Multicast Routing Algorithms Based on Levy Flying Particle Swarm Optimization

Chun Zhi1, jianming Cui2, liangshuai Zhu1
Guilin University of Technology, Guilin, Gaungxi, 541000, China
xzc_haha@sina.com, cjm@glut.edu.cn, liangshuai_zhu@126.com

Abstract. Aiming at the problems of bandwidth, network delay and cost in IPv6 multicast routing transmission, a particle swarm optimization multicast routing algorithm (LPSO) based on Levy flight mechanism is proposed to find the optimal path in the multicast tree. In the iteration process, the cost, bandwidth, delay and delay jitter of multicast tree are taken as indexes, and penalty function is combined to constrain the algorithm. Compared with existing multicast routing algorithms, this algorithm improves the global search and meets the requirements of QoS in multicast routing.

1. Introduction
In recent years, intelligent algorithms such as simulated annealing algorithm, particle swarm optimization algorithm and genetic algorithm have been widely used in many fields. For example, in reference[1], Li Lingyu and others applied particle swarm optimization (PSO) to urban traffic, and used dynamic particle swarm optimization (DPSO) to track vehicles, which reduced the impact of running energy consumption.

With the widespread of IPv6, IPv6 multicast technology has attracted wide attention. Multicast is the technology that the source host sends the same data packet to multiple but not all the required hosts [2]. It is a one-to-many communication between broadcast and unicast. IPv6 multicast group is identified by FF00::/8. If users want to transfer data from one node to another, they need to implement it through Sorber routing. The way of multicast routing is to find a multicast tree to satisfy the demand of QoS when the nodes transmit data to multiple nodes. The multicast tree can share a link as much as possible to reduce the actual cost. Usually the source node is called the root, the forwarding node is called the leaf, and a link is called the branch, which constitutes a multicast tree. The design of the algorithm is to find a minimal path to achieve the destination node.

Aiming at the problem of QoS in routing and transmission of IPv6 network, scholars have proposed many methods. In reference[3], a hybrid scattering search algorithm is proposed, which combines ant colony algorithm with scattering search. The results show that the search ability is improved. In reference[4], in order to enhance global convergence, simulated annealing and particle swarm optimization (PSO) are applied to Ad Hoc networks, which has a certain effect on satisfying the QoS constraints, but the algorithm has not discussed whether it is suitable for IPv6 networks.

Each IP multicast group can be identified with a Class D IP address:
2. Principle of particle swarm optimization

Particle swarm optimization (PSO) is one of the intelligent algorithms, which is based on the simulation of bird predation. The fitness function of each particle is calculated to evaluate the quality. Analyzing from the mathematical point of view is to regard each optimization problem as a "particle".

Given a d-dimensional vector \( X = (x_1, x_2, \ldots, x_n) \)

The particle position is expressed as \( x_i = (x_{i1}, x_{i2}, \ldots, x_{id}) \)

Velocity is expressed as \( v_i = (v_{i1}, v_{i2}, \ldots, v_{id}) \)

When searching, the best previous position the particle travels through is expressed as

\[
p_i = (p_{i1}, p_{i2}, \ldots, p_{id})
\]

Within the search range, the best position for all particles to pass through is expressed as

\[
p_g = (p_{g1}, p_{g2}, \ldots, p_{gd})
\]

The update speed and position formulas are as follows, respectively:

\[
v_m^{k+1} = \omega \cdot v_m^k + c_1 \cdot r_1 \cdot (p_m^k - x_m^k) + c_2 \cdot r_2 \cdot (p_g^k - x_m^k) \tag{1}
\]

\[
x_m^{k+1} = x_m^k + v_m^{k+1} \tag{2}
\]

Formula \( \omega \) is the weight coefficient, \( k \) is the number of iterations, \( c_1 \) and \( c_2 \) are the learning factor, usually take 2. \( r_1 \) and \( r_2 \) are random numbers in the range of \([0,1]\).

The basic steps of particle swarm optimization are as follows:

Step1: Initialization of particle swarm optimization and parameters.

Step2: Particle fitness is calculated according to fitness function.

Step3: The velocity and position of particles are updated according to formulas (1) and (2).

Step4: Determine whether the maximum number of iterations is reached, and if so, output the optimal results; otherwise, return to step2.

3. Levy flight mechanism

The key of Levy's flight mechanism is its variable step size, which makes the algorithm jump out of local search and enlarges the search scope. The updating formula of Levy's flight position is as follows:

\[
x_{i}^{k+1} = x_{i}^{k} + \alpha \odot \text{levy}(\lambda) \tag{3}
\]

Among them, \( \text{levy}(\lambda) \) is a random search path; \( \odot \) is a dot multiplication symbol; \( \alpha \) is a control factor; satisfying Levy distribution:

\[
\text{Levy} \sim u = t^{-\lambda}, 1 < \lambda \leq 3 \tag{4}
\]
Figure 2. Levi flight diagram

The calculation of Levy flight is very difficult, so Mantegna algorithm is used to approximate the calculation.

Step size formula:

\[ s = \frac{\mu}{|v|^\beta} \]  

(5)

Where \( \mu \) and \( v \) satisfy normal distribution:

\[ \mu \sim N(0, \delta_\mu^2) \]  

(6)

\[ v \sim N(0, \delta_v^2) \]  

(7)

\[ \delta_\mu = \left\{ \begin{array}{l}
\Gamma\left(1 + \beta\right) \times \sin \frac{\pi \beta}{2}
\left[1 + \frac{\beta - 1}{2} \times \beta \times 2^{\frac{\beta - 1}{2}}\right]^{-\frac{1}{\beta}}
\end{array} \right. \]  

(8)

Usually \( \beta \) is 1.5.

4. Particle swarm multicast routing based on levy flight

Multicast routing technology is a kind of TCP/IP network technology in IPv6. In general, the weighted undirected graph \( G(V, E) \) is used to represent the network communication model, \( V \) represents the set of all nodes, and \( E \) represents the link of communication. \( T(s, d) \) denotes the set of multicast trees, where \( s \) denotes the source node and \( d \) denotes the set of destination nodes [5].

The search of the optimal multicast tree is a process from the source node to the destination node. The fitness of each particle represents whether the path selection meets the requirement of QoS. When the requirement of QoS is satisfied, it will be regarded as a link to the destination node, otherwise, it will be discarded. Each particle in the algorithm represents a multicast tree including the source node and the destination node. The algorithm takes the cost, bandwidth, cumulative delay and delay jitter of multicast tree as indicators, and combines penalty function to constrain them. The fitness function formula is as follows:

\[ f = \frac{1}{\text{cost}(T(s, d))} \left[ \prod_{e \in M} \phi(\Omega - \text{dealy}(p(s, d))) + \prod_{e \in M} \phi(\text{bandwidth}(p(s, d)) - \delta) + \prod_{e \in M} \phi(\epsilon - \text{delay _ jitter}(p(s, d))) \right] \]  

(9)

Where \( \phi(z) \) is the penalty function, \( z \) is the particle constraint condition, when the particle
satisfies the constraint condition, its value is 1; otherwise \( r(0 < r < 1) \) is the penalty size, usually set to 0.5.

Particle swarm optimization (PSO) has some limitations in precision and global search, and it cannot achieve the goal well. Levy flight has been widely used in many fields, and can be combined with many intelligent algorithms to achieve good results. Because of the uncertainties of its step size, large jump searches occasionally occur in Levy flight mechanism, which makes the particles have the characteristics of diversity and improves the global search ability of the algorithm. Formula (3) is used to mutate the particles. The steps of particle swarm multicast routing algorithm based on Levy flight are as follows:

1. **Step1**: Initial particle swarm optimization, model, algorithm parameters;
2. **Step2**: Calculate the fitness of each particle according to formula (9), and judge the individual and all optimum values of the particle according to the fitness value;
3. **Step3**: Update the position and velocity of particles to determine whether the maximum number of iterations has been reached. If so, jump out of the iteration and step6;
4. **Step4**: The particle is mutated by Levy flight mechanism, and the fitness value of the particle is calculated again to determine the individual and all optimum values of the particle;
5. **Step5**: Update the position and velocity of particles;
6. **Step6**: Judge whether the condition is satisfied; if it is, end, output the optimal value; otherwise, return to step2 and continue the iteration. The flow chart of the algorithm is shown in Figure 3.

5. **Analysis of simulation results**

The algorithm is simulated with MATLAB, and experiments are carried out with different number of nodes, and compared with PSO algorithm and APSO algorithm. The cost diagram of different number of nodes is shown in Figure 4, and the network delay of different nodes is shown in Figure 5. Random generation algorithm is used to simulate the network topology, and the effectiveness of the algorithm is verified.
Begin

Initialization of Particle Swarm, Model, Algorithmic Parameters

Calculating particle fitness to determine individual and global optimum values of particles

Update particle position and velocity

If $T < T_{\text{max}}$

Yes

Levy Flight Variation Operations for Particles

Calculate the fitness of the particle again to determine the individual optimum value and the total optimum value.

Update particle position and velocity

No

If Termination Condition

Yes

End

Figure 3. Flow chart of LPSO algorithm

Figure 4. Expenses for different nodes

Figure 5. Network Delay of Different Nodes

The simulation results show that, for different number of data transmission between nodes, the contrast effect between the algorithms is obvious. With the increase of nodes, the LPSO algorithm performs better. The application of particle swarm optimization (PSO) based on Levy flight mechanism makes the algorithm perform better globally in data transmission, converges faster and has good robustness, which meets the requirement of multicast tree QoS.

6. Conclusions

In this paper, particle swarm optimization (PSO) is used to optimize multicast routing. Random jump search based on Levy flight mechanism is used to mutate the particles. Experiments show that the global search effect of the algorithm is well improved. The results show that the optimization ability of
this algorithm is higher than PSO, APSO and other algorithms, which reduces the consumption loss of multicast routing. At the same time, searching for good fitness function and the application of intelligent algorithm will be the next research content.

Acknowledgments
This work was supported by CERNET Innovation Project of China under Grant NGII20180512. The author thanked this.

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