An Improved Genetic Algorithm for Cost-Delay-Jitter QoS Multicast Routing

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Abstract

In this paper, an improved genetic algorithm is presented to solve the multicast routing problem, which is known as NP-complete problem. The contribution of this work includes: (1) the adaptive niche technique and new migration rules are designed to improve the performance of genetic algorithm. (2) In order to fulfill the adaptability of the basic operators of genetic algorithm, the artificial immune system is involved to dynamically control the crossover operator and the mutation operator. (3) A tree encoding based on the theory of generating the spanning tree is proposed to map the solution space of the multicast tree of QoS multicast routing problem, which basic definitions and axioms of the topology are described especially the character of spanning tree and the nature of the cut edge and cut set of a tree. Experiment result shows that this improved genetic algorithm has higher accuracy and performance than traditional methods.

Key words: genetic algorithm, QoS multicast routing, tree encoding.

1. Introduction

With the expansion of the scale of the Internet, the quantity of the real time transactions over the Internet is increasing gradually. Since the real-time transaction is sensitive to the characteristic of the Internet such as delay, jitter of delay, bandwidth and cost, when some paroxysmal transactions are transmitted through the Internet such as FTP, HTTP service, network video meetings and remote learning etc, the quality of the real time transaction would be influenced. Quality of Service (QoS) will guarantee the communication quality of the real-time transactions over the Internet.

The emergence of the real-time transaction brings great changes to the character and requirement of the network service and the scale of the multicast group [12]. To meet such a requirement, multicasting tree should be involved to fulfill multicast. Multicast tree is a spanning tree that covers all of the members of the multicast group. There are two advantages for multicast tree: firstly the information is parallel sent to the members of the group along the branches, by which the delay is reduced; secondly the information ready to be replicated at the nodes is reduced as well.

Usually there are two kinds of multicast tree, source tree [9] and share tree [10]. The source tree is a simple directed tree with a specific root. The share tree is an undirected tree without root. For multicast routing, a share tree covers the sources and destinations of the network without pointing out the root of the tree. Every source node of the network could be regarded as the root of the share tree, which will serve as a source tree and make available multicast.

Hence the QoS multicast routing problem is to locate a share tree of topological structure of the network considering the minimization of cost, delay, jitter of delay and the constraint of the delay and jitter. This is known as NP-Complete [7] problem.

In this paper an improved Genetic Algorithm is presented to solve the multi- objective optimization problem. Firstly, the Niche technique is utilized. [8] are some relative works Traditional GA for searching the solution of multi-peak-value function[15] is apt to obtain local optimal solution. But with the help of niche the global optimal solution would be found. Secondly migration rules are introduced. [13][14][15] all apply the conception of migration. Our migration rules is designed for colony whose size is not constant. There are two types of basic operations: immigrate and emigrate. Actually the migration rules provide an approach for communication among colonies and offer a competitive mechanism. Migration rule is significant for GA in that the dynamic-scale niche with such competitive factor will accelerate the rate of convergence. Thirdly, immune system is involved. Immune system will produce various antigens that guarantee the variety of the individuals and prevent the result of evolution from getting into local optimization, And the metabolism mechanism of the immune system maintains the balance of the whole colony by inhibition and activation among antigens. Analogously the improved GA utilizes the metabolism mechanism

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to enhance the ability of local search according to the density of individuals in the whole colony.

Finally, the most significant contribution of our improved generic algorithm is that we here present coding method based on the construction rule of the spanning tree along with the crossover operator and mutation operator based on the topological characteristic of the spanning tree according to several definitions and axioms which will be introduced later.

The paper is organized as follows: The mathematic model and network model of QoS multicast routing problem are described in Section2. In Section 3 we gives the improved generic algorithm and its implementation, In Section 4, a tree based chromosome is introduced, In Section 5 with experiment results, the improved generic algorithm is compared with the traditional generic algorithm.

2. QOS Multicast routing problem

2.1. Mathematic model

Let the network G＝(V,E,W(P)),V is the set vertexes which represent the routes or sub-networks. E is the set of edges, which represent the links of the network. The weight of the edges W(P) represents the cost and delay of the link. Given a set of source nodes $S \subseteq V$, a set of destination nodes $D \subseteq V$, for $\forall s \in S$, a minimized multicast tree $T \subseteq G$ under the QoS constraint, and T covers S and D, i.e. $S \cup D \subseteq V_T$.

Multicast Routing Multi-Objective Constraint Model (MOCM) is as follows.

$$\begin{cases} \min_{T \subseteq G} f_{\cos t} = \sum_{e \in E_T} Cost(e) \\ Delay(s,d) = \sum_{e \in Path[s,d]} delay(e) \\ \min_{T \subseteq G} f_{delay} = \sum_{s \in S} \sum_{d \in D} Delay(s,d) \\ \sum_{s \in S} \sum_{d \in D} Delay(s,d) \le \Delta \\ Jitter(s,d_1,d_2) = \left| Delay(s,d_1) - Delay(s,d_2) \right| \\ \sum_{s \in S} \sum_{d_1 \in D} \sum_{d_2 \in D} jitter(s,d_1,d_2) \le \tau \\ \min_{T \subseteq G} f_{distort} = \sum_{s \in S} \sum_{d_1 \in D} \sum_{d_2 \in D} jitter(s,d_1,d_2) \end{cases}$$

where T is a sub-tree of G, Path[s, d] is a unique shortest path from s to d; Cost(e) is the cost of e, delay(e) is the delay of e, Delay(s, d) is the total delay of all nodes along the path[s, d], $Jitter(s,d_1,d_2)$ is the delay jitter between two paths: s→ d_1 and s→ d_2. Δ and τ are allowable delay and allowable delay jitter. The delay and delay jitter are both regarded as objective. By introducing factors to every objective, the MOCM can be converted to a single objective programming problem:

Single Objective Programming Model (SOPM):

$$\begin{cases} \min_{T \subseteq G} g = \lambda_{\cos t} f_{\cos t} + \lambda_{delay} f_{delay} + \lambda_{distort} f_{distort} \\ f_{delay} \le \Delta \wedge f_{distort} \le \tau \end{cases}$$

Further, by involving punishment factors the SOPM equates to a single objective non-constraint problem (SONC):

$$\min_{T \subseteq G} g = \lambda_{\cos t} f_{\cos t} + \lambda_{delay} P_{delay}(f_{delay}) + \lambda_{distort} P_{distort}(f_{distort})$$

where the punishment functions are expected to reduce g intensively while the delay or delay jitter overflows. The design of punishment function (PF) is:

$$P_{delay}(f_{delay}) = \begin{cases} (1+\alpha)^{f_{delay}}, (f_{delay} > \Delta) \\ f_{delay}, (f_{delay} \le \Delta) \end{cases}$$

$$P_{distort}(f_{distort}) = \begin{cases} (1+\beta)^{f_{distort}}, (f_{distort} > \tau) \\ f_{delay}, (f_{distort} \le \tau) \end{cases}$$

Finally the simultaneous equation of SONC and PF is the ultimate model.

2.2. Simulation parameter

The simulation of network adopts the Wasman's method [17], i.e., any edge between i and j is produced randomly according to the distance:

$$P_{i,j} = \beta e^{\frac{-d(i,j)}{\alpha L}}$$

The cost and delay of the edge are defined as follow.

$$\cos t(i,j) = \begin{cases} d(i,j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}, if((i,j) \in E) \\ \infty, if((i,j) \notin E) \end{cases}$$

$$delay(i,j) = \begin{cases} \zeta * d(i,j), if((i,j) \in E) \\ \infty, if((i,j) \notin E) \end{cases}$$

ζ is a random number ranged from 0 to 1.

By adjusting α and β, we make sure the possibility of existence of short edges is higher than that of long edges and the average degree of nodes ranges from 4 to 6.

In this paper an ATM network of 20 terminals covering 4000m*2000m area is simulated. Hereinto α=0.5，β=0.8，$\zeta = 0.2$. Assuming that the topology produced is a complete graph G(V, E, W), if W(cost, delay)=(∝,∝), the weight of edge is replaced by a very large number, in addition, the source nodes set and the destination nodes set are produced randomly and the total number of source nodes and destination nodes take up 25% of the nodes of the network..

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3. Design of improved generic algorithm

The improved generic algorithm CGA includes three parts, i.e. niche, migration, immunity and encoding.

3.1. Niche

CGA adopts isolated niches based on dynamic scale: every colony evolves separately and has the same quantity of individuals when initialized. The average fitness (avgFit) of each single colony serves as the criterion of evaluation. There are two types of competition among colonies: firstly the colonies compete for copulatory pool, which determines the size of the next generation of a certain colony:

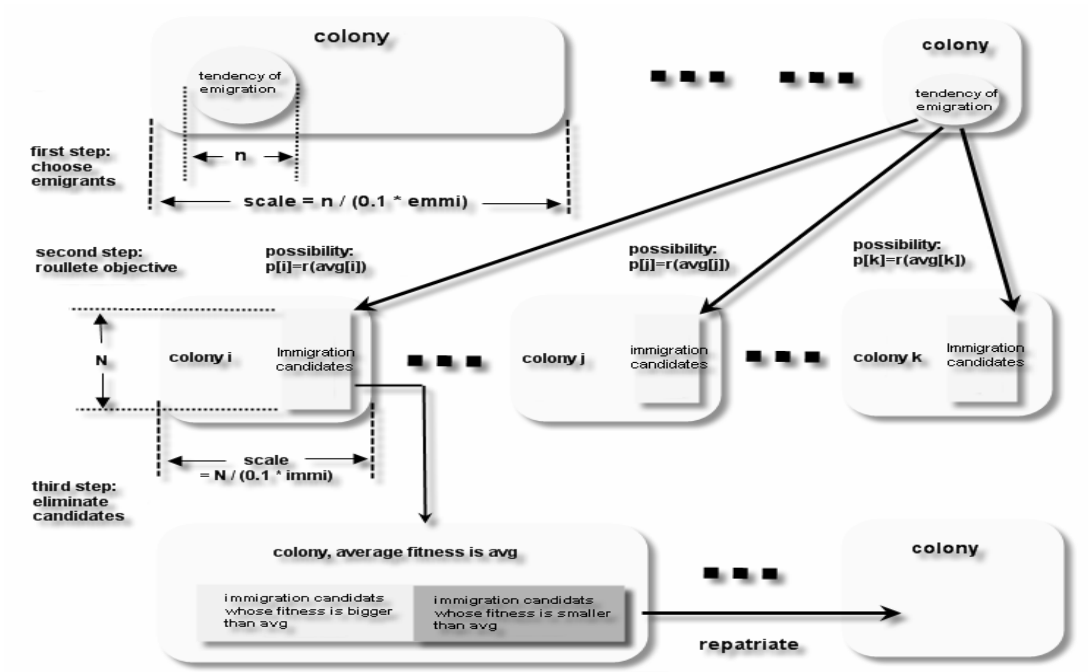

Figure 1. Migration mechanism

The evolution factor is defined as follows.

$$k = \frac{avgFit + \max - 2*\min}{avg + \max - 2*\min}$$

max and min is the maximal and minimal average fitness of all colonies, avg is the average fitness of all individuals of one generation. The evolution factor k plays a primary role in calculating the size of copulatory pool.

Pool_size = k* α *scale

α is an influencing factor ranged from 1 to 1.3 (with the crossover rate which is approximately 0.9 the general scale of the whole generation will be relatively constant), scale is the size of the colony. Pool size is the scale of the copulatory pool of the next generation of the colony.

The second type of competition is migration:

3.2. Migration rules

Migration rule provides a competition mechanism among colonies.

The three principles are the outline of the migration rules adopted by CGA

Firstly rule of emigration:

The first step of emigration is to find out individuals who are tended to emigrate.

emmi = 0.1 / k (k is the evaluation factor that has been mentioned above)

then n(= emmi * scale) individuals of a certain colony are willing to emigrate.

The next step is to determine the destiny of each emigrant in every colony. A roulette of colonies is involved to choose the destiny of the emigrants.

Secondly, immigration rule:

immi = 0.1*k

then m(= immi * scale) emigrants are allowed by a certain colony.

Fig. 1 above shows the integral migration rule.

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3.3. Immune system

Generally speaking what CGA utilizes is inhibition and elimination of antibody. In CGA, both the crossover operator and mutation operator adopt the immune system.

Firstly CGA calculates the distance of the antigen and antibody: d=Distance (antigen, antibody), if d < alpha * L (alpha is a metabolism factor, L is the length of the antigen), then the crossover possibility is:

$$P_{crossover} = P_{crossover} - \beta$$

Then CGA calculates the immune density within the whole colony:

$$d = \frac{\sum_{i=0}^{L}\sum_{j=i}^{L}\frac{1-D(i,j)}{L}}{L*L}$$

It represents the density of similar individuals, more mutation operations should be done to guarantee the variety if d is very high:

$$P_{mutation} = d^{\lambda}$$

Adjust λ to make sure that the possibility of mutation range from 0 to 1, for CGA, the possibility of mutation is stabilized around 0.03.

3.4. The model of CGA

After every improvement is described, the architecture of the CGA can be established:

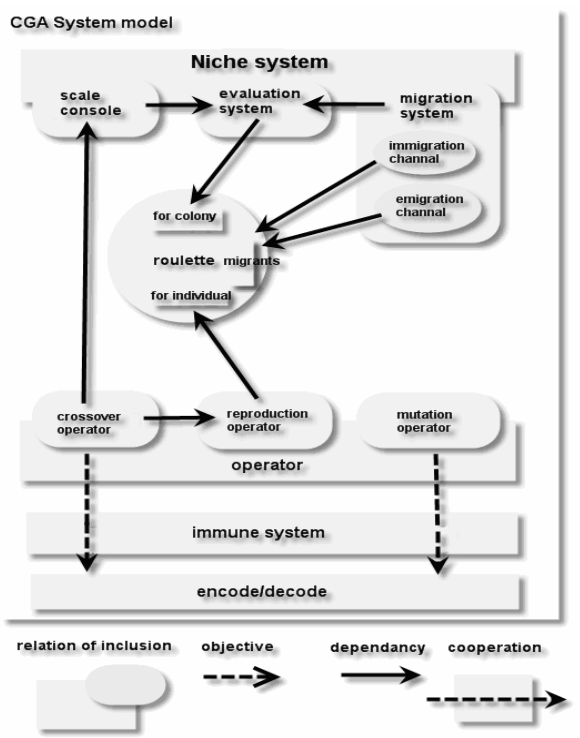

Figure 2. Architecture of CGA

4. Utilizing CGA to solve QOS multicast outing problem

Hitherto a integral architecture of CGA is well established, and the most essential for CGA to solve QoS multicast routing problem is the encoding method.

4.1. Basic definition and axioms of topology

Suppose that the readers are familiar with the fundamental definitions and characters of topology, and only a few definitions should be explained.

Definition 1: ***Cut edge***, e is one of the edges of G, if $G' = G - e$, the number of connection branches increase, i.e., then e is a cut edge of G.

Definition 2: ***Distance between trees***, assuming t1 and t2 are two spanning tree of G, there are k edges of t1 that do not belong to t2 and the distance between t1 and t2 is d(t1,t2)=k. Of course d(t2, t1)=k.

Definition 3: ***Basic transformation of tree***, Assuming t1, t2 are two trees of G, and the d(t1, t2)=1, so t1-t2=(e), t2-t1=(e). Then $t2 = t1 \oplus (e,e') = t1 - (e) + (e')$ is the basic transformation from t1 to t2.

Definition 4: ***Basic cut set***, Assuming T is a spanning tree of G, e is an edge of T, and e is an cut edge of T. Then define a edges set $S_e \subseteq E$, if $\forall s \in S_e, T_e = T \oplus (e,s)$, T_e is still a spanning tree of G, then S_e is a basic cut set of T.

Definition 5: ***The construction of spanning tree***, generally, for any spanning tree belongs to G: $t_0 = (e_1 e_2 ......e_{n-1})$, there is a $T^{e_1 e_2 ......e_k}$:

$$T^{e_1 e_2 ......e_k} = \{t_k = t_{k-1} \oplus (e_k, e_s)$$
$$| e_s \in S_{e_k} \wedge t_{k-1} \in T^{e_1 e_2 ......e_{k-1}} \wedge e_k \neq e_s, k < n\}$$

and this is the construction rule of spanning tree.

Axiom 1: For any spanning tree t of G, if t' is another spanning tree of G, then:

$$t' \in \bigcup_{k=1}^{n-1} T^{e_1 e_2 ......e_k}$$

Hitherto, the 1 axiom, along with 5 definitions are the fundamental mathematic theory of tree encoding of CGA and provide foundations for crossover operator, mutation operator.

4.2. Tree encoding

Firstly a linear tree t0 which every node is arranged one by one according to the serial number will be built up. We call t0 original tree, for example(t0->t1->…t20).

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To obtain any spanning tree within the solution space which have n^{n-2} different solutions, according to axiom 1, any spanning tree of the complete graph can be built up by a series of basic transformation of tree from original tree t0. The distance k is a random number. Fig 3 shows the procedure of construction:

According to the nature of spanning tree and cut set, the spanning tree constructed after basic transformation of tree was perfectly mapped to the whole solution space, and no invalid chromosome would be built up. The times of basic transformation of tree range from 10 to 20, so that the trees initialized would not be too close to original tree t0.

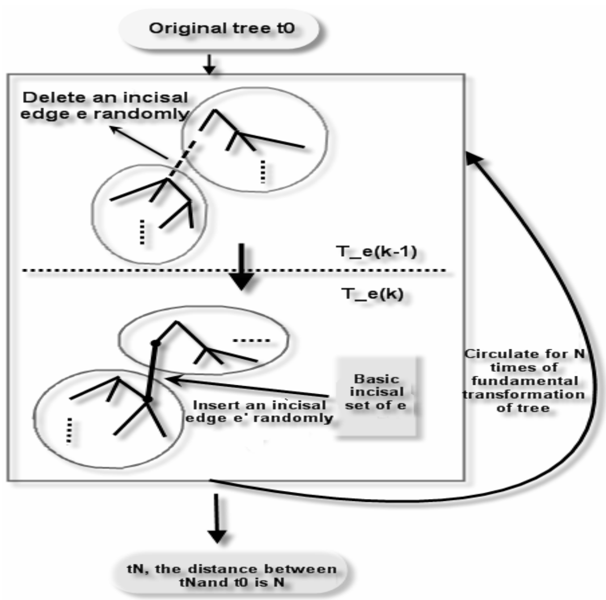


Figure 3. Initialize a tree

4.3. Crossover Operator

After initializing a tree, how does the crossover operator work? Fig 4 illustrates the principle of crossover operator.

The times of circulation k is randomly generated, such a crossover operator based on the technique of the construction of spanning tree maintains the optimal sub-structure of the father, the size of which is N-k while the other k edges is the optimal structure of the mother. And the mapping relationship will not be destroyed due to the nature of cut set of tree. Likewise no invalid solution will be generated. The mathematic language of the crossover operator is:

Assuming t_f is the gene of father, and t_m is the gene of the mother, a certain circulation of crossover operator can be represented as:

$$X^k : {t_f}^k \oplus (e, e') \mid e \in {t_f}^k \wedge e' \in (S_e({t_f}^k) \cap t_m)$$

if k=x, then the gene of the child: $t_c = X^x$.

In addition the proposition: $(S_e({t_f}^k) \cap t_m) \neq \Phi$ can be proved by reduction to absurdity according to the characteristic of spanning tree.

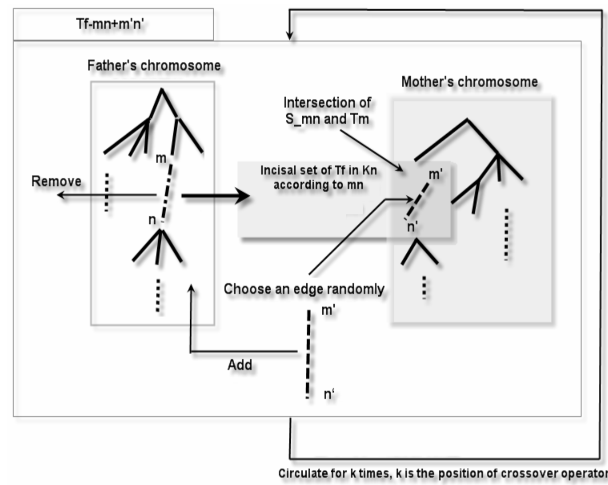


Figure 4. Crossover operator

4.4. Mutation operator

The operation mechanism of mutation operator is the same as initializing a spanning tree, however the mutation operator does not apply basic transformation of tree from a original tree instead, a random tree. And the distance between 2 trees is 1 for mutation operation rather than a random number for initializing a tree from t0.

5. Implementation and evaluation

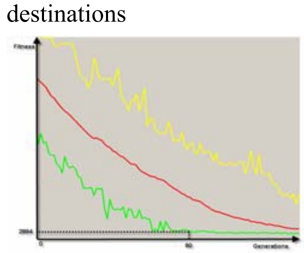
We discussed the strategy of improvement, procedure of algorithm and the technique of tree encoding, then let us see the experimental result of the CGA for QoS multicast routing:

The parameter mentioned in the model SONC and PF is:

$$\begin{cases} \alpha = 0.000065 & \beta = 0.000024 & \Delta = 200000 & \tau = 600000 \\ \lambda_1 = 0.9 & \lambda_2 = 0.08 & \lambda_3 = 0.02 \end{cases}$$

For convergency:

Case 1: 20 nodes of networks including 2 sources and 3 destinations



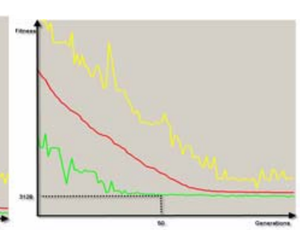


Figure 5. CGA(150 gens) Figure 6. GA(100 gens)

Case 2: 30 nodes of networks including 3 sources and 4 destinations

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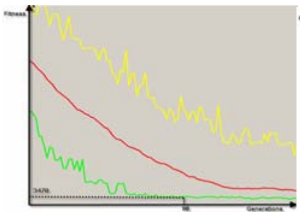

Figure 7. CGA (150 gens)

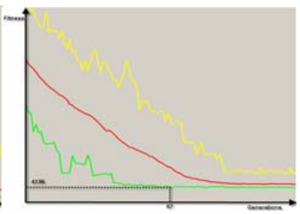

Figure 8. GA (100 gens)

From Fig. 5 to 8, the curve at the top is the maximal fitness of each generation and the curve at the bottom is the minimal fitness of each generation and the curve in the middle is the average fitness of each generation. The curve has been scaled with the program to fit the screen, so the coordinates of two separate cases are different.

The traditional GA has a relatively fast rate of convergence, and the convergence rate of CGA is moderate, however traditional GA is rapidly entrapped into a local optimal solution and converge at the 50^{th} generation, in comparison, CGA cost more evolution time to court a better solution. The main difference between the two algorithms is shown in fig 9:

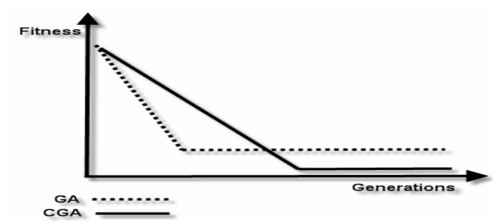

Figure 9. Comparison of GA and CGA

6. Conclusion

In this study, an improved GA called CGA was introduced to solve the cost-delay- jitter QoS multicast routing problem which is known as NP-complete problem. The niche technique, migration rule and the immune system is designed to improve the performance of the algorithm including convergence and accuracy, and a tree based encoding is put forward to map the solution space.

The operation of tree structured encoding used by CGA is very costly in that the storage structure of tree is relatively huge and the complexity of locating edges and constructing new trees is very high, the further work should be done to optimize the algorithm about topological operation such as basic tree transformation. In addition other heuristic GA should be engaged to compare with CGA.

All of the experimental result is obtained by over 2000 lines C++ code under the environment tool of Visual Studio.NET 2005 Beta 1.

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