International Journal of Future Generation Communication and Networking
Vol. 9, No. 2 (2016), pp. 19-28
http://dx.doi.org/10.14257/ijfgcn.2016.9.2.03

Multicast Routing Algorithm of Network Lifetime

Cai Jingying

Institute of Engineering, Mudanjiang Normal University
Mudanjiang 157011, China
cjydong1218@163.com

Abstract

MaxNLMRGA (Max Network-Lifetime Multicast Routing Algorithm based on Genetic algorithm) for the NLMR (Network-Lifetime Multicast Routing) problem was presented. The genetic operators of this algorithm reduce the transmission cost and energy consumption of multicast trees, and mutation operator prolongs the network lifetime, thus accelerating the convergence speed of the algorithm. Experiment results show that the multicast tree found by this algorithm not only has the minimum transmission cost, but also has the longest network lifetime. Furthermore, this algorithm converges quickly.

Keywords: *Wireless Ad Hoc network, QoS routing, Multicast, Genetic algorithm*

1. Introduction

In Ad Hoc network, many practical applications not only require less energy consumption and also consider how to prolong network lifetime. Besides, reducing multicast transmitting cost [1-2]. Network resource occupation and transmission hop is very important to Ad Hoc network. At present, in Ad Hoc network, plenty of researches have concerned about how to extend network life cycle [3]. Although such work didn't mention how to decline transmission cost, they're valuably referential to the study on maximum network lifespan minimum cost multicast routing.

In the paper, we discuss maximal network lifetime minimum cost multicast routing problem in Ad Hoc and define it. On that basis, we propose a new genetic algorithm to solve aforesaid question, which is network lifetime multicast routing algorithm (i.e. *NLMR*). Maximum network lifetime minimum cost multicast tree ensures:

(1) the longest lifetime of multicast tree's bottleneck nodes once multicast tasks are completed;

(2) the least total transmission cost of multicast tree: in the meantime of multicast tasks being completed, transmission cost reduced and remaining energy of multicast tree' bottleneck nodes growing, hence the network lifetime is prolonged; in Ad Hoc network, if the application requires not merely optimizing transmission cost and lengthening network working time, such as disaster relief and sensor network, it's advisable to utilize max. NLMCMR for multicast communication, which decreases transmission expenses and extends network service time.

2 Problem Presentation

2.1 Creation of Network Model

Suppose one wireless Ad Hoc network with N nodes. Each node has unique identifier i, $1 \le i \le N$ and network connectivity depends on the transmission power of each node. In the network, each node can adjust dynamically their sent energy. When one node joins in

ISSN: 2233-7857 IJFGCN

several multicast tasks, it can choose different emitted energy for varied multicast trees as to transfer data packets.

To simplify, we assume here all data packets of the same size. Suppose network topology is changeable, but it's not changing frequently to the extent where routing computation becomes invalid. Precisely, suppose there is at least one stable period after topological change. Also assume all nodes in wireless Ad Hoc network using omnidirectional antenna. Compared with wired network, wireless Ad Hoc network has the advantage of wireless multicasting [4-6], i.e. when one node sends one packet, all nodes in its transmitting power coverage area can receive the packet. Besides, each node i has two coverage areas, which are:

(1) Control coverage area, credited as CR_i

(2) Data coverage area, credited as DR_i

Control coverage area and data coverage area are dependent separately on the emitted energy by node is used for sending control packet and data packet.

2. 2 Establishment of Network Lifetime Model

In order to make effective use of energy of nodes in Ad Hoc network, when choosing path, we need consider energy dissipation and rest energy as well [7-8]. If paths are often chosen which consume the minimal energy, nodes on them will use up energy very soon, thus network connectivity becomes damaged and even is interrupted, impossible for communications subsequently. Therefore when choosing a path, we should avoid nodes with less remaining energy, as to prolong network lifetime. After multicast tasks are finished, residual energy of nodes on multicast tree will affect network lifespan. After such tasks are over, it would be much better if nodes with least energy have more remaining energy.

If node VI has more energy and consumes less energy when transmitting a data packet on multicast tree T, it will have more remaining energy after multicast tasks are finished. After multicast tasks are completed, the remaining energy of node $v_i (v_i \in T)$ is:

$$RE_i = R_i - c_i^T \qquad (1)$$

To simplify the problem, it is assumed that multicast sends only one data packet. When multicast sends k data packets, the residual energy of node v_i is expressed as:

$$RE_i = R_i - k.c_i^T \qquad (2)$$

So, the lifetime network is defined as:

$$NL(T) = \min_{\forall v_i \in T}\{RE_i\} = \min_{\forall v_i \in T}\{R_i - c_i^T\} \qquad (3)$$

2.3Network Lifetime Minimum Cost Multicast Routing Problem

Definition: network lifetime multicast routing, NLMR in short. For a given wireless Ad Hoc network $G(V,E)$, $s \in V$ means multicast source node; D is collection of all multicast destination nodes $(D \subset V - \{s\})$. NLMCMR is designed to find out one multicast tree T(s, D) which suffices the following conditions:

(1)The root node of $T(s, D)$ locates on node s; all destination nodes are leaf nodes of $T(s, D)$;

(2)Network lifetime $NL(T)$ is maximum;

(3)Transmission $\cos t(T)$ is minimal: transmission cost can be one function of hops, communication expenditure, mean queue length, delay and other factors; here we define cost function as:

$$\cos t(T) = \sum_{(i,j)\in T} d_{i,j} \qquad (4)$$

3 Max Network-Lifetime Multicast Routing Algorithm based on Genetic algorithm (MaxNLMRGA)

Figure 1 shows MaxNLMRGA flowchart. Figure2 shows MaxNLMRGA method. Its input is Ad Hoc network topology G, source node s and destination nodes' collection D. Chromosome (i) refers to individual i in the current population; MSTSelect() is selection operator; T_a, T_b and T_c are individuals; rand() is a function, generating randomly figure in [0,1]; Crossover() and Mutation() is respectively crossover operator and mutation operator; N_p is population size. N_g is size of population. $N_{optimal}$ is number of optimal individuals, p_c is cross probability and p_m is mutation probability. RandomDFS() is random depth first search algorithm.

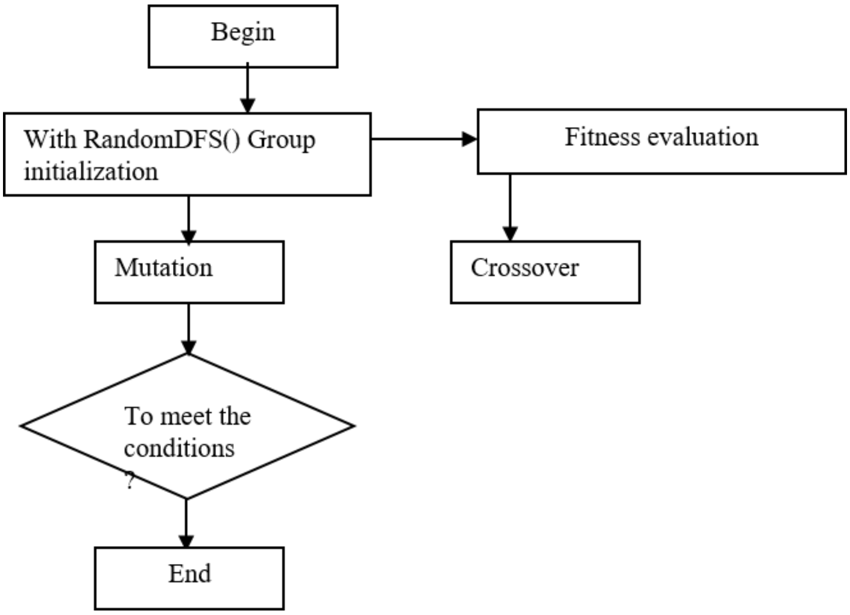

Figure 1. Flowchart of Maxnlmrga

MaxNLMRGA algorithm

Input: G, S,D
Output: multicast tree T
Begin
1 for (i=1; i<= N_p ; i++) {
2Chromosome(i) = RandomDFS(G, s, D)； }
3for (j=1; j<= N_g ; j++) {

```
4for (k=1; k<= N_p - N_optimal l; k++)
5 T_a =MSTSelect ();
6 T_b = MSTSelect ();
7 if (rand() < p_c )
8 T_c =Crossover(T_a , T_b )
9 else
10 T_c =T_a or T_b ;
11 if (rand() < p_m )
12 Mutation(T_c )}}
End
```

Figure 2. Pseudo Code of Maxnlmrga

3.1. Encoding

Use multicast trees to describe chromosomes in the genetic space. That omits encoding and decoding operation in GA process and simplifies genetic algorithm.

3.2. Population Initialization

In initializing the population, it's necessary to consider two questions:

(1) Population scale, marked as N_p ;

(2) The method for producing each individual in the population

N_p needs appropriate selection. If it's too small, the genetic algorithm will search out local optimal solution; if it's too big, the genetic algorithm will work inefficiently. When the algorithm is designed well, N_p can be set a proper value by pre-testing.

In the proposed algorithm, population initialization is based on depth first search algorithm DFS. DFS starts with source node s searching its neighboring nodes.

3.3 Fitness Function

MaxNLMRGA's purpose is to extend network lifetime and diminish transmission cost. So the fitness function is put as:

$$f(T) = \frac{a}{\cos t(T)} NL(T) \qquad (5)$$

3.4 Selective Operator

MaxNLMRGA algorithm, it adopts elitist model as selective operator. With the selection model, we can pick up the best individuals (ones with highest fitness, about N_{best} of them) and reproduce them directly to the next population. Then, from the rest individuals in the current population, we choose by roulette mechanism father individuals for crossover operation. Individual i is chosen at the probability $f(T_i)$:

$$p(T_i) = \frac{f(T_i)}{\sum_{j=1}^{N_p} f(T_j)} \qquad (6)$$

3.5 Crossover Operator

By roulette mechanism, we choose one pair of individuals as parent. Crossover operator performs crossover operation according to crossover probability p_c, in order to produce one offspring individual. Use T_a and T_b to represent the pair of parent individuals; T_c means offspring individual cross-produced by T_a and T_b. Crossover operator inherits links and multicast groups (i.e. source nodes and all destination nodes) shared by T_a and T_b to offspring individual T_c. According to the definition of fitness function and selection operator, better individuals (with higher fitness) are more possibly chosen as parent individuals. Therefore, links shared by parent individuals suggest more probably "good" character or nature of individuals. Handing down multicast groups to offspring individual T_c is to guarantee all multicast group members included in new individuals. However, shared links and multicast groups inherited to offspring individuals will result in some separate sub-trees in T_c. So it's required to choose some links with which those separate trees connect to one legal multicast tree. It is shown in figure3.

```
MaxNLMRGA Crossover operator algorithm
Input: T_a , T_b
Output: T_c
Begin
1 T_c ← null
2 T_c ← (T_a ∩ T_b) ∪ s ∪ D
3While There are more than 1 sub-tree in T_c do
4 Output T_c
End
```

Figure 3. Pseudocode of MaxNLMRGA Crossover

3.6 Mutation Operator

One aim of NLMR problem is to lengthen network lifespan. So MaxNLMRGA gives a new mutation operator. Network lifetime is shortly $NL(T) = \min_{\forall i \in T}\{RE_i\} = \min_{\forall i \in T}\{R_i - c_i^T\}$, where, $RE_i = R_i - c_i^T$ is remaining energy of node $v_i (i \in T)$; c_i^T is energy consumed by node v_i transmitting one data packet.

In NLMR problem, the node with least left energy on multicast tree T is called bottleneck node, labeled as x.

From the definition of network lifetime, we know that NL is dependent on bottleneck node x's remaining power. Since node's residual power is affected by c_x^T, mutation operator can make shorter the longest distance between x and sub nodes by adjusting its sub nodes, so as to prolong NL.

4. Comparison with other Algorithms

Here we compare MaxNLMRGA with two other multicast routing algorithms with best effects. They are Haghighat's GA (HGA) [9] and Yen's GA (YGA) [10].

4.1 Coding Way

HGA adopts Prüfer number coding way. This way has bad location inheritance. In the procedure of inheritance, illegal multicast trees will be produced, requiring examination and restoration.

YGA adopts ST encoding way. This method can lead to illegal multicast trees and routing loop during inheritance, requiring examination and restoration.

MaxNLMRGA uses tree-like coding method, using multicast tree to represent individuals. Tree-like encoding mechanism omits encoding and decoding in the genetic process, simplifying genetic algorithms. This encoding mechanism overcomes the weakness of Prüfer number coding way. Based on tree-like encoding way, we design properly crossover operator and mutation operator, avoiding the production of illegal individuals and routing loops in inheritance. Thus, no need of additional check-out and restoration simplifies the genetic algorithm.

4.2 Selection Model

HGA and YGA adopt roulette selection model. This model may eliminate the best solution in the genetic process, making convergence speed down or not converge.

MaxNLMRGA adopts elitist method and roulette selection model to complete the selective process. Prior to crossover and mutation operation, we need to reproduce directly the best individuals in current population to the next generation, to guarantee the optimal units of one generation not damaged; then, use roulette model to choose father individuals for crossover operation, making individuals with higher fitness inherit more possibly their excellent features to the next generation and making the genetic algorithm converge to the optimal solution.

4.3 Crossover Operator

HGA has bad location inheritance in crossover process. Father individuals' good natures are hardly passed down to the next generation. And in the process, it will cause infeasible solution.

In crossover process, YGA will produce routing loop and infeasible solutions.

MaxNLMRGA's crossover operator overcomes the weakness of HGA. Father individuals' good characters can bring down to the next generation by their shared links. Also in crossover operation, MAXNLMRGA won't produce routing ring and unlawful individuals. Hence, it requires no extra examination and restoration. MaxNLMRGA takes into account delay and distance, promoting the convergence speed of GA.

4.4 Mutation Operator

In the mutation operation, YGA and HGA introduce new individuals to the population, making GA not fall into local optimal solution.

Comparatively, MaxNLMRGA introduces not only new individuals, avoid falling into local optimal solution; and also considers delay and distance, optimizing delay and energy consumption and increasing convergence speed of GA.

5 Experiment Design and Discussion

5.1 The Experimental Setup

The proposed algorithm is realized with the use of MS VC++ 6.0, together with Genetic Algorithmlib (GAlib) [11]. GAlib is one GA C++ library. The experiment environment is one PC with Pentium dual core 2.5GHz CPU (2GB RAM). To make HGA and YGA applicable for *Network-Lifetime Multicast Routing* problem, in the implementation of HGA algorithm, we don't consider bandwidth inhibition, i.e. in our tested network, we think these networks satisfy the bandwidth inhibition.

Simulation tests are carried out in different random networks, whose size covers 20-100 nodes. Since the current Ad Hoc network is mainly used in small to medium scenarios like military field, disaster rescue, mobile conferencing, which have tens of nodes, so tests on network with 20-100 nodes have practical meanings. For networks with specific scale (fixed number of nodes), nodes are randomly distributed. Each node lies in at least one-node control coverage area, i.e. network is connected. Link delay is evenly distributed in [0, 50]; link distance evenly in [10, 200]. Each routing request includes three parameters: source node s, all destination node collection D and maximum delay δ. regarding each routing request, the three parameters are randomly generated. The maximum delay δ is evenly distributed in [30, 160].

For one network with specific size, experimental results are acquired based on 1000 randomly generated networks, of which 10000 routing requests are produced in each network. In the experiment, other parameters set as follows: in energy consumption model, parameter k=1, $E_0 = 1$, $\beta = 2$. Through prior implementation tests, we find MaxNLMRGA performs well when p_c =1, p_m =0.05, N_p =15. All algorithms end after 5000 individuals are produced.

5.2 Performance Evaluation Indicators of Algorithms

We tested algorithms' performance from three aspects: Transmission cost ratio,Network lifetime ratio and running time. Routing SR describes whether the multicast tree found by the algorithm meets delay constrained condition; energy cost ratio describes the energy consumption of multicast tree found by the algorithm; running time involves with the algorithm's convergence speed.

5.2.1 Transmission Cost Ratio

For a given network legend and routing request, the energy consumption of multicast tree constructed by the algorithm i is put as $\cos t_i$. As currently no algorithm can find the least energy consumption of delay constrained least energy consumption multicast tree, Transmission cost ratio is employed instead**.** Transmission cost ratio is defined like:

$$\textbf{Transmission cost ratio} = \frac{\cos t_i}{\min\{\cos t_{HGA}, \cos t_{YGA}, \cos t_{\mathrm{MaxNLMRGA}}} \qquad (7)$$

5.2.2 Network Lifetime Ratio

For a given network legend and routing request, the energy consumption of multicast tree constructed by the algorithm i is put as NL_i . As currently no algorithm can find the least energy consumption of delay constrained least energy consumption multicast tree, Transmission cost ratio is employed instead**. Network lifetime ratio** is defined like:

$$\text{Network lifetime ratio algorithm i} = \frac{NL_i}{\min\{NL_{HGA}, NL_{YGA}, NL_{\mathrm{MaxNLMRGA}}\}} \qquad (8)$$

5.2.3 Running Time

In the search process of GA, it refers to the time consumed during population evolving to a stable state. Shorter running time means less time used by GA for evolving to stable state (search the best solution) and quicker convergence speed.

5.3 Transmission Cost Ratio Comparison

Figure 4-5 compares the transmission cost when multicast group nodes are 20% and 30% of total network nodes. It's observed that MaxNLMRGA reaches the minimal transmission cost, very close to 1. HGA and YGA have bigger costs than MaxNLMRGA. Experimental results suggest that compared with HGA and YGA, the transmission cost of multicast trees constructed by MaxNLMRGA is the fewest, because it considers different factors during crossover and mutation operation.

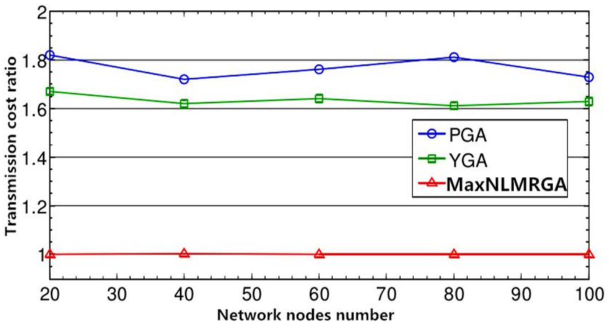

Figure 4. Comparison of Cost (Multicast Group Size: 20% Network Nodes)

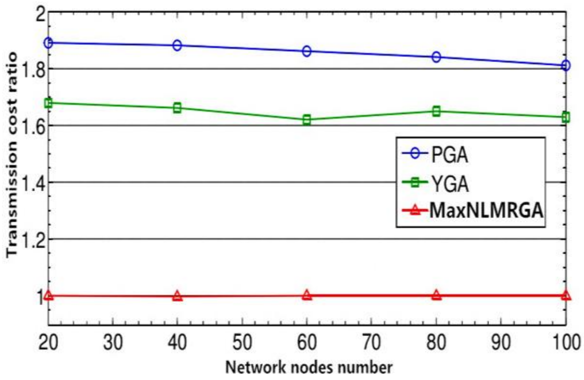

Figure 5. Comparison of Cost (Multicast Group Size: 30% Network Nodes)

5.4 Network Lifetime Ratio Comparison

Figure 6-7compares network lifetime when multicast group nodes take 20% and 30% of total network nodes.

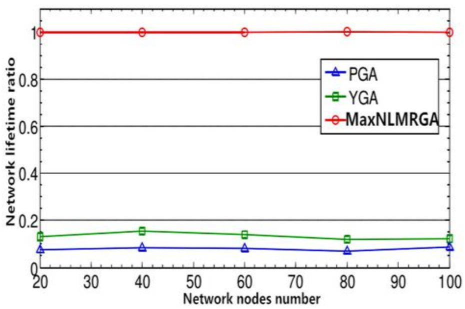

Figure 6. Comparison of Network Lifetime (Multicast Group Size: 20% Network Nodes)

From the pictures, MaxNLMRGA realizes longest lifespan, approximating 1. The other two methods' lifetime is shorter than MaxNLMRGA. Experiments prove that compared with HGA and YGA, network lifetime of multicast trees created by MaxNLMRGA is the longest, for it considers distance in crossover and mutation operation; also it improves network lifetime in mutation operation.

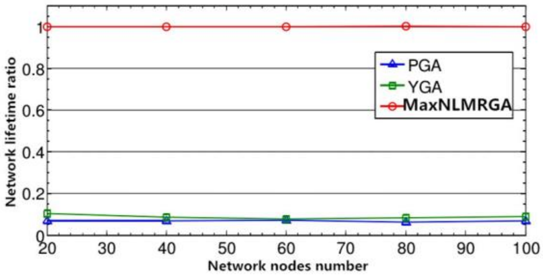

Figure 7. Comparison of Network Lifetime (Multicast Group Size: 30% Network Nodes)

5.5 Running Time Comparison

Figure 8 presents running time results when multicast group's node number is 20-30% of network nodes. From Figure 8, we see MaxNLMRGA runs the shortest time; also its running time grows slowly with aggrandizing network size. HGA and YGA run longer than MaxNLMRGA. When network scale is over 40 nodes, HGA and YGA's running time increases rapidly. Experimental results confirm that MaxNLMRGA runs the shortest time of them three GAs. The shorter time the algorithm takes to tend to be stable (find the optimal solution), the quicker the convergence speed becomes.

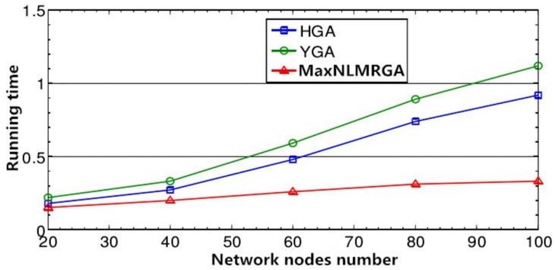

Figure 8. Comparison of Running Time (Multicast Group Size: 20%-30% Network Nodes)

6. Conclusion

To solve the problem of Network-Lifetime Multicast Routing proposed a new crossover operator and mutation operator. In the crossover operator and mutation operator consider the delay and distance, can reduce the group multicast tree delay and energy consumption, accelerate the speed of convergence of the MaxNLMRGA. Experimental results show that MRAGA algorithm to construct a multicast tree not only satisfies the delay constraints, and multicast tree energy consumption is the most minimal, and the convergence speed MaxNLMRGA algorithm is fastest.

Acknowledgement

This work was supported by Heilongjiang province innovation project. No.SY2014001

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Author

Cai Jingying, She is an associate professor at Institute of Engineering of Mudanjiang Normal University. She is in the research of data mining.

