



An Orchestration Algorithm for 5G Network Slicing Based on GA-PSO Optimization

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Abstract. Network slicing is an important technology for implementing on-demand networking based on the 5G network architecture of SDN/NFV. By analyzing the main scenarios of 5G, a network slice orchestration algorithm based on GA-PSO optimization under the SDN/NFV architecture is proposed. This algorithm uses the particle swarm optimization algorithm to quickly converge on the characteristics of the global optimal solution, and design the evaluation function of network slice performance. Moreover, the ability of genetic algorithm to quickly search randomly is used to update and optimize the network slice, and the particle swarm is used to chase the local optimal solution and the global optimal solution to obtain the optimal network slice. Simulation experiment results show that the algorithm can realize the personalized creation of network slices in multi-service scenarios, give full play to the advantages of SDN's centralized control mode, and reduce network energy consumption while improving network resource utilization.

Keywords: 5G · Network slicing · Genetic algorithm-particle swarm optimization · Orchestration

1 Introduction

With the increase in the number of user terminals, the increase in the scale of traffic, and the diversification of user needs, the current core network EPC (Packet core) gradually became unable to cope with the diversified service requirements. In the 5G era, Internet service objects and application scenarios have become diversified. It is neither realistic nor efficient to construct a dedicated physical network for each service the network slicing (NS) technology can realize the transition from “one size fits all” to “one size per service”, providing a brand-new solution for the existing network [1].

The prerequisite for network slicing is that various network elements and centralized control of SDN can be virtualized [2]. With the maturity of network function virtualization (NFV) technology, software and hardware decoupling and sharing foundations are realized Facility resources and on-demand scheduling [3], while

software-defined networking (SDN) decouples the data plane from the control plane, simplifies network management and flexibly configures routing [4]. Therefore, in NFV and SDN, Under the network architecture, the orchestration and deployment of network slices becomes feasible [5].

With different requirements and performance requirements, in the NFV and SDN network architecture, the arrangement of slices will directly affect the network load, resource utilization, and energy consumption. Based on SDN technology, researchers have done a lot of research in optimizing network slice orchestration and improving resource utilization. These research methods are all based on the optimization of network resources in a data center with a relatively simple network status. They do not consider the complex requirements of application services in terms of bandwidth, delay, and reliability. Most of them are only aimed at network resource utilization or QoS.

In order to solve the above problems, a network slicing algorithm based on GA-PSO was proposed. Specifically, this paper converts the optimization of the network into the orchestration of network slices. Through statistical analysis of user traffic, we know the distribution characteristics of the entire network, pre-construct the basic slice, and then analyze the load and demand for real-time traffic analysis. Slicing and deploying the constructed result on the switching node in the form of OpenFlow protocol flow table.

2 GA-PSO Slicing Generation Algorithm

In the routing model based on network slice division, the quality of slice division directly determines the load and resource utilization of the network. Therefore, the generation of slices is very important for the network slice architecture system based on NFV/SDN. In addition, the existing slicing algorithms generally adopt greedy strategy to divide resources and select routes one by one according to the needs of the network. The lack of global optimization does not give full play to SDN's advantages of mastering global information and centralized control. And when the network load is very large, the time complexity of dividing one by one is too large to meet the real-time demand.

2.1 Particle Swarm Optimization

Particle swarm optimization (PSO) is a swarm intelligence algorithm developed by Kennedy J and Eberhart R C et al. [7] in 1995. It is a simulation of the migration and aggregation of the bird's foraging process. The community of simple individuals and the interactive behavior between individuals simulate the search for the global optimal solution. The basic PSO algorithm defines two very important parameters: in a certain generation of population, the particle with the highest fitness is called P_{BEST} ; and the global optimal solution found by the particles of all populations so far is called G_{BEST} . And save the position it finds, used to guide and update the position and speed of particles. The position $X_{ij}(t + 1)$ and speed update equations $V_{ij}(t + 1)$ are as follows:

$$V_{ij}(t+1) = w \cdot V_{ij}(t) + C_1 \text{random}(0, 1)[p_{ij} - X_{ij}(t)] + C_2 \text{random}(0, 1)[g_{ij} - X_{ij}(t)] \quad (1)$$

$$X_{ij}(t+1) = X_{ij}(t) + V_{ij}(t+1), j = 1, 2, \dots, d \quad (2)$$

Where w is the inertial weight, C_1 and C_2 are positive learning factors, and $\text{random}(0, 1)$ is the random number distributed uniformly from 0 to 1.

2.2 GA-PSO

The Basic Idea of the Algorithm. This paper draws on the ideas of hybridization and mutation in GA (genetic algorithm) [8] and applies these two ideas to slice optimization. A slicing as a subgraph represents a feasible solution, so the evolution of the population and the migration of particles are transformed into a process of subgraph hybridization.

The basic idea of the algorithm is to obtain two types of primitive particles according to the 3 main application scenarios proposed by 3GPP, and then the two types of primitive basic particles are further initialized to obtain a certain number of primitive particles to form an initial population. Each particle represents a topological subgraph, evaluate the fitness of each particle, store the current individual optimal particle and global optimal particle, update and optimize the subgraph according to the idea of hybridization and mutation, and generate a new topological subgraph. Particle swarm follows the current optimal particle and searches in the solution space, that is, iteratively finds the optimal subgraph as the final routing scheme.

Basic Particle Fitness Evaluation Function. In the “5G White Paper” [6], the main application scenarios of the future mobile Internet and the Internet of Things are divided into uRLLC, mMTC, and eMBB. The key capability indicators required for each scenario are high bandwidth experience rate, ultra-high traffic density, and ultra-high Connection density, low latency and high reliability.

Combining these four key capability indicators, this paper selects the two parameters of delay and bandwidth to characterize the performance indicators of future 5G application scenarios.

The performance of network slicing is characterized by different performance parameters. However, different parameters have different value ranges and units, so quantitative comparison and analysis cannot be performed. In this paper, the zero mean normalization method is used to normalize different transmission parameters, and the normalization calculation formula is:

$$P^{nor} = \frac{p - \mu}{\sigma} \quad (3)$$

Among them, P^{nor} is the normalized value of the performance parameter; p is the performance parameter; μ is the average value of the performance parameter; σ is the variance of the performance parameter.

The evaluation of the fitness of a particle is made according to the transmission parameters of the slice it represents, that is to say the fitness of the particle is the fitness of NS. This paper designs an evaluation of particle fitness based on an exponential function the function is as follows:

$$Fitness(\alpha, \beta, D, B) = -\alpha e^D + \beta e^B \quad (4)$$

Among them, D is the path delay value with the largest delay in a normalized sub-graph; B is the minimum bandwidth of the link in a normalized sub-graph; α is the proportion of low-delay requirement slices in all slices; β is the proportion of high-bandwidth demanded slices in all slices.

Algorithm Implementation Steps. The specific steps of the network slice orchestration algorithm based on GA-PSO optimization are as follows:

- Step 1** The transmission parameters that characterize the performance of the network slice are normalized. The normalization method is based on Eq. (3).
- Step 2** low-latency slices, high-bandwidth slices, and high-reliability slices to form a hybridization pool. The slices in the pool are randomly hybridized and initialized according to the hybridization and mutation algorithms in Sect. 3.2.4, and initialized $2n$ particles, each particle is an NS, representing a topological subgraph G .
- Step 3** For each type of slice, select the appropriate parameters, calculate the fitness of the population particles according to Fitness (α, β, D, B), and sort them, and select the n particles with the highest fitness to form the initial population.
- Step 4** Record the slice with the highest fitness in Step 3, which is the local optimal particle G_{pb} and the global optimal particle G_{gb} .
- Step 5** Set the number of iterations m and the optimal solution control threshold τ describing the stability of the optimal solution.
- Step 6** According to the algorithm in Sect. 3.2.4, according to the local optimal NS and the global optimal NS, all particles in the particle swarm are updated by means of hybridization and mutation.
- Step 7** Calculate the fitness of the population particles according to Fitness (α, β, D, B), update the local optimal particle G_{pb} , if the current local optimal particle G_{pb} fitness value is higher than the current global optimal particle G_{gb} , then update the global optimal particle Optimal particles; otherwise the optimal solution control counter is incremented by 1.
- Step 8** Check the iteration termination condition, if the number of iterations reaches m times or the value of the optimal solution control counter is greater than the optimal solution control threshold τ , then go to Step 9, otherwise go to Step 6.
- Step 9** Output the optimal subgraph G_{gb}

3 Experimental Analysis

3.1 Experimental Setup

In order to verify the performance of the network slice orchestration algorithm based on GA-PSO optimization proposed in this paper, an experimental environment is designed, and the topology is shown in Fig. 1. In the network environment, the source (O) nodes O_1, O_2, \dots, O_n are the nodes that accept user traffic and are responsible for receiving user traffic, and D_1, D_2, \dots, D_n are the destination (D) nodes; $S_1, S_2, S_3, \dots, S_m$ is a switch running the OpenFlow protocol; the controller is the controller of the entire SDN.

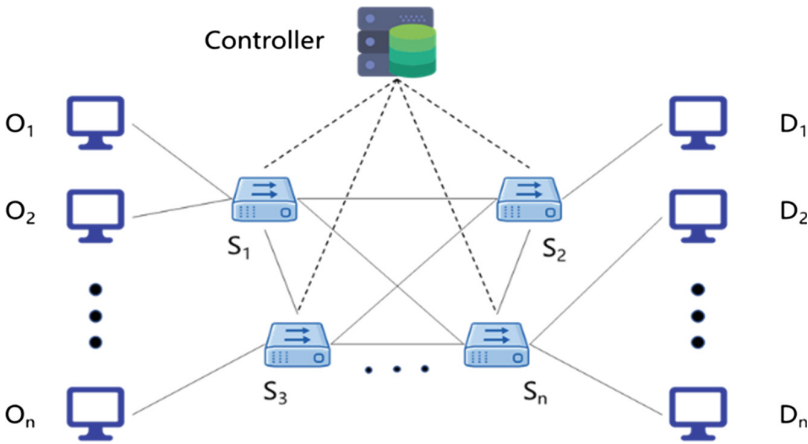


Fig. 1. Topological schematic diagram of experimental environment.

3.2 Experimental Design and Result Analysis

This paper chooses two algorithms to compare with the proposed GA-PSO. Method one is the OSPF algorithm. Another method is the greedy strategy [9].

In the following experimental analysis process, keeping the traffic demand, that is, the total amount of slices unchanged, by adding the nodes of the network (the network size changes) to compare the time taken by the three algorithms to generate routing strategies and the energy consumption after routing deployment.

In the case of the same number of traffic requirements (the number of traffic in this article is 30), this article compares the performance of the three methods under different network scales.

- (1) Time complexity: The algorithm's Time complexity is a very important indicator, which indicates whether the algorithm can achieve the expected effect in the actual deployment environment. When the network scale is small, the algorithm using the greedy strategy is similar to or even better than GA-PSO in time complexity. However, the time used by the network scale also increases rapidly

and the performance deteriorates. Although the time used by GA-PSO algorithm is not very small when the network size is small, with the increase of the network size, the time used by GA-PSO algorithm grows slowly and has good time stability for different networks, which is obviously better than the queuing algorithm based on greedy strategy.

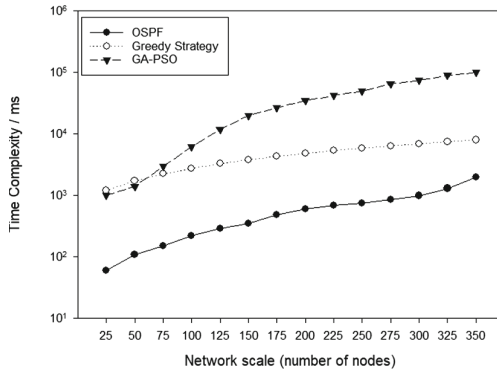


Fig. 2. Time complexity of three algorithms under different network scales.

- (2) Energy consumption: In the future, energy saving becomes an unavoidable and important issue. As can be seen from Fig. 3, the larger the network size, the GA-PSO algorithm has energy consumption advantages over the other two algorithms. The more obvious, at the same time, as the network scale increases, the network energy consumption of the GA-PSO algorithm grows slowly, showing good balance ability and energy consumption stability. Although it can be seen from Fig. 2, when the network scale is 350, GA-PSO takes about 14% more time than OSPF, but the energy cost decreasing in Fig. 3 is about 32%.

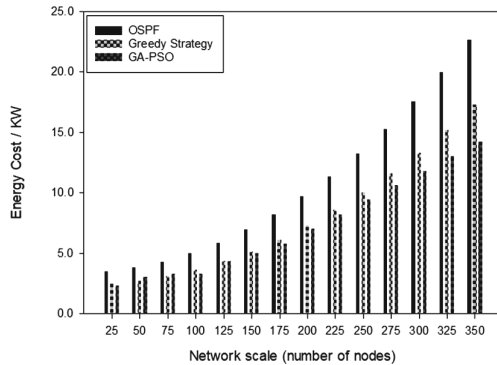


Fig. 3. Energy consumption of three algorithms under different network scales.

4 Conclusion

In this paper, through the analysis of the current main application scenarios and the research on the algorithm of network slicing, a network slicing algorithm based on GA-PSO optimization is proposed. The characteristics of this algorithm are: drawing on the idea of hybridization and mutation in the GA algorithm, the traditional PSO algorithm Improvements were made, and the PSO's group intelligence feature was applied to the optimization problem of network subgraphs, which made the algorithm's global search performance substantially improved, and gave full play to the superiority of the centralized control of the SDN architecture. Experimental data shows that the algorithm has a good effect on the optimization of high-load traffic in large-scale networks.

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