responsible for relaying business between member nodes and the control node. Other member nodes don't need to maintain complex routing information, which greatly reduces the number of routing control information, therefore the network has good scalability.

Traditional Ad Hoc network routing algorithms are mostly based on distance vector or link-state and can be divided into table driven and on-demand routing protocols. In table driven routing protocols, each node periodically broadcasts its information and updates the local routing table continuously to ensure that the information in the routing table are the newest in order to directly search path when the routing request message is launched. The most representative protocols of table driven routing protocols include DSDV [5], OLSR [6]. In on-demand routing protocols, nodes don't need to maintain routing information periodically, only when the source node has data to send the routing search mechanism starts. These protocols reduce the excessive consumption of network bandwidth and energy compared to table driven routing protocols. The best known on-demand routing protocols are DSR [7], and AODV [8]. When the network topology changes frequently, table driven routing protocols have more control information leading to system performance degradation. Therefore, for Ad Hoc networks, although having a certain delay, on-demand routing protocols are more practical.

With nodes' high mobility in Ad Hoc network, the traditional wireless Ad Hoc network routing protocols cannot adapt to the changeable topology and the performance of protocols also becomes poor. Artificial intelligence algorithms and swarm intelligence algorithms with the characteristics of distributed, self-organized and intelligent are increasingly applied in Ad Hoc network routing search. The most prominent intelligent algorithms are Genetic Algorithm (GA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO), etc.

GA algorithm, proposed by Michigan University professor Holland and his students in 1975, is a kind of random search algorithm based on biological natural selection and genetic mechanism. Reference [9] is a survey on application of GA for QoS routing in Ad Hoc networks and gives a comparison between GA-based routing algorithms GAMAN and GLBR. ACO algorithms proposed by Italian scholar Dorigo. M in 1996. The algorithm simulates the foraging behavior of ant colony in the nature. A routing discovering algorithm RACO is proposed in [10] to solve the limitation of ACO by using the characteristics of the network and the concept related-node. Simulation shows RACO can reduce the convergence time and iteration of algorithm. PSO algorithm is a kind of evolutionary computation technology, proposed by Kennedy in 1995, imitating social behavior of animals or insects, such as birds, fish, etc. A novel approach based on PSO for solving the minimum energy broadcast problem in Ad Hoc networks was proposed in Ref. [11] and the simulation results show that it can compete and outperform state-of-the-art works.

The majority of researches above can play an important guide role for routing algorithms based on intelligent optimization algorithms in cluster Ad Hoc network. It should be noted, however, that there have been few attempts to compare network performance results with different intelligent optimization algorithms. In this paper, we introduce several intelligent optimization algorithms and compare performance of routing protocols based on these intelligent optimization algorithms in Ad Hoc networks. After performance analysis we get accurate network performance results, which provide theoretical basis for the practical application of cluster Ad Hoc networks in the future.

This paper has three purposes: (a) to establish a cluster system model; (b) to give an introduction of the routing process based on the most representative intelligent optimization algorithms in Ad Hoc networks; (c) to analyze and compare the performance of these routing algorithms. The remainder of the paper is organized as follows. In Sect. 2, we establish a cluster system model. Then in Sect. 3, we introduce how the routing algorithms work in Ad Hoc networks. And in Sect. 4, we simulate the performance of these routing algorithms on average throughput, packet loss rate, success link rate and average link hop. Finally we draw a conclusion in Sect. 5.

2 Cluster Ad Hoc Network Model

In cluster-structure Ad Hoc network, three kinds of nodes are used including control node, relay node and user node. Control node is in charge of controlling and managing relay nodes and user nodes, so in our mobile model control node is limited to move in the area near network center in order to better manage network nodes in different positions. Relay node is responsible for relaying business between user nodes and the control node, so we make all the relay nodes uniformly distribute in the network to ensure that all user nodes can transmit data to the control node with the aid of relay nodes, and avoid the case that some relay nodes' burden overweight, and some are out of use. Movement of user nodes has high randomness and independence, so the moving range is the entire network.

Three kinds of nodes have different move range according to their function, but on the whole each node moves using random waypoint mobile model (RWP). RWP model works as follows:

Node moves in a limited area, usually a rectangular or circular area. Node in the network first randomly selects an initial position, known as the "waypoint", and pauses in the current position for a random time, and then selects a random location in the network as target location, and moves to the target location with a random velocity. After arriving at the target location it stays for a randomly period of time, and then repeats the process. The waypoint in every section of the movement is chosen randomly, and has nothing to do with the history and the current waypoint location, and this is also fit for the velocity. Figure 1 shows the model of cluster Ad Hoc network.

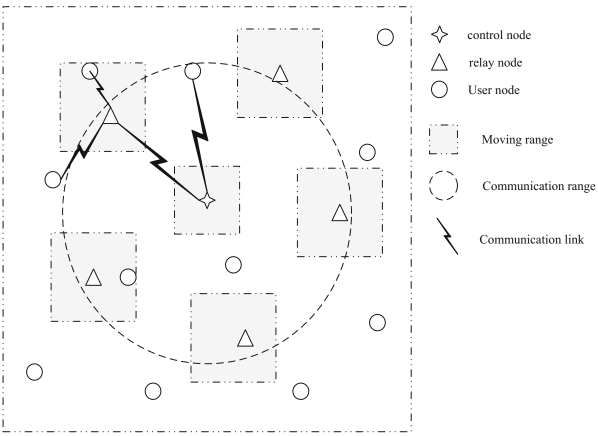

Fig. 1. Cluster Ad Hoc network model

3 Principle of Intelligence Algorithms

There are many intelligent optimization algorithms that are adopted in Ad hoc network routing protocols and the most prominent of them are Genetic Algorithm (GA), Ant Colony Optimization (ACO), Particle Swarm Optimization (PSO). So next we will describe the working process of these three algorithms in routing search problem.

3.1 Genetic Algorithm

In genetic algorithm search starts from a set of randomly generated initial "chromosome" (called population), then the population is put in the environment of the question, and a "chromosome" is chosen to replicate according to the principle of survival of the fittest, next through the crossover and mutation process produce a new generation of "chromosome" group that adapt to the environment much better. The performance of "chromosome" is measured by fitness, according to the value of fitness a certain number of individuals are chosen from the previous generation and future generation as the next generation of population, and then continue to evolve. After several generations, the algorithm converges to the most adaptable "chromosome" and it is the optimal solution of the problem.

Its basic steps for routing search are shown as follow:

(i) Initialize population size, crossover probability, mutation probability and iteration number.
(ii) Randomly generate initial population; Calculating the fitness of initial population.
(iii) Choose the parent body 1 and the parent body 2 according to a certain selection strategy.

(iv) Produce a random number in [0,1]. If it is greater than the crossover probability, the parent body 1 and the parent body 2 execute crossover to generate son 1 and 2; Otherwise the parent body 1 and the parent body 2 are replicated as child 1 and 2 directly.
(v) Produce a random number in [0,1]. If it is greater than the mutation probability, child 1 and 2 execute mutation.
(vi) Judge whether the number of children is equal to the population size, if so turn to step vii; else to step iii.
vii) Evaluation the fitness of new population; Children become parents.
(viii) Judge whether it meets termination conditions, if so stop the process; else turn to step iii.

Genetic algorithm has the advantages of simple and easy to implement and it can achieve parallel processing and has the ability to global search. So it is suitable for solving complex and nonlinear problems that are difficult for traditional search. Deficiencies are shown as precocious phenomenon and poor local optimization ability.

3.2 Ant Colony Optimization

During foraging ants leave pheromones on the path they walk and they tend to move in the direction of high pheromones, which volatilize as time goes. The more ants walk on a path, the more pheromones left on this path and in return will attract more ants walk through this path. Take advantage of this positive feedback, ants will eventually find an optimal path.

The working process of ACO is roughly listed as follows:

(i) Initialize pheromones concentration on each path;
(ii) Place several ants on the source node. Each ant first judges whether destination node is the neighbor node of the current node, if so then directly builds routing from source node to destination node, otherwise chooses the next node in the neighbor nodes collection according to a certain probability and records it in the routing table, meanwhile clears the chosen node in the neighbor node table in case of visiting repeatedly;
(iii) When ants reach the next node, repeat step ii, until all the ants arrive at the destination node or reach the end conditions, then stop this iteration. Then, compute length of all the available paths and select the optimal path in this iteration;
(iv) After one iteration update pheromones on each path based on the ant's visit (including volatilization);
(v) Then begin the next iteration, repeat step ii–iv, until reach the iteration number. Select the shortest path in optimal paths of all iterations.

ACO has significant advantages in converging speed and stability of the optimal solution, but the performance of ACO is determined by the pheromones. Shortage of the initial pheromone makes it easy to cause converging speed slower. Inappropriate pheromones setting can also cause slow convergence or converging to a local optimal solution.

3.3 Particle Swarm Optimization

PSO is a kind of optimization tool based on iteration. System is initialized to a group of random solutions and searches for the optimal solution through iteration. Instead of crossover and mutation in genetic algorithm, in PSO the particles in the solution space follow the optimal particle to search. Compared with genetic algorithm, the advantage of PSO is simple and easy to implement, and it doesn't have many parameters to adjust. PSO has been widely used in function optimization.

A group is composed of m particles fly at a certain speed in d dimension search space. During search time, each particle considers both its own best point and the best point of the entire group in search history to update location and speed. The location of particle i is $x_i = (x_{i1}, x_{i2}, \ldots, x_{id})$, its speed is $v_i = (v_{i1}, v_{i2}, \ldots, v_{id})$, the best point in its search history is $p_i = (p_{i1}, p_{i2}, \ldots, p_{id}), 1 \leq i \leq m$, the best point of all the particles in their search history is $p_g = (p_{g1}, p_{g2}, \ldots, p_{gd})$. Generally speaking, the particle's position and speed belong to continuous real number, each particle's position and speed update according to the formulas (1) and (2).

$$v_{id} = w \times v_{id} + c_1 \times rand() \times (p_{id} - x_{id}) + c_2 \times rand() \times (p_{gd} - x_{gd}) \quad (1)$$

$$x_{id} = x_{id} + v_{id} \quad (2)$$

In (1) w is called inertia weight, the value of w indicates how much the inheritance of the current speed, so appropriate value can make particles have a balanced exploration and search ability. c_1 and c_2 are called learning factors, generally $c_1 = c_2 = 2$. Learning factors make particles have self-summary and the ability to learn from excellent individuals in groups, so that the particles move towards best point of their own and the entire group in search history. Rand() is pseudo-random number uniformly distributed in [0, 1], that is $rand() \in U[0, 1]$.

The main steps of PSO are given as follows:

(i) Initialize particles size and iteration number; randomly generate initial particles.
(ii) Calculate the fitness of initial particles. Choose the individual best point and the global best point according to the particles fitness.
(iii) Update position and velocity of each particle according to the individual best point and the global best point.
(iv) During each iteration, repeat step ii, iii, until reach the limitation of iterations. The final global best point is the best routing from source node to destination node.

In these three routing algorithms, GA and PSO use fitness and ACO use pheromones to choose best solution. Fitness and pheromones are calculated with "distance" between two adjacent nodes. In our model "distance" is calculated with signal to interference plus noise ratio (SINR) between two adjacent nodes, as formula (3) shows. Q is a constant, whose value shows the influence of "distance" while calculating probability and in our model it is set to 1, A_j is the adjacent nodes collection of node j. Formula (3) demonstrates "distance" between node i and j in conditions whether node i belongs to A_j. The better channel condition is, the bigger SINR is between two nodes and therefore the shorter "distance" is.

$$d_{ij} = \begin{cases} \frac{Q}{SINR_{ij}} (i \in A_j) \\ \infty (i \notin A_j) \end{cases} \tag{3}$$

4 Network Performance Analysis

In our simulation the network coverage area is 1000 km * 1000 km, node speed is 200–300 m/s and routing updates per second. There are one control node, 10 relay nodes and 150 user nodes in the network. Using AODV routing protocol for comparison, we simulate ACO, PSO, GA and AODV routing protocols in MATLAB to analyze the average throughput of three kinds of nodes, packet loss rate, successful routing rate and the average link hop performance.

As shown in Figs. 2, 3, 4, using ACO, PSO and GA algorithm, the average throughput of three kinds of nodes is higher than that of AODV respectively. In addition, ACO and PSO are better than GA for average throughput of relay nodes.

Figure 5 shows average system packet loss rate for different routing algorithms. As seen, with GA, ACO and PSO the system packet loss rates are close and a little bit bigger than that of AODV, but using these four routing algorithms the system packet loss rates are all within 1%.

Figures 6 and 7 respectively show under different number of nodes, the rate that four algorithms successfully find routing and the average link hop of four algorithms. Apparently, the successful rates for four algorithms under different number of nodes are all very high, but GA algorithm performs poorer than the other three algorithms. As for average link hop, ACO and PSO perform exceed than GA, and AODV has the worst performance.

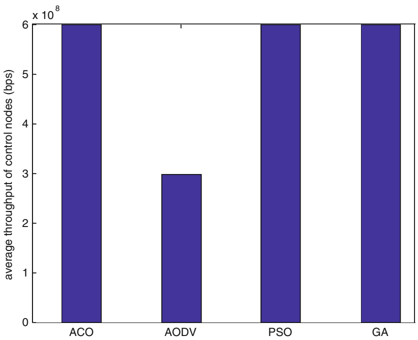

Fig. 2. Average throughput of control nodes for different routing algorithm

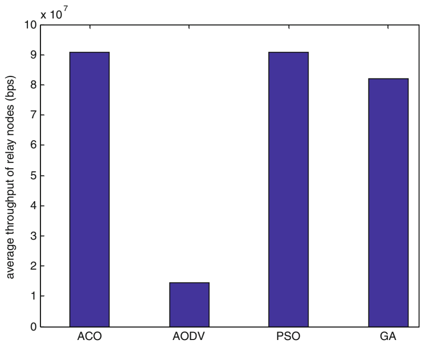

Fig. 3. Average throughput of relay nodes for different routing algorithm

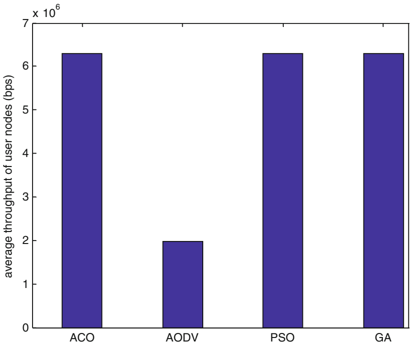

Fig. 4. Average throughput of user nodes for different routing algorithm

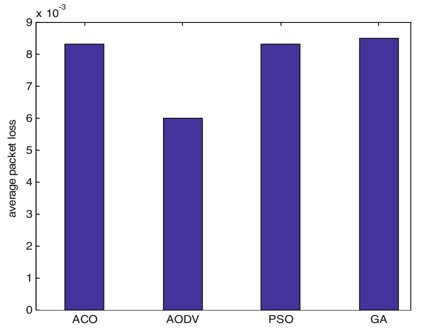

Fig. 5. Average system packet loss for different routing algorithm

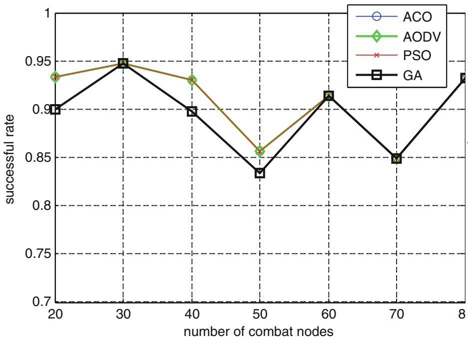

Fig. 6. Successful routing rate of different routing algorithm

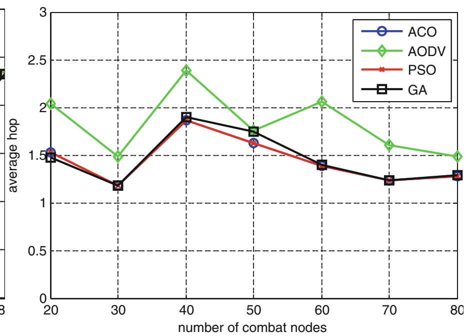

Fig. 7. Average link hop of different routing algorithm

5 Conclusion

In cluster Ad Hoc network, we set up a mobile model suitable for scenarios that have a large amount of nodes with high mobility, and demonstrate the working process of ACO, PSO and GA for routing search problem in detail. After simulating these three algorithms and comparing them with AODV algorithm, we draw a conclusion. Overall, performance of ACO and PSO exceeds GA and all of the intelligent algorithms simulated perform better than AODV. As few papers give performance comparison among intelligent algorithms in Ad Hoc network routing problems, work of this paper can provide theoretical basis for the practical application of cluster Ad Hoc networks in the future.

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