Application and Research of Computer Network Multicast Algorithm Based on GA

Yafang Li

Suzhou Chien-Shiung Institute of Technology, Taicang, Jiangsu, 215411, China

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Abstract: This article focuses on the computer network multicast algorithm, aiming at improving the performance of multicast algorithm by introducing GA to meet the requirements of efficient and reliable data transmission in complex network environment. In this article, the relevant theoretical basis is first expounded, and then a computer network multicast algorithm based on GA (Genetic Algorithm) is designed. In this article, the fitness function is constructed by improved real number coding and comprehensive multi-factors, and genetic operations such as roulette wheel selection method, elite retention strategy, partial matching crossover and mutation operation are combined. The simulation environment is built by OPNET Modeler software, and the performance indexes such as network delay, bandwidth utilization and packet loss rate are set for experiments. The results show that when the number of destination nodes is 50, the network delay of the new algorithm is only 50ms, which is better than the 80ms of the traditional algorithm. Under heavy network load, the bandwidth utilization rate of the new algorithm is 70%, which is higher than that of the traditional algorithm (50%). When the network is heavily congested, the packet loss rate of the new algorithm is 8%, which is lower than that of the traditional algorithm of 15%. The research shows that GA-based multicast algorithm has obvious advantages over traditional algorithms in various performance indexes, and can better adapt to complex network environment.

1. Introduction

With the rapid development of information technology, the scale of computer network continues to expand, and network applications are increasingly diversified. The status of multicast technology in the field of computer network is becoming more and more critical [1]. Multicast, as a technology that can efficiently transmit data to multiple receivers at the same time, is widely used in many scenarios such as video conference, online live broadcast, software distribution and so on. It aims to optimize the utilization efficiency of network resources and reduce the network load [2]. When dealing with the complex and changeable network environment, the traditional multicast algorithm often exposes some defects, such as insufficient optimization ability and slow convergence speed, which can not meet the strict requirements of today's network applications for efficiency and reliability [3].

In this context, GA, with its unique global search ability, parallelism and good adaptability to complex problems, provides a new idea for the optimization of computer network multicast algorithm [4]. GA simulates the process of biological evolution, and efficiently searches in the solution space through operations such as selection, crossover and mutation to find the optimal solution [5]. Introducing GA into computer network multicast algorithm is expected to overcome the limitations of traditional algorithms and improve multicast performance [6]. This article focuses on the computer network multicast algorithm based on GA. The research aims to reveal the advantages and potential of the algorithm in the computer network environment through the design, performance analysis and practical application exploration of the algorithm, and promote the computer network multicast technology to move towards a more efficient and intelligent direction.

2. Related theoretical basis

The computer network multicast algorithm is responsible for constructing a multicast tree in the

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network and realizing efficient data transmission from the source node to multiple destination nodes. Different types of multicast algorithms, such as source-based tree algorithm and shared tree algorithm, have different strategies in constructing multicast trees to meet different network requirements [7]. However, traditional algorithms are prone to poor path selection and unreasonable resource allocation in complex networks.

GA is a search algorithm that simulates natural selection and genetic mechanism. It encodes the solution of the problem into chromosomes, and the population consists of multiple chromosomes [8]. The algorithm evaluates the advantages and disadvantages of chromosomes according to fitness function through selection operation, so that chromosomes with high fitness have more chances to be passed on to the next generation. Crossover operation exchange some genes of two chromosome to create new individuals. Mutation operation randomly changes some genes in chromosomes to maintain population diversity. GA can effectively deal with complex and nonlinear problems that are difficult to be solved by traditional optimization algorithms.

3. Design of computer network multicast algorithm based on GA

Based on the in-depth study of GA and computer network multicast technology, this article designs a computer network multicast algorithm based on GA. It aims to give full play to the advantages of GA and improve the performance of multicast algorithm. Coding is the key step to map the solution space of multicast problem to GA chromosome space. This article adopts an improved real number coding method. Traditional binary coding is too long when dealing with large-scale network nodes, which leads to low computational efficiency. However, real coding directly uses the actual network parameters, such as the coordinates of nodes and the bandwidth of links, as gene values, which greatly simplifies the coding structure [9]. Taking the location information of network nodes as an example, the two-dimensional or three-dimensional coordinates of nodes in the network topology are directly used as the genes of chromosomes, which not only intuitively and efficiently expresses the topological structure information of multicast trees.

The construction of fitness function is the core of algorithm design. Fitness function is used to evaluate the quality of multicast tree represented by each chromosome in network environment. The fitness function constructed in this article comprehensively considers many factors. On the one hand, network delay is an important index that affects multicast performance, so the maximum delay from the source node to each destination node in multicast tree is included in the fitness function calculation. Let the source node be s, the set of destination nodes be D, the multicast tree be T, and the delay from node i to node j be d_{ij}, then the maximum delay from the source node to each destination node is:

$$L_{max} = \max_{d \in D}\{ d_{sd}\} \quad (1)$$

Try to reduce this value to ensure the real-time data transmission. On the other hand, the link bandwidth utilization rate can not be ignored. By calculating the ratio of the link bandwidth occupied by the multicast tree to the total available bandwidth, the algorithm is prompted to choose the multicast tree structure with high bandwidth utilization rate. Let the total link bandwidth occupied by multicast tree T be B_{used} and the total available network bandwidth be B_{total}, then the bandwidth utilization ratio is:

$$U = \frac{B_{used}}{B_{total}} \quad (2)$$

So as to effectively improve the utilization efficiency of network resources. At the same time, in order to ensure the reliability of multicast tree, this article also considers the link stability factor. Let the stability weight of link l be w_l, and give higher weight to the link with high stability in the calculation of fitness function F. The fitness function can be expressed as:

$$F = \alpha \frac{1}{L_{max}} + \beta U + \gamma \sum_{l \in T} w_l \quad (3)$$

Where α, β, γ are weight coefficients, and $\alpha + \beta + \gamma = 1$. By adjusting these coefficients, the influence of various factors on fitness can be balanced.

The selection operation adopts the combination of roulette wheel selection method and elite retention strategy. Roulette wheel selection method determines the probability of chromosome selection according to the fitness ratio. If the population size is N and the fitness of the i chromosome is F_i, the selection probability is:

$$P_i = \frac{F_i}{\sum_{j=1}^{N} F_j} \quad (4)$$

The higher the fitness, the more likely the chromosome is to be selected, so as to simulate the survival mechanism of the fittest in natural selection. However, this method has some randomness, which may lead to the loss of the optimal individual in the evolution process. Therefore, the elite reservation strategy is introduced to directly reserve some individuals with the highest fitness in the current population to the next generation to ensure that excellent genetic information will not be lost due to genetic manipulation.

Let the population at generation t be denoted as $P(t) = \{x_1^{(t)}, x_2^{(t)}, \dots, x_N^{(t)}\}$, where $x_i^{(t)}$ represents the chromosome of the i-th individual. The evolution process of the GA is governed by the following update rules:

$$x_i^{(t+1)} = \begin{cases} Crossover(x_a^{(t)}, x_b^{(t)}), & with\ probability\ p_c \\ Mutation(x_i^{(t)}), & with\ probability\ p_m \\ x_i^{(t)}, & otherwise \end{cases} \quad (5)$$

Where p_c and p_m are the crossover and mutation probabilities, respectively, and $x_a^{(t)}, x_b^{(t)}$ are selected parents based on roulette wheel selection. The expected average fitness of the population evolves according to the schema theorem:

$$E[f^{(t+1)}] \geq f^{(t)} \left(1 + \frac{\delta}{\bar{f}^{(t)}}\right) \quad (6)$$

Where $f^{(t)}$ and $\bar{f}^{(t)}$ denote the fitness of a schema and the average population fitness at generation t, respectively, and δ represents the selection pressure. Ultimately, the algorithm converges when the variance of fitness values falls below a threshold ε:

$$\mathrm{Var}\left(f\left(x_1^{(t)}\right), \dots, f\left(x_N^{(t)}\right)\right) < \varepsilon \quad (7)$$

The crossover operation is designed as a partially matched crossover. When two parent chromosomes cross, a gene fragment on the chromosome is randomly selected first, and then the two fragments are exchanged. In the process of exchange, in order to avoid illegal multicast tree structure, partial matching is adopted, that is, the genes in the exchange segment are re-matched to make them conform to the network topology and multicast tree construction rules. The mutation operation is to make random small changes to the genes on the chromosome. For example, a node gene is randomly selected and its coordinates or link bandwidth parameters are fine-tuned, so as to introduce a new gene combination, increase the diversity of the population and avoid the algorithm falling into a local optimal solution.

4. Algorithm performance analysis and simulation experiment

In order to comprehensively and accurately evaluate the performance of GA-based computer network multicast algorithm (hereinafter referred to as "new algorithm"), a number of key performance indicators have been set. Among them, network delay reflects the time required for data transmission from the source node to the destination node, which is an important indicator to measure real-time. Bandwidth utilization reflects the utilization degree of network resources, that is, the ratio of bandwidth occupied by multicast transmission to total available bandwidth. Packet loss rate indicates the proportion of packets lost during data transmission and reflects the reliability of transmission. This simulation experiment is carried out by OPNET Modeler network simulation software. In this article, a complex network topology with 100 nodes is constructed to simulate the characteristics of uneven distribution of nodes and diversified link bandwidth in the actual network. The link bandwidth between nodes is set at random between 1 Mbps and 100 Mbps to simulate the bandwidth conditions in different network environments. Five source nodes are set, and the destination nodes are dynamically adjusted according to the experimental requirements, ranging from 10 to 50, to study the performance of the algorithm in multicast scenarios of different scales. At the same time, random noise is introduced to interfere with link transmission to simulate the noise and interference in the actual network.

Figure 1 shows the comparison of network delay between the new algorithm and the traditional multicast algorithm under different number of destination nodes.

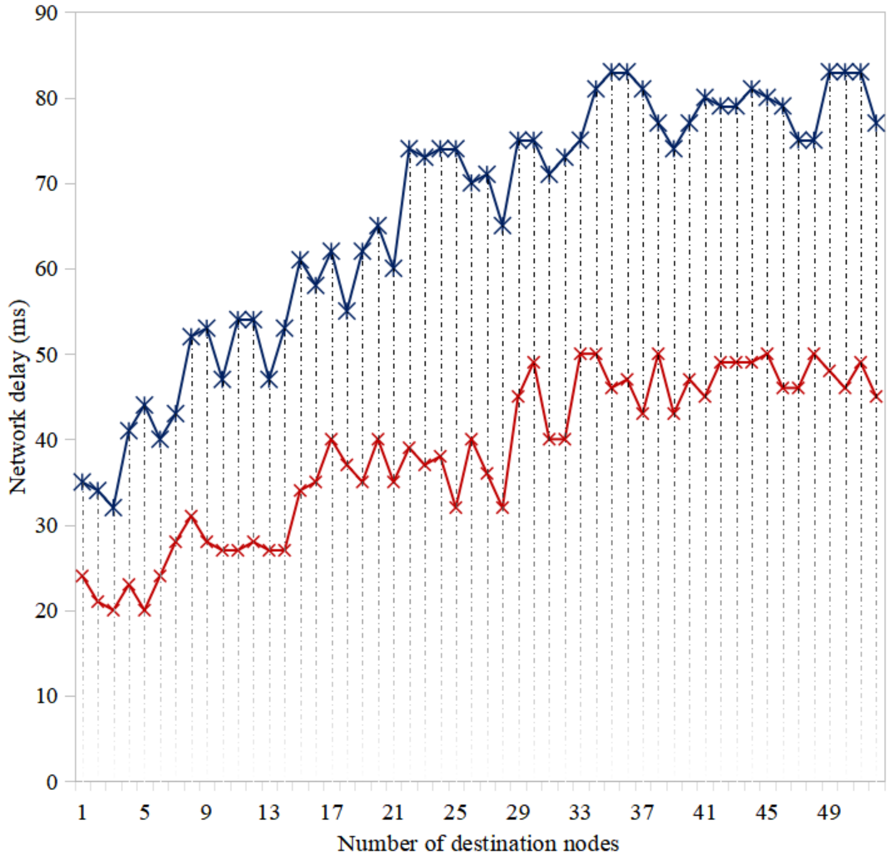

Figure 1 Comparison of network delay under different number of destination nodes

It can be clearly seen from the figure that with the increase of the number of destination nodes, the network delay of both algorithms increases. However, the new algorithm always maintains a low delay level, especially after the number of destination nodes exceeds 30, the advantages become more and more obvious. When the number of destination nodes is 50, the delay of the traditional algorithm reaches 80ms, while the new algorithm is only 50 ms. This is due to GA's optimal path selection in the process of multicast tree construction, which effectively reduces the number of hops and link delay of data transmission.

Table 1 Comparison of Bandwidth Utilization under Different Network Loads

Network Load Level	Bandwidth Utilization (Traditional Algorithm)	Bandwidth Utilization (New Algorithm)
Light	75%	85%
Moderate	65%	78%
Heavy	50%	70%

Table 1 shows the bandwidth utilization of the traditional algorithm and the new algorithm under different network loads. Under light network load, the bandwidth utilization rate of the traditional algorithm is 75%, while that of the new algorithm is as high as 85%. This shows that the new algorithm shows better resource allocation ability from the beginning and can use network bandwidth more effectively. With the network load changing from moderate to heavy, the bandwidth utilization rate of traditional algorithms drops sharply, from 65% to 50%. This is because it is difficult for traditional algorithms to allocate bandwidth resources flexibly and efficiently in the face of increasing network load, which leads to increased resource waste.

In sharp contrast, the new algorithm can still maintain 70% bandwidth utilization under heavy load. With the reasonable allocation of link bandwidth and the optimization of multicast tree structure, the new algorithm can dynamically adjust the resource allocation strategy and maximize the use of available bandwidth under complex network load conditions. This result fully shows that the new algorithm has obvious advantages in improving the utilization efficiency of network resources, and can ensure the efficient operation of the network and provide stable bandwidth support for data transmission even under the condition of heavy network load pressure.

Packet loss rate is a key index to measure the reliability of the algorithm. In the simulation experiment, with the aggravation of network congestion, the packet loss rate of the traditional algorithm increases rapidly, while the new algorithm considers the link stability factor when constructing the multicast tree, and the packet loss rate increases slowly. Table 2 shows the comparison of packet loss rates between the new algorithm and the traditional algorithm under different network congestion levels.

Table 2 Comparison of Packet Loss Rates under Different Network Congestion Levels

Network Congestion Level	Packet Loss Rate (Traditional Algorithm)	Packet Loss Rate (New Algorithm)
Level 1 (Light Congestion)	2%	1%
Level 2	4%	2.5%
Level 3	7%	4%
Level 4	11%	6%
Level 5 (Heavy Congestion)	15%	8%

With the network congestion gradually rising from level 2 to level 5, the packet loss rate of the traditional algorithm quickly climbed from 4% to 15%. When the traditional algorithm faces the aggravation of network congestion, the limitations of its coping mechanism are exposed, and it cannot effectively deal with the pressure brought by congestion, resulting in a large number of data packets being lost. In contrast, the packet loss rate of the new algorithm increased slowly from 2.5% to 8%. The new algorithm fully considers the link stability factor when constructing the multicast tree. In the process of deteriorating network congestion, it can still reduce the possibility of packet loss by optimizing transmission paths and rationally allocating bandwidth. It shows stronger reliability and stability, can better adapt to the complex and changeable network environment and ensure the quality of data transmission.

5. Conclusions

This article studies the computer network multicast algorithm, integrates GA into it, and designs a complete computer network multicast algorithm based on GA. In the simulation experiment, the new algorithm is compared with the traditional algorithm by setting the performance index strictly and building a complex network topology to simulate the actual network environment with the help of OPNET Modeler.

The experimental results clearly show that the new algorithm has excellent performance in network delay, bandwidth utilization and packet loss rate. Taking the network delay as an example, when the number of destination nodes increases, the delay of the traditional algorithm increases greatly, while the delay of the new algorithm is only 50ms when the number of destination nodes is 50, which has obvious advantages compared with the 80ms of the traditional algorithm. This reflects the optimization effect of the new algorithm in multicast tree path selection. In terms of bandwidth utilization, the new algorithm can still reach 70% under heavy load, which is much higher than the traditional algorithm's 50%, which strongly proves that the new algorithm makes efficient use of network resources. In terms of packet loss rate, with the aggravation of network congestion, the new algorithm always keeps a low level, only 8% in severe congestion, which is significantly lower than the traditional algorithm's 15%, highlighting its ability to ensure data transmission integrity in complex network environment. The computer network multicast algorithm based on GA has effectively improved the multicast performance and provided an effective way for the development of computer network multicast technology.

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