A secure multicast routing algorithm Based on distributed PCE in multi-domain optical networks

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Abstract. Aiming at the calculation of secure multicast routing in multi-domain optical network, a new secure multicast routing algorithm based on distributed path calculation element was proposed. Firstly, the distributed PCE multicast routing model was constructed, and the intra-domain cost, inter-domain cost, maximum available wavelength and related constraints were defined. Secondly, the pheromone update strategy of ant colony algorithm with ant queen was locally simplified and modified to make it suitable for the distributed PCE architecture of multi-domain optical network. At the same time, by optimizing the trust value calculation method in the lightweight cross domain trust model, the algorithm can be applied to the calculation of trust value of multicast routing in multi-domain optical networks. Finally, the specific implementation steps of the algorithm were given. The analysis and experimental results show that the algorithm can not only ensure the security of cross domain multicast routing, but also prevent the malicious nodes from destroying. Compared with the typical multicast routing algorithm, it has better performance in multicast tree cost and blocking rate in malicious node environment.

1. Introduction
With the rapid increase in the demand for Qos services, real-time applications such as video conferencing and distance education carried by optical networks have rapidly become popular, and the problem of multicast in optical networks has attracted more and more attention [1-2]. Different from the calculation problem of the multicast tree in the general network, the core of the optical layer multicast problem is how to find a suitable route for a given multicast service and allocate the corresponding wavelength, so as to realize the normal transmission of data services. Therefore, research on safe and efficient multicast routing algorithms is very important for optical layer multicast.

At present, many achievements have been made at home and abroad for the research of multicast routing algorithms in optical networks. Literature [3] proposed a heuristic method based on genetic algorithm for the multicast problem of optical network without wavelength conversion and light splitting. In reference to the high cost of multicast services in optical networks, the literature [4] proposed a heuristic algorithm for the least cost path under the hierarchical PCE architecture. However, none of the above algorithms involves the security issues of optical networks. Literature [5] proposed a new security strategy and routing algorithm for multi-point eavesdropping attacks in optical networks to provide better security and resource utilization for optical networks. Reference [6] combined the artificial fish school algorithm with the multi-domain optical network architecture based
on hierarchical PCE, and proposed a multi-domain optical network attack sensing routing algorithm for the physical layer attack problem, but it is not suitable for distributed PCE. Multicast tree calculation under the architecture.

Therefore, under the distributed PCE architecture, this article first builds a distributed PCE multicast routing model, then combines the ant colony algorithm and trust management, and proposes a distributed PCE-based multi-domain optical network secure multicast routing algorithm SMRAD. This algorithm has good applicability for secure multicast routing calculation under this architecture.

2. Problem Description

Definition 1: Define the multi-domain optical network under the distributed PCE architecture as $G = (V, E)$, where $V = \{V_1, \ldots, V_n\}$ is a collection of nodes. The link between node $V_i$ and node $V_j$ is represented as $e_{ij}$. The collection of optical links is $E = \{e_{ij} | 1 \leq i, j \leq n\}$. The source node is $s$, and the route from the source node to each destination node is represented as $T=(V_i, E_i)$ ($T \subseteq G$). Definition 2: Define the inter-domain directed graph as $G^* = (V^*, E^*)$, where $V^*$ represents the set of all domain nodes, $E^*$ represents the set of all domain nodes, and $E^*$ represents the link set of neighboring nodes $p$ to $q$. Each link defines a set of parameters $\{(c^*_p, w^*_p)\}$. Where $w^*_p$ represents the available wavelength between domains, and $c^*_p$ represents the inter-domain cost of neighboring nodes $p$ to $q$.

For any two nodes $m$ and $n$ in different domains, their inter-domain routing is recorded as $P^*(m, n)$. The inter-domain costs of $m$ and $n$ is $C(m, n) = \sum_{i, j \in P^*(m, n)} c^*_i + m_i \sum_{j \in m_i^*} c^*_j$. Among them, $c^*_i$ represents the approximate intra-domain chain cost when the multicast tree has not been established in each domain, and $m_i^*$ represents the number of egress nodes in each domain. The maximum usable wavelength between domains is $m_i = \min_{1 \leq i \leq n} (w^*_p)$.

Definition 3: The directed graph in the defined domain is $G = (V, E)$, where $V$ represents the set of all nodes in the domain, and $E$ represents the link set of adjacent nodes $x$ and $y$ in the domain. A set of parameters $\{(x, y, w^*_x)\}$ is defined for each link in the link set, where $x^*_p$ represents the available wavelength in the domain, and $c^*_o$ represents the cost of adjacent nodes $x$ to $y$ in the domain. For any two nodes $a$ and $b$ in the domain, the route between them is recorded as $P^*(a, b)$. The intra-domain costs of $1$ and $2$ are: $C(a, b) = \sum_{i, j \in P^*(a, b)} c^*_i$. The maximum usable wavelength in the domain is $W^*(a, b) = \min_{1 \leq i \leq n} (w^*_p)$.

For a multicast request, $E$ is the minimum cost tree, and the cost of the multicast tree is:

$$C(T) = \sum_{(x, y) \in T} C(x, y)$$  \hspace{1cm} (1)

Assuming that the intra-domain trust value constraint of a multicast is $1$, the inter-domain trust value constraint is $2$, and the minimum available wavelength is $3$, then the multi-domain optical network secure multicast routing problem under the distributed PCE architecture can be expressed as satisfying the following three conditions:

1. The multicast tree should include all source nodes and destination nodes.
2. For the establishment of each multicast tree, the inter-domain and intra-domain trust values satisfy:
   $$Tr_{tg} \geq \Delta_1, Tr_{tg} \geq \Delta_2$$  \hspace{1cm} (2)

3. Maximum available wavelength meets:
   $$W(P_j(s,v)) \geq \min_{v} W_{min}, \forall v \in M$$  \hspace{1cm} (3)
3. On the basis of satisfying condition 1 and condition 2, complete the establishment of the multicast tree \( T = (V, E) \subseteq G \) from \( S \) to all destination nodes through the algorithm, and ensure that the generated multicast tree corresponds to the cost in formula (1) as little as possible.

3. Algorithm steps
The steps of the SMRAD algorithm are as follows:

Input: Given graph \( G = (V, E) \), source node \( S \) and destination node \( v_j \).

Output: The cross-domain multicast tree that meets the trust value and wavelength constraints and has the lowest cost \( T^* \).

Step 1: Filter out the wavelengths that meet the conditions according to the constraints.

Step 2: The PCE of the domain where the source node \( S \) is located judges whether the destination node \( v_j \) is in the domain, and if so, it proceeds to step 5. If not, go to step 3.

Step 3: PCEs cooperate with each other to find the domain where the destination node \( v_j \) is located.

Step 4: Start the calculation of inter-domain multicast tree \( T^* \).

Step 4.1: Know the source node \( S \) and destination node \( v_j \) and their domains. Remember that the maximum number of cycles is \( N \), the initial value of \( N \) is 0, the calculation rule is set to \( N = N + 1 \), the initial value of the pheromone increment for each optical path is configured to be \( \Delta \tau_r = 0 \), \( \Delta \tau_r^* = 0 \) and the time is \( t = 0 \). Place \( M \) ants at the source node, and each ant corresponds to the corresponding taboo table. At this time, the source node is in the taboo table.

Step 4.2: According to the neighboring node trust value algorithm and the inter-domain multicast routing trust value algorithm, the trust value of the routing between nodes and between domains is obtained.

Step 4.3: Each ant starts to search and construct a path. In this process, it will take the node with a higher trust value as the next hop node. When all ants have completed the search, calculate the trust value of the search path and delete The path that does not satisfy formula 6 and all the information of the remaining path is passed to the queen.

Step 4.4: The source domain PCE ranks the ants according to the trust value of the search path. Then the pheromone is updated according to the following rules: the source domain PCE obtains the current set of better solutions, the pheromone enhancement is only performed on the edges belonging to the shortest path, and the higher the ranking ant, the higher the pheromone obtained.

Step 4.5: Get the path of the current optimal solution. If the number of searches is less than \( N \), then go to step 4.6, otherwise go to step 4.3 to search again.

Step 4.6: Record the current round and the current optimal solution, and clear the taboo table of the previous optimal solution path. Check whether the obtained solution path meets the wavelength limit. If it does, rank the set of better solutions according to the cost to obtain the optimal solution among the better solutions, and proceed to step 4.7. Otherwise, go to step 4.1.

Step 4.7: The source domain PCE obtains a trusted and minimal cost inter-domain multicast tree from the source node to the destination node that meets the constraints \( T^* \).

Step 5: Start the calculation of multicast tree \( T^* \) in the domain.

Step 5.1: Know the entry and exit nodes of each domain. Remember that the maximum number of cycles is \( P \), the initial value of \( P \) is 0, the calculation rule is set to \( P = P + 1 \), and the initial value of the pheromone increment for each optical path is \( \Delta \tau_r = 0 \), \( \Delta \tau_r^* = 0 \) and time \( t = 0 \). Place \( R \) ants at the domain entry node, and each ant corresponds to the corresponding taboo table. At this time, the domain entry node is in the taboo table.

Step 5.2: According to the neighboring node trust value algorithm and the intra-domain multicast routing trust value algorithm, the trust value of the routes between nodes and within the domain is obtained.
Step 5.3: Each ant starts searching and constructing a path, and still uses the node with a higher trust value as the next hop node. When all ants have completed the search, calculate the trust value of the search path and delete those that do not satisfy formula 6 Path and pass all the information of the remaining path to the queen.

Step 5.4: The PCE of each domain ranks the ants according to the trust value of the search path. Then the pheromone is updated according to the following rules: PCE of each domain obtains the set of current better solutions, pheromone enhancement is only performed on the edges belonging to the shortest path, and the higher the ranking ant, the higher the pheromone.

Step 5.5: Get the path of the current optimal solution. If the number of searches is less than $P$, then go to step 5.6, otherwise go to step 5.3 to search again.

Step 5.6: Record the current round and the current optimal solution, and clear the taboo table of the previous optimal solution path. Check whether the obtained solution path meets the wavelength limit. If it does, rank the set of better solutions according to the cost to obtain the optimal solution among the better solutions, and proceed to step 5.7. Otherwise, go to step 5.1.

Step 5.7: Each domain PCE obtains a credible and least costly intra-domain multicast tree $T'$ from the respective domain entry node to the respective domain exit node that meets the constraints.

Step 6: The PCE of each domain exchanges the calculated path to the PCE of the source node domain to obtain a cross-domain multicast tree that satisfies the trust value and wavelength constraints and has the lowest cost.

The path selection rules and pheromone update strategy of the ant colony in the algorithm are as follows:

Suppose the total number of ants is $m$, $\tau_{ij}(t)$ represents the amount of information remaining between nodes $i$ and $j$ at time $t$; $\alpha$ is the pheromone heuristic factor, which mainly affects the global optimization ability and convergence speed of the algorithm; $\beta$ is the pheromone self-heuristic factor. $\eta_{ij}(t)$ represents the heuristic information between nodes $i$ and $j$; $\text{allowed}_{ij}$ represents the set of nodes that the ant can choose next; $p_{ij}^t(t)$ represents the probability of the ant transferring from $i$ to $j$ at any time $t$.

$$p_{ij}^t(t) = \begin{cases} \frac{\tau_{ij}^\alpha(t)\eta_{ij}^\beta(t)}{\sum_{j \in \text{allowed}_{ij}} \tau_{ij}^\alpha(t)\eta_{ij}^\beta(t)}, & j \in \text{allowed}_{ij} \\ 0, & \text{otherwise} \end{cases}$$

$$\tau_{ij}^\alpha(t) = \alpha$$

Among them, $\eta_{ij}(t)$ is the trust value of neighboring node $j$.

4. Simulation setup
In order to verify the effectiveness of the algorithm, this paper uses NS2 to conduct experiments, and chooses the multi-constrained QoS multicast routing algorithm of literature [7] and the improved ant colony algorithm of literature [8] as two typical multicast routing algorithms for comparison. First, the software design is generated through the NSBench script and the network topology shown in Figure 1 is generated as the topology of a single domain. There are 14 nodes and 17 links in the network, and then the experimental network topology shown in Figure 2 is formed. The number of domains 3 can be set according to actual needs. In the experiment, the average rate of PCReq message arrival obeys the Poisson distribution. The proportion of malicious nodes in all nodes is set according to the experimental requirements. Other parameter settings are shown in Table 1.
Figure 1. Network topology of a single domain

Figure 2. Experimental network topology

Table 1. Parameter settings.

| Parameter                | Value |
|--------------------------|-------|
| Number of wavelengths    | 20    |
| Wavelength bandwidth     | 2Gbps |
| $\alpha$                 | 1     |
| $\beta$                  | 0.5   |
| $Q$                      | 1     |
| $\rho$                   | 0.5   |
| $Tr_{th}$                | 0.3   |

5. Simulation analysis
Under the condition that the number of domains is 6 and the network load is 80Erl, the ratio of different malicious nodes is set. The network connection blocking rate of the three algorithms in the malicious node environment is shown in Figure 3.
The experimental results show that as the proportion of malicious nodes increases, the blocking rate of network connections without the application of the trust model of the multi-constrained QoS multicast routing algorithm and the improved ant colony algorithm increases sharply, exceeding the tolerance of the network and affecting normal data transmission. The SMRAD algorithm has increased more steadily. This is because there is a probability of selecting malicious nodes in the routing process without the control of a trust mechanism. When the number of malicious nodes increases, the probability of routing calculation failure also increases, and the SMRAD algorithm in routing selection, only nodes with higher trust values are selected, which has a certain shielding effect on malicious nodes.

6. Summary
This paper proposes a secure multicast routing algorithm SMRAD based on distributed PCE architecture. Analysis and experimental results show that, compared with typical multicast routing algorithms, SMRAD algorithm has better convergence, multicast tree cost and better performance in malicious node environments, which can meet the requirements of secure multicast under distributed PCE architecture.

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