A Route Optimization Model Based on Link State Awareness in SDN

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\textbf{ABSTRACT} In addressing the routing issue in the SDN environment, an improved ant colony algorithm is proposed in this paper, in which the ants tend to balance the path with less pheromone. Besides, the Top-K optimal path algorithm is used to optimize the evaluation set, speed up the evaluation, collect the status of the link in the network, and dynamically adjust the evaporation speed of the pheromone to ensure the real-time accuracy of the routing strategy. The QoS requirements of the service are also guaranteed according to the collected link QoS requirements. In such a scheme, combining the advantages of probabilistic routing and deterministic routing, path optimization is better achieved. The simulation of the traffic shows that the model can significantly improve the throughput of traffic in the SDN network, reduce the packet loss rate, and effectively guarantee load balancing.
1. INTRODUCTION

In traditional networks, how to better optimize network forwarding paths has always been a problem for scholars. Software Defined Networking was originally a new network architecture for control and forwarding plane separation proposed by Professor Nick McKeown of Stanford University and others around 2009 [1]. The architecture has the advantages of flexible routing policy control and centralized network topology sensing [2]. Taking advantage of these advantages, we can better calculate and deliver the path forwarding strategy.

In the SDN environment, the default algorithm used by most controllers is based on the Dijkstra algorithm with the shortest hop count. When the controller selects the forwarding path, it always calculates the shortest path from the source host to the destination host in the current network environment. When the load on the network is relatively large, the delay and packet loss rate increase due to congestion on some links on the shortest path, while the link utilization rate on other non-shortest paths is lower. The path is not optimal. In response to this, scholars have proposed many classic routing algorithms, such as ant colony algorithm [3], genetic algorithm [4] and so on. The ant colony algorithm, as a bionic algorithm, has achieved good results in solving the routing problem of SDN networks [5][6]. The adaptive ant colony algorithm proposed by Stefano AD [7] et al. initially implements load balancing by adapting the ant colony algorithm to the SDN network. However, under actual conditions, the current link state and QoS requirements of different traffic are in the path. It should also be taken as a factor in consideration.

Based on the above problems, this paper improves the ant colony algorithm by designing a path optimization model under SDN, and uses the advantages of SDN to filter the Top-K optimal path through QoS requirements and link state to speed up the evaluation of the algorithm. Perceived changes in link state Dynamically adjust the volatility coefficient of the pheromone, so that the SDN network achieves better results in the QoS requirements and load balancing.

2. ANT COLONY ALGORITHM PRINCIPLE

In the process of foraging, ants express a better path by secreting pheromones of different intensities, and later ants tend to choose more pheromone paths, resulting in more and more ants on the optimal path. The ants on other paths will gradually decrease over time and eventually disappear, thus forming an optimal path. Inspired by this, an ant colony algorithm was proposed.

The transition probability of ants in each node in the traditional ant colony algorithm is:

$$p_{ij}^k = \sum_{j \in L} \frac{\tau_{ij}^k \eta_{ij}^k}{\sum_{j \in L} \tau_{ij}^k \eta_{ij}^k}$$  \hspace{1cm} (2.1)

Where k is the label of the individual ant colony, i is the current position of the ant colony, and j is the location that the ant colony can select. $p_{ij}^k$ indicates the probability that the ant k in the i position selects the j position, and L is the set of the next optional position of the ant. $\tau_{ij}^k$ indicates the pheromone concentration between i and j. When an ant passes a point or passes all points, it implements an update strategy for the pheromone of the node concerned. The pheromone concentration update strategy can be expressed by the following formula:

$$\tau_{ij}(n+1) = \rho \times \tau(n) + \sum_{k=1}^{m} \Delta \tau_{ij}^k$$  \hspace{1cm} (2.2)

$\rho$ represents the evaporation rate of the pheromone on the path. According to the concept of ant colony algorithm, combined with the advantages of SDN, we propose a path optimization model based on link state perception in SDN environment.

3. PATH OPTIMIZATION MODEL

In the SDN environment, unnatural ant colony algorithm by improved ant colony algorithm, the data packet is regarded as an ant and the load on the network link is regarded as a pheromone, so that the ant
tends to a link with a lower pheromone concentration. At the same time, according to the collected link state, the volatilization speed of the pheromone is adjusted, and the optimization of the path evaluation set is performed by using the Top-K optimal path.

In section 3.1 we describe the architecture of the entire path optimization model. In section 3.2 we describe the unnatural ant colony algorithm, in section 3.3 and section 3.4 we optimize the path model by optimizing the ant colony algorithm's evaluation set and dynamically changing the volatilization velocity of the link pheromone, and in section 3.5 we give a typical route strategy solving process.

3.1 ARCHITECTURE
The path optimization model is divided into the following four modules:
- Pheromone management module (PMM). Collection and update of pheromones on various links in the network.
- Network link information collection module (NIM). Collect information about each link in the network, such as delay, packet loss rate, jitter rate, and bandwidth.
- QoS requirement registration module (QRM). Register the QoS requirements of the service traffic to the system as a reference for delivering the corresponding routing strategy.
- Routing strategy formulation and delivery module (RDM). The QoS of the registered service traffic is used as a reference when the corresponding routing strategy is delivered.

The architecture diagram is shown in Figure 1:

\[ P^{i}_{j} = \prod_{j \in L} \frac{\tau_{ij}^{\alpha} \eta_{ij}^{\beta}}{D} (D = \sum_{j \in L} \tau_{ij}^{\alpha} \eta_{ij}^{\beta}) \]  

(3.1)

\( \) represents all candidate links. We reduce the evaluation range of the ant colony algorithm by designing the Top-K optimal path algorithm to determine the set \( L \) of optional links.

3.2 Unnatural ant colony algorithm
Unlike the standard ant colony algorithm, the unnatural ant colony algorithm is more like an unnatural behavior, which forces the ants to move along all of their covered paths to achieve load balancing. That is, avoid trying the path with the strongest pheromone and exploring the path with the weakest pheromone. We treat packets as ants and treat the load on the network link as pheromones. Optimize network performance in terms of throughput, communication latency and packet loss. Through this strategy, routing algorithms can reduce network congestion, improve throughput and low latency, and ensure even distribution of load across all links.

In the initial phase we put an equal amount of pheromone for each link. Then the probability that the ant selects the line \( ij \) at node \( i \) is:

\[ P^{i}_{j} = \prod_{j \in L} \frac{\tau_{ij}^{\alpha} \eta_{ij}^{\beta}}{D} (D = \sum_{j \in L} \tau_{ij}^{\alpha} \eta_{ij}^{\beta}) \]  

(3.1)

\( \) represents all candidate links. We reduce the evaluation range of the ant colony algorithm by designing the Top-K optimal path algorithm to determine the set \( L \) of optional links.
3.3 Top-K optimal paths algorithm
KC Abbaspour et al. [8] have proposed that pre-processing of pheromone is not applied before the actual operation of the ant colony algorithm, a certain number of paths are found by preprocessing, and then the route is selected according to the pheromone, so that a better path selection can be obtained. So, we use Top-K optimal path algorithm for pre-optimization. First, the path of the first N(N > K) shortest hops is obtained by implementing the Yen algorithm [9], and then by querying the QoS requirements of the service registration, we select the QoS requirements that satisfy the service, and at the same time relatively better. K paths as an evaluation set L for the unnatural ant colony algorithm.

3.4 Pheromone volatilization strategy based on link state
The pheromone volatilization strategy in the ant colony algorithm determines the convergence speed of the algorithm. This paper uses the network status of the NIM to dynamically change the pheromone volatilization speed of the corresponding link. Because the concentration of pheromone in the link in the unnatural ant colony algorithm does not reflect the state of the current link, we set different volatilization speeds depending on the state of the link. The volatilization speed of the path pheromone with a good link state will be faster. After evaluation, this paper formulates the volatility of the pheromone in each link as the formula:

$$\rho = \max \{10 \times \varphi, 10 \times \lambda, \beta\}$$  \ (3.2)

$\varphi$ indicates the jitter rate of the link, $\lambda$ indicates the packet loss rate of the link, and $\beta$ indicates the bandwidth usage of the link.

3.5 Routing strategy solving process
Assume in our SDN network architecture as shown in Figure 2:

![Figure 2](image_url)

A, B, C, D, E, F are OpenFlow switches. U is the user and S is the service provider. Now we want to import the traffic of user U into service S. The routing strategy solving process is as follows:

1. QoS requirements for user registration services.

2. When the first data packet of user U reaches E, there is no matching forwarding rule, and the controller is queried to obtain a forwarding rule. At this point, the controller uses the Top-K optimal path algorithm to select the Top-K optimal path that meets the user’s QoS requirements. Because the network size in the graph is small, it is assumed that all reachable paths are selected by us as the optimal path. Then the three candidate paths are E-A-B, E-F-D-B, E-F-D-C-B. Then, L in the unnatural ant colony algorithm is the link in the three paths.

3. The pheromone concentration of the E-links E-A and E-F of the E-node in the L-set is obtained from the pheromone management module(PMM), and the probabilistic route is selected according to
the formula (3.1). Suppose we have chosen link E-F. In order to prevent the loop from appearing, the link is placed in the taboo table after each link, that is, we put E-F into the taboo table. When the data packet arrives at the switch D, there are two alternative links D-B and D-C in the set L. At this time, we query that B is the destination switch, so, the link D-B is directly selected as the forwarding path.

(4) When the data packet arrives at the switch B, a route from the user U to the network service S is formed in the network.

(5) After that, we use the global update strategy to update the pheromone concentration. The pheromone management module (PMM) detects the number of data packets transmitted through the path, and generates a corresponding backward ant to release the pheromone on the link along the path. At the same time, the pheromone of each link along the way is evaporated according to the volatilization coefficient given in formula (3.2).

4. PERFORMANCE TESTING
Set up the network topology shown in Figure 3 under Mininet and use software named iperf for traffic simulation.

We set the bandwidth of each link to 2Mb/s and continuously increase the load in the link. The path optimization model is compared with the traditional SDN based Dijkstra algorithm with the shortest hop count. The average packet loss rate of the entire network as shown in Figure 4:
It can be seen that compared with the traditional Dijkstra algorithm based on the shortest hop count, the proposed model can better reduce the packet loss rate in the network and increase the throughput in the network, so that the whole network has a good stability.

At the same time, when we set the bandwidth of a link such as OF1-OF2 to 0.5 Mb/s, the load balancing performance of the path optimization model when the link state is poor is simulated. Because we optimize the pheromone volatilization speed based on the current link state, compared to the model proposed in [7], load balancing can be achieved according to the link state.

The experimental results show that our proposed path state-aware path optimization model achieves our expected results.

5. CONCLUSION
In the scenario of SDN network architecture, this paper proposes a path optimization model based on the unnatural ant colony algorithm to detect the link state of the network so as to load balance the traffic in the network, the QoS requirements of users are taken into account at the same time.

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