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OPTIMIZATION OF THE TRANSMISSION PATH OF HIGH-FREQUENCY NETWORK COMMUNICATION SIGNALS IN CLOUD COMPUTING PLATFORM

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Abstract - With the rapid development of information technology, modern network communication is encountering increasing challenges and opportunities. With the popularization and implementation of 5G technology, higher demands have been placed on high-frequency signals transmission efficiency and quality. Under this background, cloud computing technology, with its powerful data processing capabilities and flexible resource allocation advantages, has emerged as an important tool for optimizing the transmission path of high-frequency signals in network communications. This paper briefly introduces the software-defined network (SDN) architecture in cloud computing technology and the use of the ant colony algorithm for planning the transmission path of high-frequency signals within the SDN architecture. Simulation experiments evaluated the packet loss rate, average delay, and average throughput of varying data sizes in the SDN under the greedy, genetic, and ant colony algorithms. The results demonstrated that high-frequency signals in the SDN architecture experienced reduced packet loss, decreased average delay, and increased throughput when using the transmission path planned by the ant colony algorithm.

Keywords: Cloud computing, SDN, High-frequency signal, Ant colony algorithm.

1. Introduction

In the current era of rapid development of information technology, continuous innovation in network communication technology is driving the digital transformation of various industries [1]. 5G technology, as a high-frequency communication signal technology, offers increased communication capacity but also imposes higher demands on the efficiency and quality of signal transmission within communication networks [2]. 5G, as a kind of high-frequency signal, is easily affected by various factors during the transmission process. For example, its high-frequency characteristic makes it difficult for the information to pass through obstacles. Therefore, more signal transmission nodes need to be deployed. More signal transmission nodes mean a larger-scale network structure, which also increases the difficulty of optimizing the signal transmission path [3]. Cloud computing technology is a novel computing mode that delivers dynamic, scalable, and virtualized resources and services over the network. At its core, cloud computing centralizes massive computing, storage, and software resources to create a unified resource pool, enabling users to access and utilize these resources as needed dynamically. Within cloud computing technology, software-defined network (SDN) technology is an important component, which is used to realize the network architecture technology of cloud computing platforms [4]. In the SDN architecture, most routers are responsible solely for data forwarding. At the same time, a small number of routers are responsible for the allocation of network resources, i.e., controlling how another part of the routers forward data. The distributed architecture of the SDN is precisely adapted to the large-scale signal transmission nodes required by 5G signals [5]. The 5G signal is transmitted using multiple distributed forwarding routers in the SDN. The status of the forwarding routers is centralized in the control router, and the transmission path of the signal is planned as a whole through the corresponding algorithm. Sudha et al. [6] proposed an energy efficient spiking deep residual network and binary horse herd optimization espoused clustering protocol for wireless sensor network. Vinod et al. [7] proposed the lifetime maximization energy-aware routing protocol for wireless sensor networks and verified through experiments that this protocol achieved high quality without introducing

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excessive network access program overhead. Suzuki et al. [8] proposed the task offloading problem of multi-cloud and multi-edge networks considering network topology and bandwidth constraints. They also proposed a task offloading method based on cooperative multi-agent deep reinforcement learning. This paper introduces the SDN architecture in cloud computing technology and the ant colony algorithm for planning high-frequency signal paths within the SDN architecture, followed by simulation experiments.

2. Optimization of High-frequency Signal Paths in Communication Networks based on Cloud Computing Technology

2.1 SDN Architecture in Cloud Computing Technology

SDN technology is an important component in cloud computing technology, offering a unique network architecture that enables more flexible, intelligent, and programmable network resource management for cloud computing platforms [9]. The fundamental architecture of an SDN is illustrated in Figure 1. The switch functions essentially as a router but is solely responsible for data forwarding within the SDN. The control layer comprises clusters of SDN controllers, and it gives a data transmission policy based on the network state and relevant algorithms and transmits it to the switches in the data layer [10].

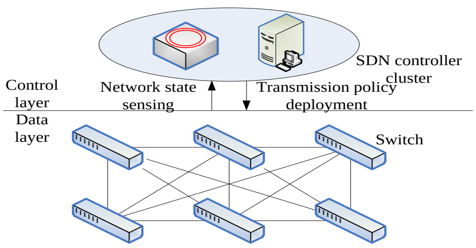

Figure 1: Basic architecture of a SDN

The cloud computing platform aims to consolidate distributed network resources before redistributing them, aligning with the principles of the SDN structure. Distributed network resource nodes are interconnected via switches, and SDN controllers manage these switches through network state sensing and transmission policy deployment [11].

2.2 Optimization of Transmission Paths for High-frequency Signals in Communication Networks

5G signal is a kind of high-frequency signal. The feature of high frequency enables it to carry more data and information but also makes the signal easily blocked by obstacles. Therefore, a large number of transmission nodes are required for 5G signals. The nodes' structure for transmitting 5G signals must not be overly complex considering the cost of node deployment. The SDN within cloud computing technology is well-suited to meet the requirements of 5G signal transmission. Wireless node employed for 5G signal transmission can function as a switch within the SDN architecture [12]. Subsequently, a cluster of SDN controllers can plan the transmission path for 5G signals and relay this planned path to the switch.

This paper uses an ant colony algorithm to optimize the signal transmission path. The steps are shown below.

① The cluster of SDN controllers gathers the network status of the switches in the network, acquires the topology between the switches as well as the starting and ending points for each data transmission.

② The parameters of the ant colony, including the size of the ant colony, the initial pheromone concentration of the transmission path, and the maximum number of iterations, are initialized.

③ Colony ants select the next switch node according to the probability, and the selection probability is affected by the pheromone concentration, which is calculated by the following formula [13]:

$$p_{ij}^{k}=\begin{cases}\dfrac{\tau_{ij}^{\alpha}\eta_{ij}^{\beta}}{\sum\limits_{s\in allowed_k}\tau_{is}^{\alpha}\eta_{is}^{\beta}} & j\in allowed_k \\ 0 & else\end{cases}, \tag{1}$$

where p_{ij}^{k} is the probability of ant k transferring from switch node i to switch node j in this round of iteration, $allowed_k$ is the set of the next switch node that ant k can choose at a node i, τ_{ij} is the pheromone concentration of path (i,j), η_{ij} is the heuristic factor of path (i,j) [14], which is the reciprocal of the length of path (i,j), i.e., the objective function, α and β are the weight of the pheromone and the heuristic factor.

④ After the ant reaches the next switch node based on the probability, the node will be added to the ant's taboo list, preventing the ant from selecting it again in the current iteration. Simultaneously, the ant will check if the node reached is the target node. If not, the ant will select the next node following step ③. If the target node is reached, the search of this ant stops.

⑤ Whether the transmission path optimization is finished is determined. If the number of iteration rounds reaches the maximum or the objective function converges to stability, the optimization is finished; otherwise, go to step ⑥. The general path optimization problem takes the path length as the objective function. However, this paper aims to optimize the transmission path of high-frequency signals, which cannot be measured according to the conventional physical path. The bandwidth occupancy rate of the wireless channel, bandwidth occupancy level, and transmission delay should be considered. Moreover, in order to facilitate the operation of the ant colony algorithm, the triangular module operator [15] is used to integrate the three optimization objectives mentioned above into a single path selectivity, and its calculation formula is:

$$\begin{cases} Y(x_1,x_2)=\dfrac{x_1x_2}{1-x_1-x_2+2(x_1+x_2)} \\ Z_k=Y\left[CB_k,Y(PS_k,T_k)\right] \\ CB_k=\max[\mu_{ij}(t)] \\ PS_k=\max[\mu_{ij}(t+T)] \\ T_k=mT_{switch}+T_{jitter}+\sum_{i=1}^{R}\sum_{j=1}^{R}\dfrac{d_{ij}\cdot x_{ij}}{v_{date}} \end{cases}, \tag{2}$$

where $Y(x_1,x_2)$ is the triangular module operator, x_1 and x_2 are two parameters to be fused, Z_k is the path selectivity of the transmission path obtained by ant k in this round of iteration, i.e., the optimization objective, CB_k is the bandwidth occupancy rate of the transmission path searched by ant k in this round of iteration, $\mu_{ij}(t)$ is the bandwidth occupancy of path (i,j) at time t, PS_k is the bandwidth occupancy level of the transmission path searched by ant k in this round of iteration, T_k is the delay of the transmission path searched by ant k in this round of iteration, T_{switch} is the node switching delay, T_{jitter} is the random jitter delay, d_{ij} is the transmission length of path (i,j), x_{ij} is an indicative parameter that is 1 when path (i,j) is within the transmission path of ant k in this round of iteration, and 0 otherwise, v_{date} is the transmission speed of information, and R refers to the total number of nodes.

⑥ When the iteration termination condition is not reached, the pheromone on the path of the entire switch node network is updated, and return to step ③. The corresponding formulas are:

$$\begin{cases} \tau'_{ij}=\rho\tau_{ij}+\Delta\tau'_{ij} \\ \Delta\tau'_{ij}=\sum_{k=1}^{m}\Delta\tau'^{k}_{ij} \\ \Delta\tau'^{k}_{ij}=\begin{cases}\dfrac{Q}{Z_k} & \text{The path of ant k contains edge (i, j) in this iteration} \\ 0 & else\end{cases} \end{cases}, \tag{3}$$

where ρ is the residual coefficient of pheromone [11], $\Delta\tau'_{ij}$ is the pheromone increment of edge (i,j), m is the number of ants in the colony, $\Delta\tau'^{k}_{ij}$ is the pheromone increment of ant k on edge (i,j), Q is the amount of pheromone that the ants can release, and Z_k is the path selectivity under the path that ant k searches, i.e., the objective function.

3. Simulation Experiment

3.1 Experimental Setup

Simulation tests were carried out in a gymnasium with an internal area of 8,000 m^2. Thirty wireless routers were arranged in the gymnasium as switches of the SDN, and another wireless router with a wired connection to the master server was set up as the SDN controller. The configuration parameters of the wireless routers as the switch and controller were gigabit ports, 100 MB/s maximum bandwidth of the link, and 10 m effective transmission distance of the wireless signals. In addition, before the formal test, the forwarding delay of the wireless routers and the random disturbance delay during signal transmission were examined. The average forwarding delay of the routers was 0.1 ms, and the random disturbance delay during signal transmission was 0.1 ms. To set up the distribution network with 30 wireless routers functioning as switches, each router must be within the effective transmission range of at least one other router.

3.2 Experimental Project

After configuring the SDN as outlined in the preceding section, ten servers were linked to it, each connected to a unique wireless router at random. Every server generated data of varying sizes (50 MB, 100 MB, 150 MB, 200 MB, and 300 MB) and transmitted it randomly to other servers.

Throughout the testing phase, the wireless router acting as the SDN controller and the master server collaborated to gather the SDN status. The transmission path between nodes was planned using the master server in the SDN controller based on the tasks assigned to the ten servers. This paper utilized the ant colony algorithm for path planning.

To evaluate the performance of the algorithm proposed in this paper further, it was compared with two other transmission path planning algorithms: the greedy algorithm and the genetic algorithm. The greedy algorithm selected the node with the shortest distance from the current node, i.e., the node with the smallest path selectivity, to plan the transmission path. In contrast, the genetic algorithm treated nodes as gene segments on a chromosome. With the gene segments at the head and tail of the chromosome being fixed, the intermediate nodes were randomly generated.

The order of the nodes represented by the gene segments in the chromosome was the transmission path.

3.3 Experimental Results

In the SDN under three transmission path planning algorithms, the packet loss rate when the server transmitted data using high-frequency signals from the wireless router is shown in Figure 2. As the transmission data volume increased, the packet loss rate of the SDN under the three algorithms also increased. The greedy and genetic algorithms experienced the most significant increase, whereas the ant colony algorithm showed a relatively minor increase. Moreover, the ant colony algorithm exhibited the lowest packet loss rate under the same transmission data volume.

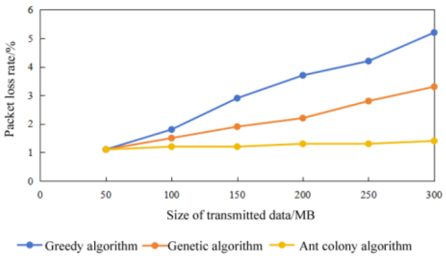

Figure 2: Packet loss rate for transmission of different sizes of data under three transmission path planning algorithms

In the SDN under the three algorithms, the average delay when the server transmitted data using high-frequency signals from the wireless router is illustrated in Figure 3. As the volume of transmitted data increased, the trend of the average delay in the SDN under the three algorithms remained stable initially and then rose. Specifically, the greedy algorithm showed a rise in average delay when the data size reached 150 MB, the genetic algorithm experienced a significant increase when the data size was 200 MB, and the ant colony algorithm demonstrated a notable increase when the data size was 250 MB. Additionally, the average delay of the ant colony algorithm was the lowest under the same data size among these algorithms.

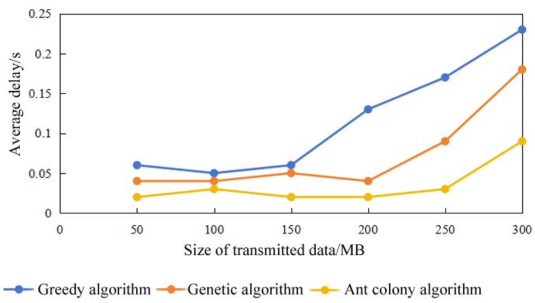

Figure 3: Average delay of transmission of different sizes of data under three algorithms

The average throughput of the SDN under the three transmission path planning algorithms, when the server transmits data using the high-frequency signal from the wireless router, is depicted in Figure 4. As the volume of transmitted data increased, the variation trend of the average throughput in the SDN under both the greedy algorithm and the genetic algorithm initially rose and then stabilized. Moreover, it continued to increase under the ant colony algorithm. The average throughput of the ant colony algorithm was the highest among the three algorithms under the same volume of transmitted data.

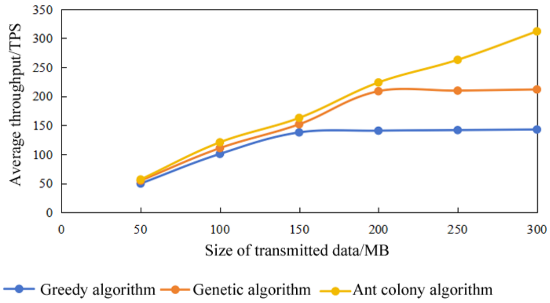

Figure 4: Average throughput of transmission of different sizes of data under three algorithms

4. Conclusions

This paper briefly introduces the SDN architecture in cloud computing technology and the ant colony algorithm for planning the transmission path of high-frequency signals within the SDN architecture. Simulation experiments were conducted to test the packet loss rate, average delay, and average throughput under various data transmission sizes in the SDN under the greedy, genetic, and ant colony algorithms. As the volume of transmitted data increased, the packet loss rate of the three algorithms also increased. The packet loss rate of the ant colony algorithm was the lowest compared to the other algorithms under the same size of transmitted data. The average delay of the SDN under the three algorithms stabilized initially and then increased as the transmitted data volume increased. The ant colony algorithm exhibited the lowest average delay among the three algorithms under the same data size.

As the size of the transmitted data increased, the average throughput of the SDN under both the greedy algorithm and genetic algorithm initially rose and then stabilized, while under the ant colony algorithm, it continued to increase. The average throughput of the ant colony algorithm was the highest for the same volume of transmitted data. In conclusion, analyzing optimized transmission paths for high-frequency signals based on cloud computing technology is a crucial method to enhance the quality and efficiency of network communication. Using data acquisition and analysis, transmission path optimization algorithms, and dynamic allocation of network resources within cloud computing technology can realize the optimization of the transmission path for high-frequency signals, improve data transmission speed and stability, and reduce transmission delay and packet loss rate.

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