Re-routing with Ant Colony Optimization for Information-Centric Networks

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Abstract: To solve network-related problems such as communication failures and network delays, a new network technology called an information-centric network (ICN) has been studied. However, there are various problems to be solved to develop ICNs, and they have not been put into practical use. In addition, research on ICNs has not considered re-routing, which is the reuse of routing information left by other users. In this study, we propose a method of re-routing in an ICN with ant colony optimization by reusing routing information to achieve efficient routing.

Keywords: information-centric network, ant colony optimization

Classifications: Network

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1 Introduction

Current network communications are based on a series of operations: searching for the location of a server to communicate with, accessing the server via its IP address, and retrieving content from it. However, it is not efficient for users to always have to access remote servers because retrieving content may increase communication traffic or cause communication failures. Therefore, an information-centric network (ICN) [1] that discovers and retrieves content by using an identifier that indicates the content itself is needed.

There are many different types of research on ICN routing[3, 4, 5]. One of which is using ant colony optimization (ACO)[2]. However, conventional research on routing using ACO for ICNs does not consider re-routing, where when one user searches for and downloads content, and then another user downloads the same content using the same path that the first user used to download. In this study, we will focus on re-routing. We aim to improve re-routing by reusing the routing information left by previous users. In particular, the proposed method is characterized by the fact that pheromones, which indicate information about the route to the destination in ACO, do not have any directionality, making it possible to search for content caches that are close to the user.

2 Related Study

SoCCeR[3], one of our previous works, is a method to determine the optimal destination of content in an ICN with multiple identical content by using ACO. When packets are sent to multiple identical content, and the desired content is reached, the delay time from the user to the content and the load on the server that holds the content are returned by the packets sent back to the user from the desired content. This enables the content to be retrieved from a server at low loads, reducing the overall burden compared with the case where the content is retrieved from a random server.

Manome et al.[5] proposed a method to enable routing between users and content by using ACO even if content is physically moved in an ICN. This method reduces the rewriting of routing tables by leaving routing information between the pre-movement node and the destination node when content movement occurs so that the routing between the user and the content can always be maintained.

There are many studies that have applied ACO to these various problems, but none of them use the routing information of other users for re-routing. Therefore, we propose a method to improve the performance of re-routing by reusing pheromones left by previous users.
3 Proposed Method

3.1 Overview

We assume an environment where an original server itself does not broadcast content information. We also assume an environment in which a cache exists, which is similar to the content in the original server. A user node shall retrieve content from either the original content or the cache. For the caching method, we assume edge caching[6] where the user node maintains the cache.

Figure 1 shows an overview of the content search and acquisition. When a user node searches for content, a small packet called an I-ant is generated from the user node, which searches the network for content nodes on the basis of routing information. After the I-ant finds the content node, it retraces the path it took and returns to the user node. At that time, it drops a pheromone on the path that represents the path information. The value of the pheromone is determined by the number of nodes the I-ant has passed through, and the value is recorded in each node’s table. When the I-ant returns to the user node, a new I-ant does the exact search. By repeating this operation, it is possible to search for the shortest path to the content node. The red line in Fig. 1 shows the pathway created in this way. This pheromone-based pathway can be reused by users seeking similar content, and thereby speeding up the discovery of the content node and facilitating the discovery of the shortest path.

The main feature of the proposed method is that it does not set any directional pheromone, which makes it possible to search both the cache and the original content, as shown in Fig. 1.

3.2 Formulation

The I-ant sent out by the user node searches for a content node on the basis of the pheromone concentration; when selecting a path, the I-ant selects neighbor nodes probabilistically. The probability is given by the following equation:

\[ p_j = \frac{\tau_{ij}}{\sum_{l \in L} \tau_{il}}. \]  

(1)

Where \( i \) is the index of the current node, \( j \) is the index of the neighboring node, and \( L \) is the set of neighboring nodes. \( \tau_{ij} \) is the pheromone concentration attached between nodes \( i \) and \( j \). If the hop count of an I-ant exceeds the TTL (Time to Live), the I-ant is discarded.

After content discovery, the I-ant determines the pheromone amount \( \Delta \tau \) by the following:
\[ \Delta \tau = \frac{S}{\lambda}. \]  

(2)

Where \( S \) is constant and \( \lambda \) is the number of nodes that the I-ant has traversed from the user node to the content node. In this way, routes with a large and small number of hops will be marked with a light and dark pheromone, respectively. When the I-ant returns to the user node, it updates the pheromone concentration it sought on the route. When the pheromone concentration between nodes \( i \) and \( j \) is \( \tau_{ij} \), the update is done as follows:

\[ \tau_{ij} := \tau_{ij} + \Delta \tau, \]  

(3)

\[ \tau_{ji} := \tau_{ij} + \Delta \tau. \]  

(4)

By updating the pheromone in this way, in edge caching, other user nodes that want the same content can reuse this pheromone and retrieve the content from the one that is closer to the original content and cache.

In addition, pheromones are volatile, and the pheromones attached to each pathway volatilize at regular intervals. The pheromone volatilization is calculated using the pheromone volatility \( \rho \) as follows:

\[ \tau_{ij} := \rho \tau_{ij} (0 < \rho < 1). \]  

(5)

When updating the pheromone, the upper and lower limits of the pheromone concentration should be set as shown in Eq. (6). This can enable the I-ant to diversify the pathways it chooses.

\[ \tau_{ij} := \begin{cases} \tau_{\text{max}} & (\tau_{ij} > \tau_{\text{max}}) \\ \tau_{\text{min}} & (\tau_{ij} < \tau_{\text{min}}) \\ \tau_{ij} & \end{cases} \]  

(6)

In addition, the minimum value of the pheromone is defined by using a constant value \( T \) and the number of neighboring nodes \( n \), as follows:

\[ \tau_{\text{min}} = \frac{T}{n}. \]  

(7)

By dividing the minimum pheromone value by the number of neighboring nodes, the difference between the pheromone concentration attached to the correct route and the pheromone concentration attached to other routes becomes larger during the route selection at the hub node, making it easier to search for the shortest route.

4 Case Study

We evaluated the effectiveness of the proposed method by measuring the number of hops to reach the content node through numerical simulation using the BarabasiAlbert (BA) model and a random model. The BA model is a network model with a “scale-free property” in that there are hub nodes with a
large number of links, while the random model lacks the “scale-free property”. In addition, the number of nodes in each network is assumed to be between 1,000 and 5,000.

We also prepared two methods for comparison. The first (Comparison 1) is a method that does not reuse the pheromones left by other users and is fixed at $\tau_{\text{min}} = 1.0$. The second (Comparison 2) is a method where pheromones are reused and is fixed at $\tau_{\text{min}} = 1.0$. The minimum distance from the user node to the content node was set to three hops. To confirm the effectiveness of the proposed method, the comparison method was chosen to be different from the proposed method in that it reuses the pheromones, and the number of neighboring nodes determines the minimum pheromone concentration.

Figures 2 and 3 show the results of the numerical simulation with the random network and BA model, respectively. The vertical axis shows the average number of hops and the horizontal axis indicates the number of nodes. The red line shows the actual shortest path from the user node to the content; the closer the average hop count is to the shortest path, the better the performance. Figure 2 shows that the proposed method and Comparison 2 are able to find the shortest path. This is probably because the reuse of pheromones makes it easier to find the content. In addition, in the random model, the effect of reusing pheromones in finding the shortest path is significant. Figure 3 shows that the proposed method can find the shortest way in the BA model. This is because the search for the shortest path through the hub node was facilitated by changing the minimum concentration of pheromones in accordance with the number of node links. It also shows that the effect of reusing pheromones is small in finding the shortest path in the network model with hub nodes.

5 Conclusion

In this research, we proposed a routing scheme using ACO that considers re-routing. From the experimental results, we were able to confirm the effectiveness of our method. In the future, it will be necessary to consider routing methods that take into account parameters other than the number of hops, as well as the case where there are multiple types of cached content.
Fig. 3. Comparison with a BA model.

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