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Security Isolation Algorithm of 5G Network Slice Based on Particle Swarm Optimization

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Network slicing, an important feature of 5G (Fifth Generation of Mobile Communications Technology), is widely used in various business scenarios, and it has become increasingly important to address the accompanying security isolation problem. Different network slicing needs to handle different types of data traffic, and there are strict requirements for the security guarantee of each network slicing. In this paper, a 5G network slice security isolation algorithm based on particle swarm optimization, is proposed. This study analyzed the security requirements of different vertical industries for network slicing, including resource isolation and communication privacy protection, and designed a resource allocation model suitable for 5G network slicing, taking into account the security isolation requirements and resource competition relationships of different slicing. Finally, based on the communication strategy optimization method using particle swarm optimization, a 5G network slice test was carried out on a front-line intelligent city system to ensure the communication privacy and security between slices. The experimental results showed that the average bandwidth utilization rate of the 5G network slice security isolation algorithm based on particle swarm optimization was 85%; the effect benefit ratio was 90%, and the average delay was 20 milliseconds. The average bandwidth utilization without optimization scheme was 70%; the cost-effectiveness ratio was 69%, and the average delay was 36 milliseconds. These results showed that particle swarm optimization provided 5G network slice security isolation algorithm with better security performance, faster response speed, lower resource consumption, and stronger robustness and resilience. This algorithm can effectively improve the security and performance of a 5G network slice, and provide users with more reliable services.

Keywords: network slicing; particle swarm optimization; security isolation algorithm; 5G network; resource isolation

1. INTRODUCTION

With the rapid development of the Internet of Things and the promotion of digital transformation, as the next generation mobile communication technology, a 5G network is set to become the key infrastructure that connects various intelligent terminals and applications. However, 5G networks face a series of security issues, one of which is the challenge of network slicing security isolation. Network slicing is an important feature of 5G networks, which allows network resources to be divided and customized based on different application scenarios and service requirements. Through network slicing, personalized service quality and security guarantees can be provided for different applications. However, the security isolation of network slicing is a complex and critical issue [1]. In an environment where multiple slices work in parallel, there may be resource competition and interference between different slices, leading to the disruption of security isolation. In addition, malicious attackers can exploit the vulnerabilities of network slicing to invade other slices through one slice, which can endanger the security of the entire network. Therefore, designing an effective 5G network slicing security isolation algorithm is crucial for ensuring the security and reliability of the network. Particle swarm optimization is an optimization algorithm based on swarm intelligence, which simulates the behavior of birds foraging, and searches the global optimal solution through

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iteration [2]. This paper explores a 5G network slice security isolation algorithm based on particle swarm optimization. This algorithm achieves effective security isolation of network slices by optimizing the allocation of slice resources and considering the competition and interference relationships between each slice.

5G is intended for large-scale and heterogeneous industrial clusters, and its core technology is an effective means of achieving heterogeneous communication between multiple industrial clusters under the same physical network. Network slicing refers to a logical network that can provide specific network capabilities and attributes. It satisfies the differentiated needs of vertical industries in the form of services, ensuring that each business can customize the network according to its specific needs. Wang and Zhang (2018) described the basic concepts and architecture of network slicing, then provided a summary of the problems, isolation mechanisms, and standard formulation of network slicing. They also conducted a comprehensive analysis of the main technologies applied to network slicing and predicted its development trend [3]. In response to the dynamic nature of service requirements in 5G networks, Tang et al. (2020) proposed a dynamic configuration method for multi-class service function chains based on controlling Markov decision processes. This method achieved dynamic configuration of multi-class service function chains in 5G networks while meeting the average latency and average cache and bandwidth resource consumption of each slice [4]. The 5G bearer network is the basic network for China's future 5G development. Its development faces five major problems, namely, "large bandwidth", "low latency", "flexible access", "high-precision synchronization", and "network layering". Wang et al. (2018) proposed a layered structure for network slicing in 5G bearer and conducted in-depth discussions on several key technologies involved, including software defined network control surface slicing, flexible Ethernet based forwarding surface hard slicing, bearer device slicing and virtualization technology, and end-to-end slicing arrangement for 5G services [5]. However, these studies on network slicing do not provide technical evidence; moreover, particle swarm optimization technology is found to be more helpful to the research on network slicing.

5G networks have the characteristics of multiple services, and therefore the volume of their data traffic increases significantly. To address this issue, Chen et al. (2018) proposed a function migration method based on network slicing to achieve load balancing. This algorithm has greater accuracy and faster convergence time than other algorithms, which can effectively improve the resource utilization and energy consumption of the data center, and has better adaptability [6]. Pan et al. (2020) studied a network slicing deployment strategy based on the isolation level to ensure a balance between performance isolation and security isolation. Firstly, the isolation level of network slices was defined from the perspectives of performance isolation and security isolation. When selecting an appropriate location, it is necessary not only to ensure that multiple network slices can meet the corresponding performance and security requirements, but also to limit the coexistence conditions of multiple virtual nodes based on the differences in isolation levels. With the objective of minimizing the allocation cost, an optimization model was established by using the integer linear programming method. The particle swarm optimization algorithm was used to solve the optimization problem. Through simulation experiments, it was proven that the proposed algorithm not only meets the performance requirements of the system, but also meets the security requirements of the system [7]. However, these researchers did not analyze the security isolation algorithm of 5G network slice based on particle swarm optimization, as they did not give it in-depth consideration.

With the widespread application of 5G networks, network slicing technology was introduced to achieve flexible deployment of multiple scenarios and services. However, due to the characteristics of resource sharing and virtualization between network slices, the security isolation of network slices becomes a challenge. In order to solve this problem, in this study, a 5G network slice security isolation algorithm was designed based on particle swarm optimization. In regard to network slicing, this study analyzed the security needs of different vertical industries, especially in terms of resource isolation and communication privacy protection, and designed a resource allocation model suitable for 5G network slicing. This model takes into consideration the security isolation requirements and resource competition between different slices, and comprises a communication strategy optimization method based on particle swarm optimization to ensure the privacy and security of communication between network slices. The performance of the algorithm was evaluated by testing the 5G network slice of a specific intelligent city system.

2. SLICING SECURITY ISOLATION ALGORITHM

2.1 Security Requirement Analysis of Network Slicing

With the development of 5G networks, network slicing has become an emerging technology that can segment network resources into multiple independent virtual networks to meet the needs of different vertical industries [8–9]. However, security is a crucial consideration when implementing network slicing. This paper provides a detailed analysis of the security requirements for network slicing in different vertical industries from two perspectives: resource isolation and communication privacy protection.

(1) Resource isolation requirements

Resource isolation is one of the core requirements for network slicing security [10–11]. Different vertical industries need to determine the amount of computing, storage, and bandwidth resources required for slicing based on their own characteristics and application scenarios. The following is an analysis of the needs of several vertical industries in terms of network slicing resource isolation.

Intelligent manufacturing: Intelligent manufacturing involves a large amount of data transmission and processing, so each slice requires sufficient computing, storage, and bandwidth resources. At the same time, in order to ensure real-time and reliability, each intelligent manufacturing slice needs independent physical isolation to prevent other slices from consuming too much of the resources and causing performance degradation.

Smart city: In the field of smart cities, different application scenarios have different bandwidth requirements. For example, in scenarios such as traffic monitoring, environmental monitoring, and intelligent parking, each application scenario requires sufficient bandwidth resources to ensure service quality. Therefore, in network slicing, it is necessary to allocate bandwidth resources reasonably to meet the needs of various application scenarios.

Medical industry: The medical industry involves a large amount of sensitive information, such as patient medical records, examination reports, etc. In order to protect the security of these sensitive data, it is necessary to ensure resource isolation between each slice and prevent unauthorized access and data breach.

Financial industry: In the financial industry, each network slice may carry business data from different financial institutions such as banks and securities companies [12–13]. To prevent malicious attackers from stealing data or launching other types of network attacks, it is necessary to ensure resource isolation and communication security between slices.

(2) Communication privacy protection requirements

Communication privacy protection is also an important requirement for network slicing security. Different vertical industries have different requirements for communication privacy protection between slices. The following is an analysis of the needs of several vertical industries in network slicing communication privacy protection.

Medical industry: Each network slice in the medical industry may carry sensitive information of patients, such as medical records, examination reports, etc. [14–15]. In order to ensure the security of these sensitive data, encryption and authentication measures need to be taken to prevent unauthorized access and data breaches.

Financial industry: Network slicing may contain business data from different financial institutions such as banks and securities companies. In order to prevent data breaches and malicious attacks, the communication between slices must be encrypted, and measures such as digital signature and access control must be taken to ensure the security of communication.

Government industry: The government uses network slicing to support various services, such as e-government and public security. In these applications, privacy protection of communication is crucial to prevent the leakage of sensitive information and unauthorized access.

Business enterprises: Businesses may process a large amount of business data and customer information in network slicing. In order to protect trade secrets and customer privacy, communication between slices must be encrypted and other security measures such as access control and security auditing must be taken.

It is crucial to ensure network slicing security by means of resource isolation and communication privacy protection [16–17]. The demand for network slicing security in different vertical industries is diverse, and customized solutions need to be developed based on the respective characteristics of various entities. When dveloping 5G networks, the security of network slicing is an important research and practical field, providing secure and reliable network services for different industries.

2.2 Design of Slice Resource Allocation Model

The allocation of slicing resources faces many challenges, including security isolation requirements and resource competition relationships. To effectively address these issues, it is necessary to design an efficient resource allocation model suitable for 5G network slicing.

(1) Security isolation requirements

When designing a slice resource allocation model, it is first necessary to consider the security isolation requirements of different slices. Due to the potential involvement of highly sensitive and confidential data when slicing across different vertical industries, resource isolation is key to ensuring data security and reliability. To meet the safety isolation requirements, the following measures can be taken:

Physical isolation: Each slice can run on independent physical devices, such as independent servers or cloud resources. This can ensure that the resources of different slices are isolated from each other, preventing all slices from interfering with the resources of all other slices.

Virtual isolation: When there are shared physical resources, virtualization technology can be used to isolate different slices. By using technologies such as virtual machines or containers, an independent running environment can be created for each slice, ensuring that the resources of various slices do not interfere with each other.

Access control: To prevent unauthorized access, access control mechanisms can be used to restrict communication between slices and data access.

Data encryption: For particularly sensitive data, data encryption technology can be used to ensure the security of the data during transmission and storage. Encrypting and decrypting data through encryption algorithms can prevent unauthorized users from accessing sensitive information.

(2) Resource competition considerations

In addition to security isolation requirements, the slicing resource allocation model also needs to consider the competition relationship between resources. Due to the shared resources in 5G network slices, there may be resource contention issues between slices [18]. To address this issue, the following measures can be considered:

Resource reservation: Based on the needs and importance of different slices, certain resources can be reserved for each slice during resource allocation. This can ensure that critical tasks or high-priority slices obtain the required resources without being preempted by other low-priority slices.

Resource scheduling: By means of dynamic resource scheduling algorithms, slicing resources can be dynamically allocated and adjusted according to actual needs.

Bandwidth management: As bandwidth is a valuable resource, it is necessary to manage bandwidth allocation equitably when allocating resources. A fair bandwidth sharing mechanism for different slices can be provided by technical means such as traffic control, priority scheduling and bandwidth guarantee.

Optimization algorithm: By utilizing optimization algorithms and machine learning techniques, resource allocation optimization can be achieved by considering the specific needs of slicing and network conditions. By analyzing historical data and applying real-time monitoring, resource allocation can be predicted and adjusted in advance to achieve optimal resource utilization.

(3) Scalability and flexibility design

The slicing resource allocation model should also have scalability and the flexibility to adapt to the constantly growing network size and changing business needs. For this purpose, the following design principles can be applied:

Layered architecture: Adopting a layered architecture, the slicing resource allocation model is divided into different modules and levels. This can achieve modular design and flexible expansion, providing support for new business requirements and technological innovation.

Automated management: Automated management mechanisms are introduced, including auto-configuration, auto-optimization and auto-failure recovery. Through automated management methods, manual intervention can be reduced, and the efficiency and reliability of resource allocation can be improved.

Autoscaling: Autoscaling of resources is implemented as required to meet peak business demand and network load changes. Flexible resource allocation and dynamic adjustment can be achieved through cloud computing and virtualization technology.

The resource allocation model suitable for 5G network slicing needs to comprehensively consider security isolation requirements and resource competition relationships [19]. By implementing measures such as physical isolation, virtual isolation, access control, and data encryption, the resource security isolation of each slice can be ensured. At the same time, the problem of resource competition is solved by means such as resource reservation, resource scheduling, bandwidth management, and optimization algorithms. In addition, the model becomes extensible and flexible by applying design principles such as hierarchical architecture, automatic management and autoscaling. These designs enable efficient, secure, and reliable allocation of slicing resources to be achieved, providing high-quality services for 5G networks.

2.3 Communication Strategy Optimization Methods

In 5G networks, in order to ensure communication privacy and security between slices, and to find the best communication solution, optimization methods need to be applied when designing communication strategies. In this paper, a communication strategy optimization method is designed based on particle swarm optimization, which can effectively optimize the communication strategy between slices.

(1) Particle swarm optimization algorithm

A particle swarm optimization algorithm is a heuristic optimization algorithm, which is inspired by the foraging behavior of birds [20]. This algorithm continuously updates the position and velocity of particles by simulating information exchange and cooperative behavior among individuals in bird swarms, in order to find the optimal solution.

In the particle swarm optimization algorithm, each particle represents a candidate solution [21]. Its position represents a certain parameter combination of the solution, and its speed represents the search direction and step size of the solution. By iteratively updating the position and velocity of particles, all particles gradually gather near the optimal solution, thereby finding the best optimization result.

(2) Communication strategy optimization based on particle swarm optimization

In communication strategy optimization, the communication strategies between slices are represented as a multidimensional parameter space, where each parameter represents the configuration of a certain communication strategy. By optimizing these parameters, the optimal communication strategy can be found to ensure communication privacy and security between slices. The specific process is described below.

1) Definition of objective function

An objective function needs to be defined to evaluate the effectiveness of communication strategies. The objective function should consider both communication privacy and security between slices, which can be expressed as:

$$f(x) = w_1 * f_1(x) + w_2 * f_2(x) \tag{1}$$

where w_1 and w_2 are weights; $f_1(x)$ and $f_2(x)$ are two objective functions that measure communication privacy and communication security, respectively. For example, communication privacy can be one of the goals, and the privacy level of communication data can be measured by quantitative indicators such as information entropy. At the same time, communication security can be considered as the second goal, taking into account factors such as encryption algorithms and authentication mechanisms.

2) Initialization of particle swarm

According to the dimensions of the parameter space, a group of particles is initialized, each particle representing a candidate solution. The position and velocity of each particle are set. Position comprises the parameter values of the communication strategy, while speed is the direction and step size of the search. Suitable parameter ranges can be set to ensure coverage of the search space.

3) Iterative updates of particles

According to the iterative process of the particle swarm optimization algorithm, the position and speed of each particle are constantly updated.

The formula for updating particle position is:

$$X_i(t+1) = X_i(t) + V_i(t+1) \tag{2}$$

where $X_i(t)$ represents the position of particle i at iteration t (communication strategy parameter value);

The formula for updating particle velocity is:

$$\begin{aligned} V_i(t+1) = \omega * V_i(t) + c_1 * r_1 * (p_{\text{best},i}(t) - X_i(t)) \\ + c_2 * r_2 * (g_{\text{best}}(t) - X_i(t)) \end{aligned} \tag{3}$$

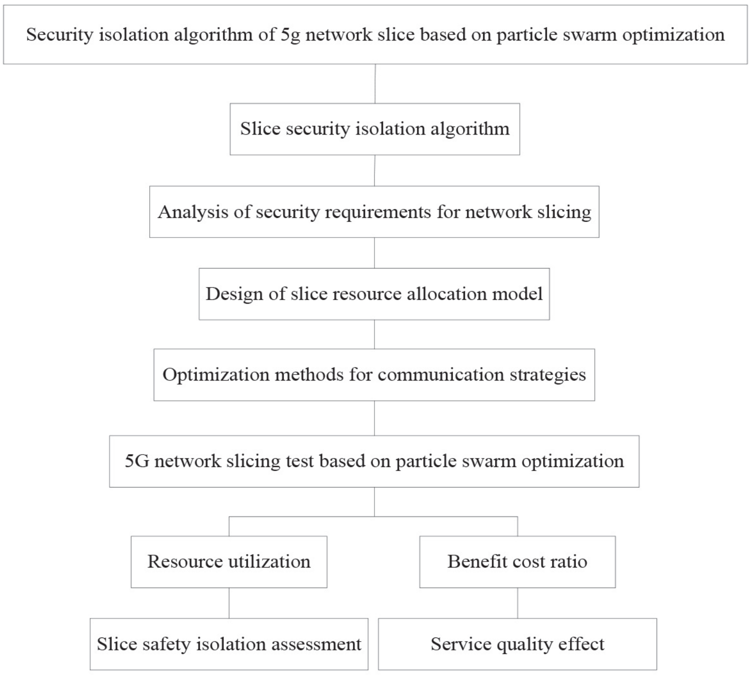

Figure 1 Proposed framework.

where ω is the inertia weight; c_1 and c_2 are acceleration factors; r_1 and r_2 are random numbers between 0 and 1; $p_{\text{best},i}(t)$ is the optimal position for individual particles; $g_{\text{best}}(t)$ is the global optimal position. $V_i(t)$ represents the velocity of particle i at iteration number t.

By calculating the fitness (i.e. objective function value) of each particle, as well as the global best fitness and best position, the speed and position of the particles are updated.

The formula for updating the optimal position of particles is:

$$p_{best,i}(t+1) = \begin{cases} X_i(t+1), & \text{if } f(X_i(t+1)) < f(p_{\text{best},i}(t)) \\ p_{\text{best},i}(t), & \text{otherwise} \end{cases} \tag{4}$$

In this way, each particle in the particle swarm gradually approaches the global optimal solution. The global optimal location update formula is:

$$g_{best}(t+1) = \begin{cases} X_i(t+1), & \text{if } f(X_i(t+1)) < f(g_{\text{best}}(t)) \\ g_{\text{best}}(t), & \text{otherwise} \end{cases} \tag{5}$$

4) Termination condition judgment

After each iteration update, it is necessary to determine whether the termination condition is met. The termination condition can be to reach the maximum number of iterations, or the objective function value has converged sufficiently close to the optimal solution.

5) Output of optimal solution

After the algorithm terminates, the communication strategy parameter values corresponding to the global optimal position are output. These parameters are optimized communication strategies that can be used to ensure the communication privacy and security of each slice.

(3) Advantages and applicability of optimization methods

The communication strategy optimization method based on particle swarm optimization has the following advantages and applicability:

Global search ability: Particle swarm optimization algorithm has good global search ability in the search space, which can prevent reaching the local optimal solution. By continuously updating the velocity and position of particles, the optimal solution can be effectively searched within the parameter space.

Scalability: This method is suitable for any dimension of parameter space and can be flexibly applied to various complex communication strategy optimization problems.

Parallel computing: Particle swarm optimization algorithm is naturally suitable for parallel computing, which can speed up the search process and improve the optimization efficiency.

Parameter adjustment: The performance and rate of convergence of the algorithm can be further optimized by adjusting the parameters of the algorithm such as the number of particles, inertia weight, etc.

The communication strategy optimization method based on particle swarm optimization can effectively optimize the communication strategy of slices to ensure communication privacy and security. By defining the objective function, initializing the particle swarm, iteratively updating particles, determining termination conditions, and outputting the optimal solution, the optimal communication strategy parameter values can be found. The proposed framework is shown in Figure 1.

3. 5G NETWORK SLICING TEST BASED ON PARTICLE SWARM OPTIMIZATION

3.1 Network Parameters

The 5G network slicing test conducted in this study was based on a first-tier intelligent city system, one of the first

Table 1 Algorithm parameters.

Network parameters	Reference value
Maximum number of iterations	150
α/β	0.4 / 0.6
Number of particles	80
Particle dimension	10
Inertia weight	0.5
Number of slices	10–15
Maximum guaranteed bandwidth	100 Mb/s
Single terminal bandwidth limit	20 Mb/s

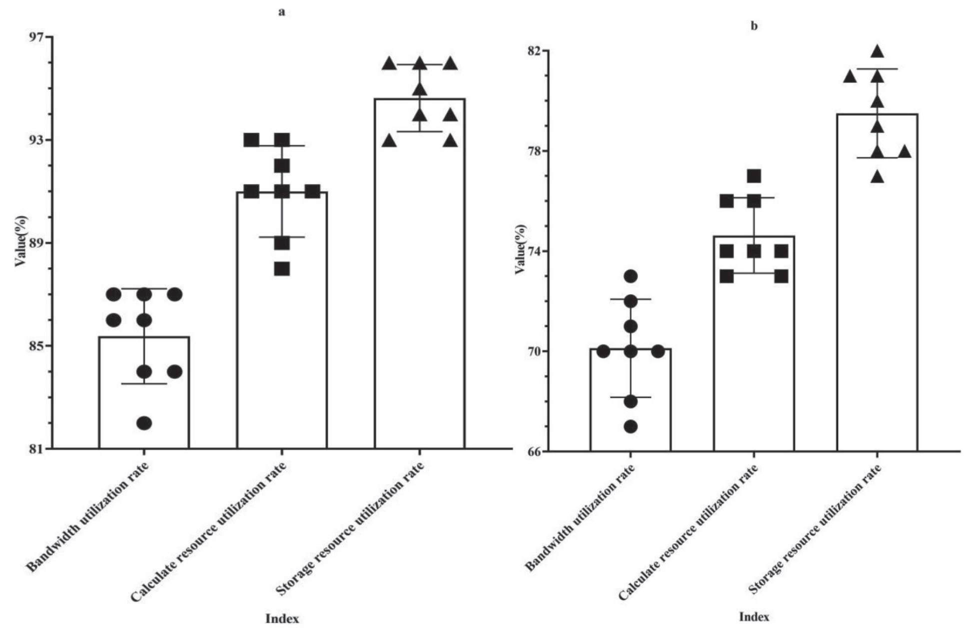

Figure 2 Resource utilization rate (a) Security isolation algorithm of 5G network slice based on particle swarm optimization (b) An unoptimized 5G network slicing security isolation algorithm.

commercial cities in China's 5G network. The algorithm parameters in the plan are shown in Table 1.

Maximum number of iterations: 150 iterations were set according to calculation resources and algorithm rate of convergence. A and inertia weight: α/β ratio of 0.4/0.6 was established, and the inertia weight was set to 0.5 to maintain a balance between global and local search capabilities. Number of particles: 80 particles were selected to take into consideration both search efficiency and computational complexity. Particle dimension: Appropriate dimensions were established based on actual application scenarios and the number of slicing parameters. The city chosen for this study was set at 10 dimensions. Slice quantity: According to the development needs of first-tier smart cities, the number of slices can be set to between 10 and 15. Maximum guaranteed bandwidth: based on the size and demand of the city, the maximum guaranteed bandwidth was set to 100 Mb/s to meet the bandwidth requirements of different slices. Single terminal bandwidth limit: According to the actual situation and business needs, the single terminal bandwidth limit was set to 20 Mb/s to limit the bandwidth usage of a single terminal.

In this study, the intelligent city system was tested eight times. By comparing the data on resource utilization, benefit cost ratio and security performance level of the slicing scheme based on particle swarm optimization and non-optimization, the quality-of-service results for the network was determined.

3.2 Network Slicing Testing

(1) Resource utilization rate

The following three indicators can be used to determine resource utilization:

Bandwidth utilization rate: measures the ability of two algorithms to reasonably allocate bandwidth requirements for different network slices, as well as the utilization rate of the allocated bandwidth relative to the total bandwidth.

Computational resource utilization: determines the ability of two algorithms to allocate computing resource requirements for different network slices in a reasonable manner, as well as the utilization rate of the allocated computing resources relative to the total resources.

Storage resource utilization rate: measures the ability of two algorithms to reasonably allocate storage resources to different network slices, as well as measuring the utilization rate of the allocated storage resources relative to the total resources.

Figure 2 shows the resource utilization rate. Figure 2 (a) shows the security isolation algorithm of 5G network slice

Table 2 Comparison of mean resource utilization indicators.

	Security isolation algorithm of 5G network slice based on particle swarm optimization	An unoptimized 5G network slicing security isolation algorithm
Bandwidth utilization rate	85%	70%
Calculate resource utilization rate	91%	75%
Storage resource utilization rate	95%	80%

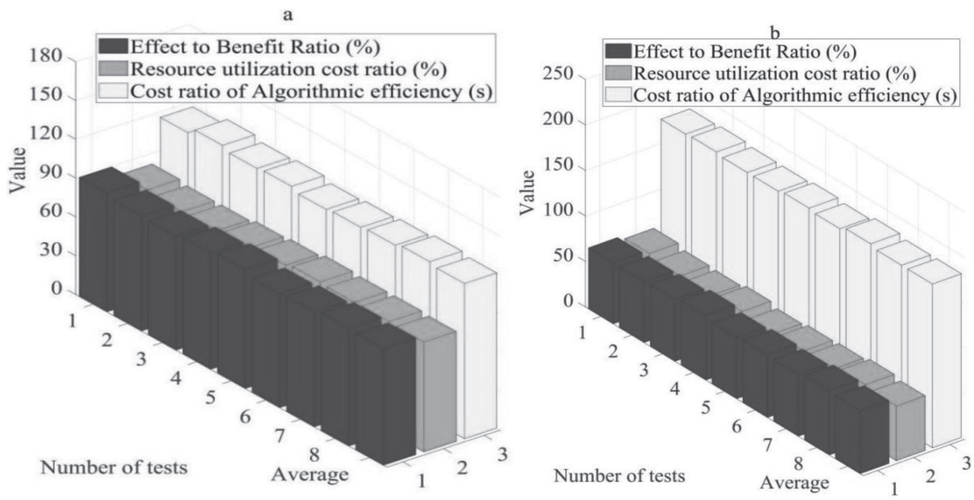

Figure 3 Benefit cost ratio (a) Security isolation algorithm of 5G network slice based on particle swarm optimization (b) An unoptimized 5G network slicing security isolation algorithm.

based on particle swarm optimization, and Figure 2 (b) shows the security isolation algorithm of 5G network slice without optimization. The horizontal axis in Figure 2 shows the three indicators of resource utilization rate, while the vertical axis shows the numerical values of the indicators. Table 2 shows the comparison of the mean values of resource utilization indicators.

As shown in Table 2, the bandwidth utilization of the security isolation algorithm for 5G network slices based on particle swarm optimization is between 82% and 87%, with an average of 85%; the utilization rate of computing resources ranges from 88% to 93%, with an average of 91%; the utilization rate of storage resources ranges from 93% to 96%, with an average of 95%. The bandwidth utilization of the unoptimized 5G network slicing security isolation algorithm ranges from 67% to 73%, with an average of 70%; the utilization rate of computing resources ranges from 73% to 77%, with an average of 75%; the utilization rate of storage resources ranges from 77% to 82%, with an average of 80%. These results indicate that the 5G network slice security isolation algorithm based on particle swarm optimization performs better than the non-optimization algorithm in terms of bandwidth, utilization of computing resources and storage resources. It can more effectively utilize network resources and improve overall resource utilization efficiency. This would help smart city systems to provide better service quality and performance.

(2) Benefit cost ratio

The following three experimental indicators can be used to compare cost-benefit ratios:

Effect to benefit ratio: This indicator measures the effectiveness and related benefits of algorithms in achieving secure isolation. The formula used to evaluate each algorithm's effectiveness is: cost-effectiveness ratio=safety isolation effect/cost. The effectiveness of security isolation can be determined by measuring the degree of isolation between network slices, the confidentiality of data transmission, and can be expressed as a percentage. The cost comprises the time complexity of the algorithm, the consumption of computing and storage resources, and other factors.

Resource utilization cost ratio: This indicator measures the cost incurred by algorithms in achieving resource utilization efficiency. The following formula can be applied to determine the cost: resource utilization cost ratio = resource utilization rate/cost. Resource utilization includes bandwidth utilization, computing resource utilization, storage resource utilization, etc., which can be expressed as a percentage.

Algorithmic efficiency cost ratio: this indicator measures the relationship between the efficiency and cost of the algorithm when it implements the security isolation task. It can be determined using this formula: algorithmic efficiency cost ratio=time required to complete the task/cost. The time required to complete a task can be measured (in seconds) as the execution time required by the algorithm.

Figure 3 shows the cost-benefit ratio. Figure 3 (a) shows the security isolation algorithm of 5G network slice based on particle swarm optimization, and Figure 3 (b) shows the security isolation algorithm of 5G network slice without optimization. In Figure 3, the horizontal axis represents the number of training sessions and the vertical axis represents the value of the indicator.

The algorithm based on particle swarm optimization had a higher benefit ratio, reaching 90%. This meant that while achieving secure isolation, the algorithm produces a better

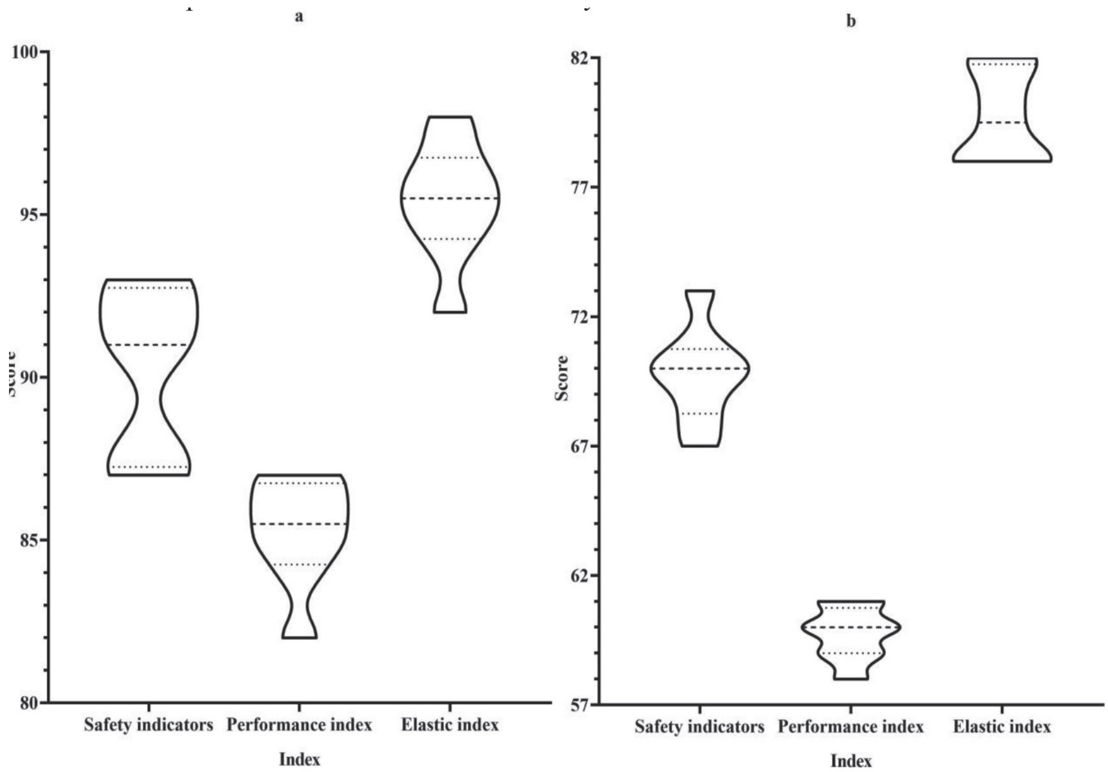

Figure 4 Slice safety isolation assessment (a) Security isolation algorithm of 5G network slice based on particle swarm optimization (b) An unoptimized 5G network slicing security isolation algorithm.

network slicing isolation result and offers additional benefits. The non-optimization algorithm achieved a cost-effectiveness ratio of only 69%. Compared with the algorithm based on particle swarm optimization, it had poorer performance in terms of achieving safety isolation and other benefits.

The algorithm based on particle swarm optimization performed better in terms of resource utilization cost ratio, reaching 85%; hence, it was cost-efficient. Without optimization algorithms, only 60% resource utilization and cost ratio can be achieved. Compared with the algorithm based on particle swarm optimization, it performed poorly in terms of achieving a balance between resource utilization and cost.

The algorithm based on particle swarm optimization performed well in regard to algorithmic efficiency cost ratio, and required 120 seconds to complete the task. This meant that under the same cost constraints, the algorithm can complete security isolation tasks faster. The cost of algorithmic efficiency without optimization algorithm was relatively low, and the time required to complete the task was 180 seconds. Compared with the algorithm based on particle swarm optimization, it performed poorly on achieving a balance between execution efficiency and cost.

From the above analysis, it can be seen that the 5G network slice security isolation algorithm based on particle swarm optimization performed better than the non-optimization algorithm in terms of effect benefit ratio, resource utilization cost ratio and algorithmic efficiency cost ratio. It achieves a better isolation result and related benefits, and produces a better balance between resource utilization and algorithmic efficiency. This would help improve the overall performance and efficiency of 5G network slicing security isolation.

(3) Slice safety isolation assessment

In terms of slice safety isolation evaluation, the following three experimental indicators can be applied for comparison:

Safety indicator: this measures the security performance of algorithms when applied to slice security isolation.

Performance index: this shows the performance of algorithms in slicing performance.

Elastic index: this measures the robustness and resilience of algorithms when dealing with abnormal situations and network fluctuations.

Figure 4 shows the results of the slice safety isolation achieved by two different algorithms. Figure 4 (a) shows the security isolation algorithm of 5G network slice based on particle swarm optimization, and Figure 4 (b) shows the security isolation algorithm of 5G network slice without optimization. The horizontal axis in Figure 4 represents the three indicators for slice safety isolation evaluation, while the vertical axis represents the score of the indicators. Table 3 shows the comparison of mean values for slice safety isolation evaluation.

In eight tests, the safety indicator scores of the 5G network slice security isolation algorithm based on particle swarm optimization were between 87 and 93, and the overall score was 90; the performance index scores were between 82 and 87, with an overall score of 85; the elastic index ranged from 92 to 98, with an overall value of 95. The safety indicator scores of the unoptimized 5G network slicing security isolation algorithm were between 67 and 73, with an overall score of 70; the performance index scores were between 58 and 61, with an overall score of 60; the elastic index ranged from 78 to 82, with an overall value of 80. It showed that the

Table 3 Comparison of mean values for slice safety isolation assessment.

	Security isolation algorithm of 5G network slice based on particle swarm optimization	An unoptimized 5G network slicing security isolation algorithm
Safety indicator	90	70
Performance index	85	60
Elastic index	95	80

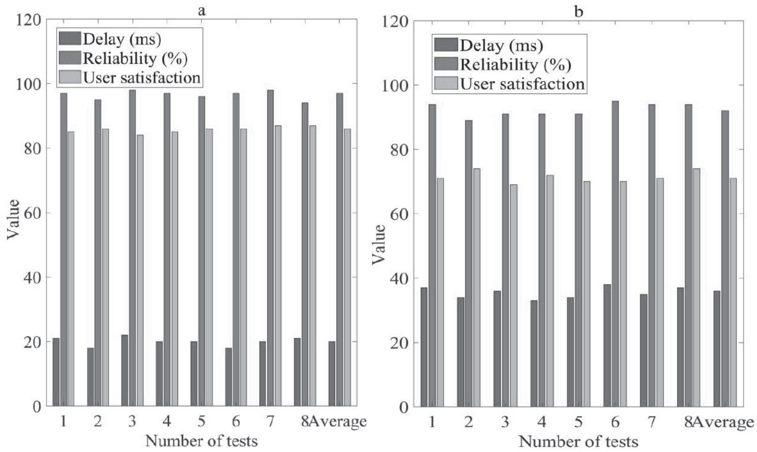

Figure 5 Service quality effect (a) Security isolation algorithm of 5G network slice based on particle swarm optimization (b) An unoptimized 5G network slicing security isolation algorithm.

security isolation algorithm of 5G network slice based on particle swarm optimization performed better than the non-optimization algorithm in terms of security, performance and elasticity. It provided better security performance, faster response speed, lower resource consumption, and stronger robustness and resilience. This helps to improve the security and performance of 5G network slicing, providing users with more reliable services.

3.3 Service Quality Effects of Actual Network Testing

Experimental setup: A representative 5G network testing scenario, an intelligent city system, was selected. Two experimental groups were established: the slicing scheme group based on particle swarm optimization and the slicing scheme group without optimization. For each experimental group, the same network topology, user requirements, and resource allocations were set.

Experimental indicators were:

Delay: this is the delay of data transmission. Delay can be calculated by measuring the time required from sending data to receiving data.

Reliability: this is the reliability of network transmission. It can be measured by means of indicators such as error rate, packet loss rate, or rate of retransmission.

User satisfaction: users' satisfaction with online services can be evaluated by means of user surveys or questionnaires, with a maximum score of 100 points.

Two types of experiments were conducted: one with the slicing scheme group based on particle swarm optimization and other with the slicing scheme group without optimization. Data transmission was conducted in the network testing scenario, and data transmission volume, latency, error rate, and other data were recorded. A user satisfaction survey was conducted to collect feedback from users of online services.

Figure 5 shows the service quality results. Figure 5 (a) shows the results for the security isolation algorithm of 5G network slice based on particle swarm optimization, and Figure 5 (b) shows the results for the security isolation algorithm of 5G network slice without optimization. In Figure 5, the horizontal axis represents the number of training sessions and the vertical axis represents the value of the indicator.

The average delay of the slicing scheme group based on particle swarm optimization was 20 milliseconds, while the average delay of the slicing scheme group without optimization was 36 milliseconds. Hence, the optimization scheme can decrease the delay of data transmission and improve the response speed of the network.

The slicing scheme group based on particle swarm optimization achieved 97% reliability, while the slicing scheme group without optimization achieved only 92% reliability. This indicated that the optimization scheme can reduce error rate, packet loss rate, or retransmission rate, and improve the reliability of data transmission.

The user satisfaction score of the slicing scheme group based on particle swarm optimization was 86, while that of the slicing scheme group without optimization was 71. The optimization approach can improve both network service quality and user satisfaction.

To sum up, the slicing scheme based on particle swarm optimization had obvious advantages over the non-optimization scheme in terms of delay, reliability, user satisfaction and other indicators. The results indicated that the optimization scheme can provide better quality, more reliable, and more satisfying network services to meet user needs.

4. CONCLUSIONS

The security isolation algorithm of 5G network slice based on particle swarm optimization is an effective method that can improve the resource utilization, delay, network performance, quality, reliability and robustness of a 5G network. The particle swarm optimization algorithm enables resources to be intelligently allocated to different network slices, which can ensure that each slice can obtain appropriate bandwidth, delay and quality of service. This utilizes network resources more efficiently and improves the overall performance of the network. In terms of latency, this algorithm can respond more quickly to user requests and reduce data transmission and processing time, which improves user experience and meets the requirements of real-time applications and low latency communication. In addition, the algorithm based on particle swarm optimization can also strengthen the reliability and robustness of the network. It can dynamically adjust resource allocation to adapt to changes in user needs and in the network environment, thereby improving the stability of the entire network. The 5G network slice security isolation algorithm based on particle swarm optimization has shown excellent performance in many respects. It can improve the resource utilization and efficiency of 5G networks, and reduce latency; it can provide a better user experience and enhance the reliability and robustness of the network. Therefore, this algorithm has broad application prospects and can make positive contributions to the development of 5G networks.

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CONFLICTS OF INTEREST

The authors state that there are no conflicts of interest in connection with this study.

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