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An Optimization-based Routing Forwarding Algorithm in ICN

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Abstract: In dynamic routing construction of ICN, traditional CCN routing mechanism can improve the diversity and reliability of data forwarding. But it also brings problems in retrieval redundancy, taking some load to the network. SoCCeR strategy uses ant colony algorithm to finish single-path routing of CCN in distribution, while it has defects in ant agency control and convergence feature. Therefore, based on rapid routing this paper proposes a service nodes selecting algorithm with optimized ACO algorithm. The algorithm integrates path time-delay and load of service node into optimized selecting algorithm of routers, which makes full used of the visiting feature of users to improve visiting quality and reduce request loss efficiency. In our method, the probabilistic state forwarding rules are modified and adaptive pheromone updating formulas are introduced, to prevent ant agency to fall into search stagnation, due to abnormal accumulation of pheromone density in current optimal path. So the routing algorithm is more responsive to the dynamic changes of network topology.

Keywords: CCN, Pheromone, Content activity, CAACO

1 Introduction

Along with rapid development of resource scale and user quantity on Internet, the network communication aggravates local flow of network and displays weakness such as load imbalance, low efficiency, etc. In order to change this situation fundamentally, researchers propose a novel network system framework, Information-centric Network (ICN) [1]. It increases copy and storage function of routing node on resources, so that routing node can also be a resource provider to change the mode to obtain resources in IP network according to terminal position. Thus, users only concern the resource itself so as to adapt to large-scaled data sharing. The purpose of ICN is to develop a more effective network framework for content distribution, access and sharing. It satisfies clients request for resource by content replica and caching. At present, there has appeared many research engineer projects which mainly include Data-Oriented NetworkArchitecture(DONA), Publish-Subscribe Internet Routing Paradigm(PSIRP)Network of Information(NetInf), Content-Centric Networking(CCN), etc [2,3,4,5] The realization structure of these projects is different but their key design ideas are content-centered network. They all no longer use IP address on forwarding realization of system framework and promote routing node to own function of resources storage. In these years, the mode of directly deploying cache in router, that is, internal network cache, has been paid attention by many researchers [6]. The initial purpose of design on CCN is that the functions of network have changed from terminal-to-terminal of host communication to distribution and acquisition of content.

In CCN, common strategies include full forwarding strategy(FF) , random forwarding strategy(RF) and the shortest path forwarding(SPF) [7]. In FF, the node provides forwarding interest packet to all corresponding interfaces of most content sources. However, most interest packets will result in generating redundant flow in network. RF strategy randomly selects one forwarding interest packet in corresponding interface of content source, but RF cannot acquire effective performance. NCE adopts SPF strategy and it transmits the interest packet to the content source which has the least hop to current node. NCE method cannot guarantee selecting the optimal content source since it does not concern link status and node load. In addition, caching content replica

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on nodes is frequently changing so the selected content source nodes cannot effectively guarantee request content. Reference [8] combines network system of service center with network system of content center. It proposes a service route and service selecting method SoCCeR (Services over Content-Centric Routing). However, SoCCeR does not consider dynamic characteristics and volatility of the content on nodes, so it cannot be effectively applied in processing of CCN replica nodes. In network route processing, the flow distribution is constantly changing and network link or nodes will be randomly invalid or rejoined. Self-catalysis and positive feedback mechanism of ACO effectively match the solution feature of these problems, so ant colony intelligence is effectively applied to network routing area [9]. Related scholars propose that ant colony algorithm is applied in content center network to solve its problems in retrieval redundancy in related references in 2011, and obtain better effects.

Thus, contraposing to current CCN routing optimization algorithm, that is, the defect of SoCCeR algorithm in ant agent control and algorithm convergence, we offer improvement in two aspects: At first, content activity is introduced in routing optimization algorithm. It considers the behavior characteristics of users access and analysis on interest preference, and merges them into optimized selection algorithm of routing. So it can fully utilize features of users to improve access quality of users and reduce failure rate of users access, which also optimizes the route selection algorithm and QoS of network. Second, the probabilistic state transition rule of ant colony algorithm is modified and updating formulas of adaptive pheromone are introduced to avoid that pheromone density of current better path is constantly increasing. It avoids ant agent falls into search stagnancy, so that they have more chances to explore more optimal paths which has not been excavated. Finally, based on above improvement, we design an ant colony optimization-based service node selecting algorithm, that is, Content- Activity-Based Ant Colony Optimization (CAACO) algorithm. We specifically discuss the optimization process and realization module of this algorithm. Then the performance of algorithm is verified by some simulations. Compared to existing methods, our algorithm has fast convergence speed by distributed realization. It can be effectively applied in the environment of dynamic change of CCN content replica.

2 Analysis of Content-Center Network Routing Mechanism

CCN proposes a novel network system structure, taking information name as routing identity and IP as lower level network, without conception of ICP layer definition, adding the strategy layer and security layer [10,11]. As the next layer of network layer, strategy layer provides decisions for routing. As the last layer of network layer, security layer provides security for network. In CCN, URL is used to express information name to provide two types of packets: Interest and Data. Interest packet is request packet and Data packet is returned information packet. The workflow of CCN is shown as figure 1. At first, the server with information is flooding to the whole net. After router receives flooding data, information routers are calculated and established. When Client1 sends Interest packet, routers will search in cache first. If there is no corresponding information, the information name according to requirement will be routed to the nearest mytimes server [12]. Then it records Interest grouping track, provides path for information returning and cached mytimes information at the same time. Information packet returns Client1 according to original path. When Client2 also requires interest packet and it is routed to *B*. If there is *mytimes* information in *B*, the information will be returned from *B*.

Routing mechanism of content center network is based on Name-Based Routing. It does not need to search corresponding object storage position of content mark name. It just requires content to be routed to corresponding storage position to obtain information, and it directly routes request data packet to one or more contents to offer nodes based on name marker of content object [13]. When multi-duplication of one content is useful, FIB in router may connect between multiple next-hop port and the same one content name prefix. Then, one interest data packet will be replicated to multiple *C*, to trigger repeated returning content data packet. Although this feature offers effectiveness and diversity of data forwarding, the repeated interest data packet may cause huge energy consumption of service node. Thus, we believe that CCN node needs to extend its mechanism and make route optimization to avoid repeated calling of one request for multiple contents, so as to obtain a distributed, scalable and fault-tolerate system. Because CCN only routes request packet and data packet return to original node according to request packet path. So routing problem of CCN is how to choose an optimal content providing node for request packet. Based on above CCN node forwarding model, selecting an optimal content node equals to that node seeks the best next hop port for corresponding content item. That is, FIB of node only connects one next-hop port with this content item. Therefore, request packet will be routed to the optimal content provider along the optimal path, avoiding search redundancy effectively.

SoCCeR is an ant colony intelligence-based distributed path selection strategy which is applied in content center network. The main job of this strategy is to explore different next-hop port path information by forwarding exploration message in the network .Then it further discover the best port connected with prefix name of this content to complete path selection. SoCCeR design is based on ant colony optimization. It is a distributed and probability-based optimization method. So it is applicable

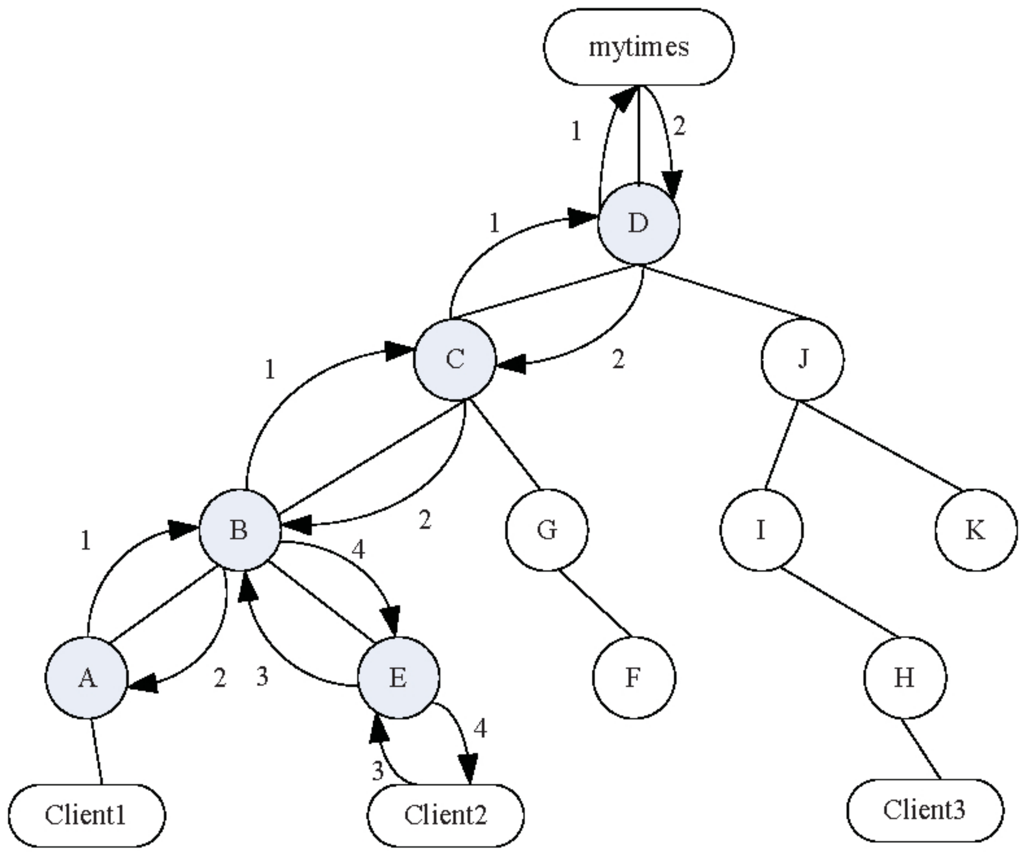

Fig. 1: Work flow of CCN

for route selection in CCN. It provides information retrieval on the some one content object in network and obtains perfect research achievements. The optimization framework of SoCCeR strategy is described as followings in detail: each network node periodically sends interest ant" at the beginning of each local time window. It takes randomly selected content item as the destination. This interest ant has one time stack to record forwarding time of its traversing various nodes. The nodes to generate interest ants push current forwarding time in stack and send it to each port which is related to this content item in its FIB. The nodes receiving interest ants will push its local time into the stack at first and transfer it to the port of the highest frequency value in pheromone table. In this way, it continues until this interest ant reaches corresponding nodes of content provider, as described in figure 2. To avoid stagnation, for instance, sustainable strengthening of current optimal path may possibly result in congestion and constant decrease of probability value of other ports. It will lead that all interest ants will be transmitted towards one direction. So nodes will transmit the interest ants to a random port in a small probability. This probability is the exploration probability and this ensures that interest ants can traverse a path which may be currently optimal but was unknown before. Repeating above process till returned ants traverse all the nodes in path and their corresponding pheromone of ports are updated, to finally reach original nodes. Interest ants and data ants periodically traverse various nodes in the network, but normal CCN data packet is only transferred on the optimal path.

The defect of SoCCeR is that its ant agent control strategy is completely random. That is to say, the generation of explorative agent in network is completely random. While FIB forwarding table of SoCCeR is updated for optimization, it randomly takes one reachable content item of this node as destination to send explorative message. The explorative message will complete path optimization with this content item in this period. Such random selecting strategy will lead that content item with higher request rate cannot obtain more fast and effective path optimization. In comparison, the path optimization of content item with lower request rate is too frequent.

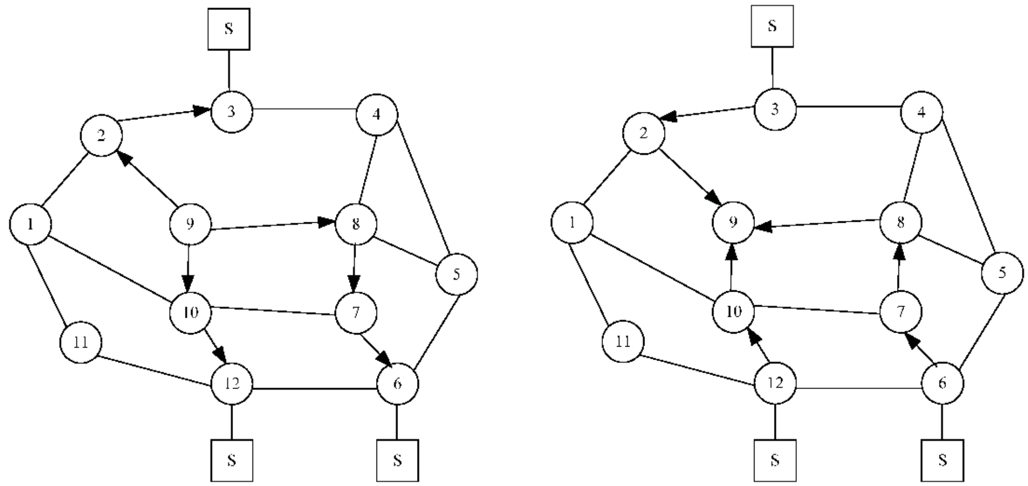

Fig. 2: Working principle of SoCCeR ant agents

3 Distributed Service Node Selection Based on Optimized ACO

3.1 Principal Idea

Basic ant colony optimization algorithm aims to search the shortest path. However, in terms of service nodes selection, ants not only need to detect the time-delay in path but also detect service load and content activity of the nodes. Thus, the basic ant colony optimization algorithm needs to be modified. Since ant colony algorithm needs to explore optimal service nodes, the improved ant colony algorithm proposed in this paper is approximate to AntNet [14], which needs two kinds of forward and backward artificial ants. Research shows that most dataflow of current internet service is from forwarding flow of streaming media data. However, 80% of users' access on streaming media concentrates in 20% of researching content. Obviously, it is essential for this access preference research to improve the performance of our optimization algorithm. Specifically, CCN nodes will generate a forward ant at the beginning of each time window. The forward ants explore path information with the purpose of one reachable content item on this node. It records the number of path hop whose initial value is zero and the load of content providers.

Destination selection of the forward ants is related to the activity distribution of different content items. It is proposed that there are N content providing nodes and each node can provide one content item. Reachable content item quantity of current nodes is n. Among all N content items, content s has the highest activity and its probability of users' access is f_s. Correspondingly, forward ant selects content item S generated by current nodes as destination with probability f_s. The higher activity of content item is, the more explorative message from nodes sending to offering nodes are, and more frequent update will occur on the paths providing nodes. Different paths of nodes owing higher activity will obtain more frequent update and they will promote the optimal path of practical selection on real data packet in network to be more approximate to the absolute optimal path. The reason is the pheromone density of links with link deficiency, congestion or other situation will volatile in a fast probability. In contrast, pheromone density on an optimal path with optimal network situation will be increased more quickly and efficiently. Therefore, by corresponding control with content activity distribution as guidance, the performance of routing optimization algorithm can be effectively improved.

Besides original forwarding information table FIB, CCN node increases status information table. Considering random CCN node v and recording t_v as status information table of v. For any content i in table t_v, status information table contains corresponding forwarding interface of F_i^v of this content and pheromone value as well as forwarding probability of each interface, as shown as figure 3.

$\tau^{v}_{i,j}(d)$, $\tau^{v}_{i,j}(l)$and ${}^{v}_{i,j}(\alpha)$ respectively denote the path time delay of transmitting interface j, load of service node and the normalized pheromone corresponding to content activity. $\forall j \in F_i^v$, $\sum_{j\in F^{v}_{i,j}} \tau^{v}_{i,j}(x) = 1$, $\forall i \in F$, $x \in \{l,d,a\}$. $P^{v}_{i,j}$is forwarding probability which shows the quality factor of j relative to other interfaces. It is calculated by weighted calculation of above three pheromone. α, β, γ are weight parameters and $\alpha+\beta+\gamma = 1$.

$$P^{v}_{i,j} = \frac{\alpha\tau^{v}_{i,j}(d)+\beta\tau^{v}_{i,j}(l)+\gamma^{v}_{i,j}(\alpha)}{\sum_{j\in F^{v}_{i,j}}(\alpha\tau^{v}_{i,j}(d)+\beta\tau^{v}_{i,j}(l)+\gamma^{v}_{i,j}(\alpha))} \tag{1}$$

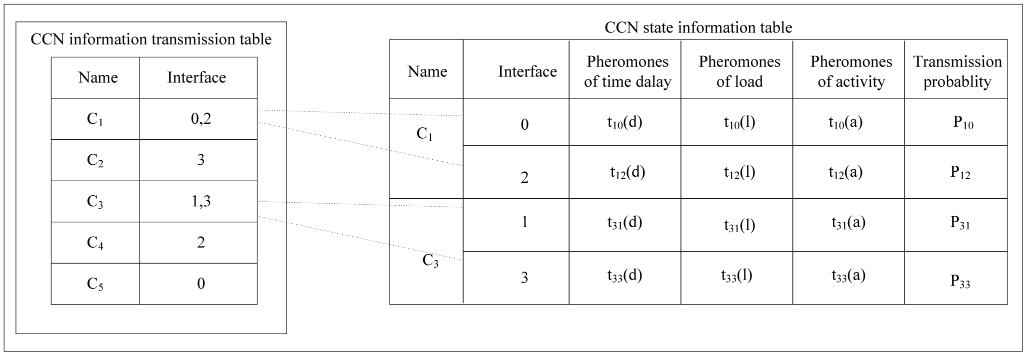

Fig. 3: Design of CCN nodes

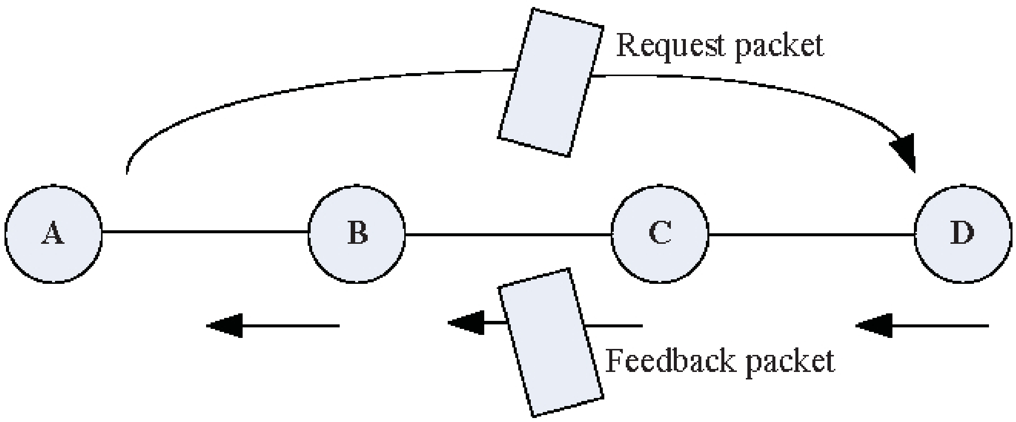

Fig. 4: Accelerating ant colony diagram

CCN nodes will periodically generate forward ants containing some content name. The forward ants are randomly transmitted to each interface to the next hop node, according to each interface probability in status information table. After repeated hop forwarding they finally reach the service node of content. The service node generates backward ants. Backward ants update pheromone value of each link on path during the process of generating nodes, from service nodes to forward ants. Routing node will update the forwarding probability of each interface with the pheromone.

3.2 *Adaptive Pheromone Updating Strategy*

Specifically, when mediate node in network receives a forward ant, it will select a next hop node based on current pheromone density in different paths and make it route towards destination node. Meanwhile, the returned backward ant will update various nodes pheromone density on path, based on path quality, that is, length of path time-delay and node load situation. Further it updates selection probability value on different paths by updating pheromone density. From this we know that the updating formulas of pheromone density are essential for probability status transformation rules of ACO. We design an adaptive pheromone updating formula, which is shown as following:

$$\tau_i(x) = \tau_i(x) + \Delta_x, \Delta_x = -n(x-1)\exp(x)(1-\tau_i(x))/gen \quad (2)$$

In this formula, Δ_x denotes the pheromone. When returned backward ants update corresponding pheromone density of nodes, they will calculate increment Δ_x based on adaptive pheromone updating formula. Based on above formula, on one hand, the pheromone increment which backward ants carry appears inverse relation of veil index. That is, the larger node load of path hop counts and content are, the smaller pheromone increment is; On the other hand, it is related to iteration times in current experiment. The larger iteration times are, the smaller pheromone increment is. This avoids falling into search stagnation of exploration agent and it has more opportunities to explore better paths which are not excavated. Particularly in unexpected situations, for instance, when current optimal next hop interface suddenly fails, the exploration agent will react more quickly to find out another optimal interface. It will not let the pheromone value of failed interface be higher to promote CCN node to still select failed Fast-Path to transmit packets.

When backward ants update pheromone density of nodes, they will further update the selected probability value of corresponding path according to probability status transferring formula. Specific formula is shown as:

$$P_i = \frac{[(1-\alpha)\tau_i^(d)+\alpha\tau_i^(l)]}{\sum_{i=1}^{N}[(1-\alpha)\tau_i^(d)+\alpha\tau_i^(l)} \tag{3}$$

At the same time, node i performs pheromone evaporation for the interfaces except j in F_i^v, that is, pheromone weakening:

$$\tau_{i,j}^v(x) = (1-\rho)\tau_{i,j}^v(x), j' \in F_i^v, j' \neq j, x \in \{d_{i,j}^v, l_{i,j}^v, a_{i,j}^v\} \tag{4}$$

If the node does not receive backward ant in time window δ_t, it performs pheromone evaporation to all the interfaces.

When explorative agent carrying path information is updating the pheromone of interface, the pheromone increment of interface is not only related to carrying pheromone of backward ants, according to adaptive pheromone updating formula, but it also relates to pheromone value of current interface as well as iteration number of current experiment. So it can avoid falling in search stagnation with increasing experimental iteration number. In addition, while network status is changing, it can find optimal path in time.

3.3 Backoff Mechanism and ACO Acceleration

Since content in cache of CCN node are dynamic and vaporable, the route of these caching nodes cannot guarantee accuracy of 100%. Therefore, under conditions that node caches are missing, backoff mechanism is significant. Probability forwarding can retransmit other service nodes to obtain request content, when a service node is missed. Reference [15] notifies the caching missing by sending feedback packet of content to original node of request packet. The source node of interest packet will reselect service node to forwarding. This paper inherits this kind of mechanism to solve caching missing of service nodes, and make an improvement of backoff mechanism to accelerate ACO.

Figure 4 refers to the schematic diagram if feedback packet to accelerate ACO. Content request packets are sent to service node D from node A. Node D checks content caching table: If cache is missing, feedback packet will be sent along the inverse path of request packet. Feedback packet is approximate to reverse proxy in ACO which contains content activity and its value is set as 0. When it passes one node, it updates pheromone value of corresponding content activity in this node status information table, so as to reduce forwarding probability of corresponding interface. The content feedback packet is transmitted from service D to A. On one hand, backoff mechanism is established to weaken pheromone of cache missing path; on the other hand, it reduces the probability of forwarding request packet to service node D and accelerates the process of ACO.

Based on above improvement, the flow of CAACO routing optimization is shown as figure 5. The processes are classified into three modules: exploring management module, exploring agent path-finding module and exploring agent path updating module. The nodes in network periodically send exploring agent while users request packet and returned the packet which is only transmitted in current optimal path. When solving the problems in search redundancy, QoS of network is also improved.

4 Simulations

We will study the performance of CAACO in CCN in following simulations. The experiment adopts GT-ITM to generate CCN network structure and MATLAB for simulation. The parameters in experiments are: There are 30 nodes in the network and the connection probability between any two nodes is 0.3; Link bandwidth is 100Mbps; In the edge nodes, we randomly select one node as content source server to publish original content; 5 nodes are selected as content agent, that is, service nodes, to be in charge of publishing and service of replica; the other nodes are general CCN routing nodes directly connected with users. The cache replacing strategy is LRU. The number of content in network is 2000 and the content data block obey uniform distribution between 128KB and 512KB; User request obeys Poison distribution with means $\lambda = 8$ and the duration time obeys negative index distribution with means 50s.

4.1 Content Request Efficiency and Time Delay

In the simulation process of figure 6, it describes statistical results of request failure rate of CAACO and SoCCeR algorithms. In this figure, abscissa denotes iteration times and ordinate denotes failure quantity of interest data packet of No.41 node in each iteration process, that is, the interest data packet that does not successfully reach content to offer acquired content. We study item s of that request from NO.41 to provide content by NO.65. The blue line refers to SoCCeR algorithm while red line refers to CAACO algorithm. From this figure we can see, in most cases, request efficiency of CAACO algorithm is lower than SoCCeR

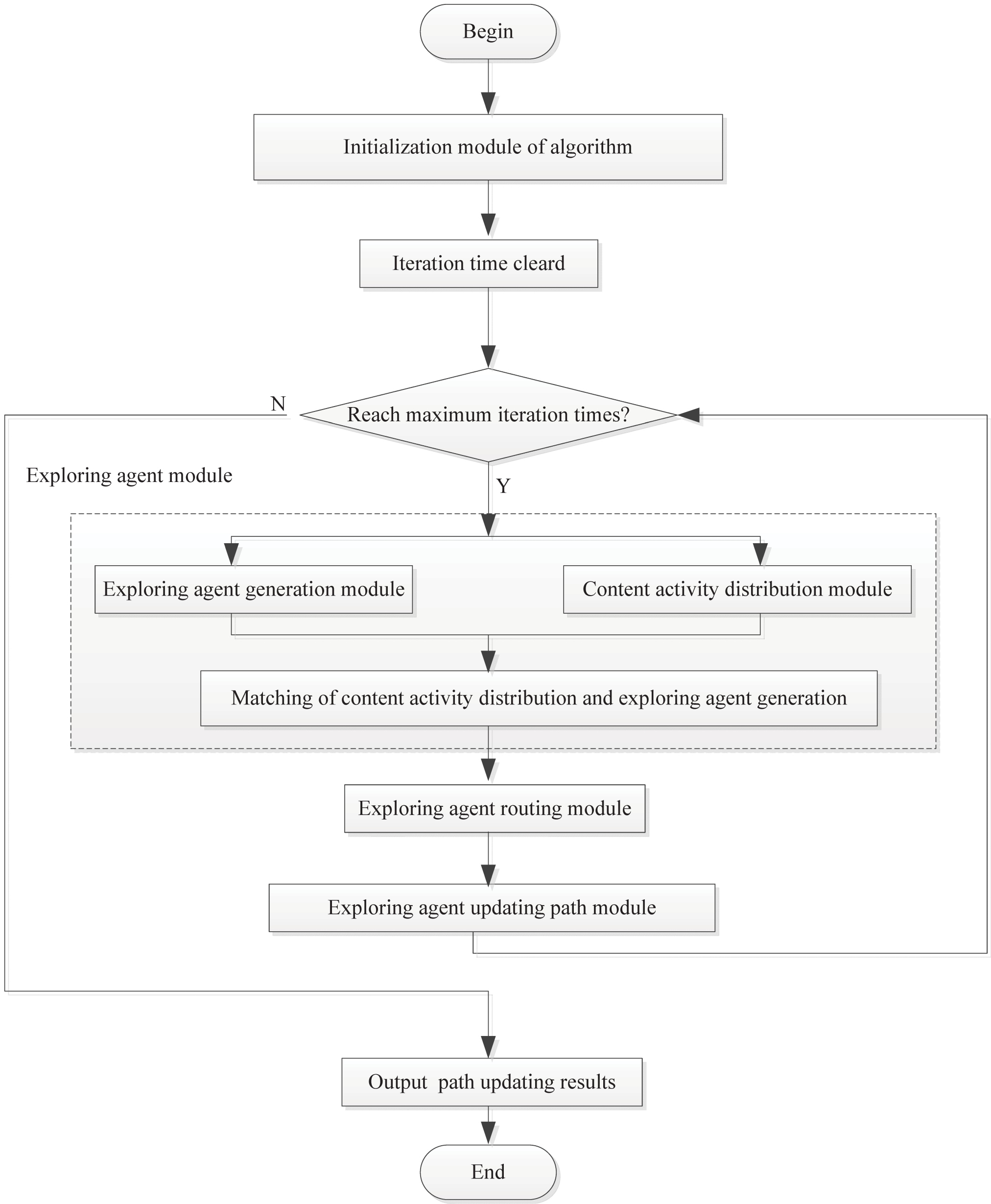

Fig. 5: Routing optimization flow of CAACO

algorithm. By observation of failure cased, the reason of failure is path looping. However, in CAACO algorithm, exploring agent distribution will explore path information which goes towards node of content provider with high activity in a larger probability, according to content activity distribution. So it can find loops of path leading to these content providing nodes in time. On the paths producing loops, exploring agent can not reach destination node within the largest hop count. It will reduce pheromone value of various nodes on this path by evaporation operation. Thus, CAACO algorithm can find path loop of content providing nodes in higher activity in time, and reduce practical efficiency of most users, which better meet the demand for content.

Figure 7 compares average request time delay of algorithms. During simulation, the completed accumulating request is used to calculate average time delay. We select three common methods in CCN: FF, RF and SPF in this experiment. It demonstrates that the average time delay of request gradually increases with increasing reaching request quantity. When request number is 410, time delay tends to be stable. The request arrival results in reducing system performance during initiative stage of simulation. When request times reach

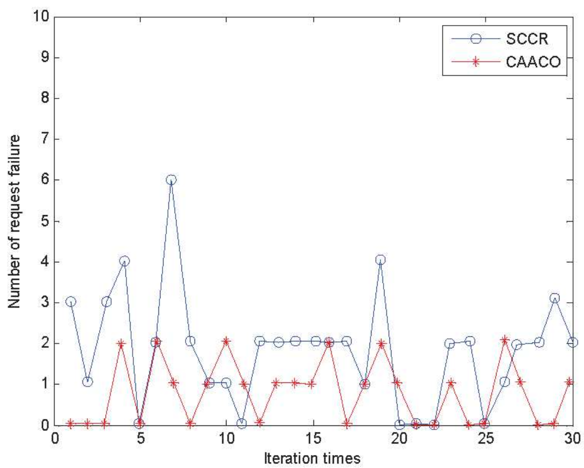

Fig. 6: Simulation of request failure efficiency

410, the existing request service completes and the resource is released, so as to provide service for new request and the system tends to be stable in the whole performance.

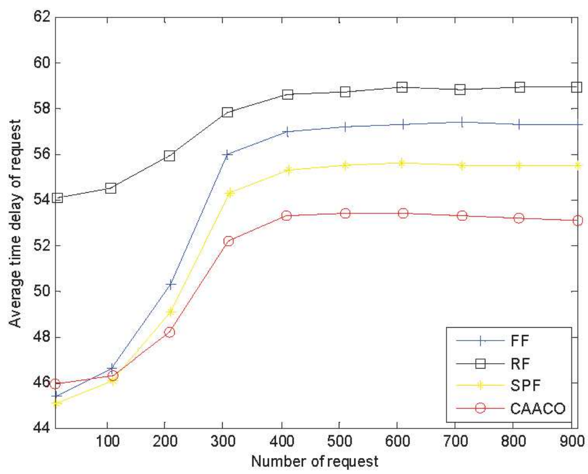

Fig. 7: Average time delay of content request

Since FF forwarding strategy will transmit interest packet to all content service node, it results in large increase of load for various nodes and its performance is worse. The average time delay of SPF is small at initial stage of simulation. This is because the hop count mainly affects the performance at initial stage. With increasing load of service node, the processing time delay starts to affect the performance. In comparison with other three strategies, the load of CAACO algorithm among various service nodes is balanced so it has the smallest average time delay. When simulation tends to be stable, there is nearly 4% reduction of CAACO algorithm in comparison with SPF strategy, in average time delay of content request.

4.2 Convergence of Forward Ants Producing Modules

In figure 8 and 9, when algorithm starts, the node selects node No.33 as the next hop node to destination node with probability about 0.8. When algorithm iterates 25 times, node No. 33 fails. We can see that the selection probability of No.33 rapidly decreases. However, for the current optimal port, that is, the selection probability of No.42 rapidly increases to become the next hop port of interest data packet forwarding. However, in convergence figure of SoCCeR algorithm, the selection probability of No.33 does not rapidly decrease after its effectiveness. Similarly, the selection probability of No.42 is not stable to become the optimal port. During iteration, there also appears the case that the selection probability of failed port 33 and port 42 is approximately equal. This easily causes misjudgment of interest data packet to result in request failure. Based on above discussion, the convergence of CAACO is also superior to SoCCeR.

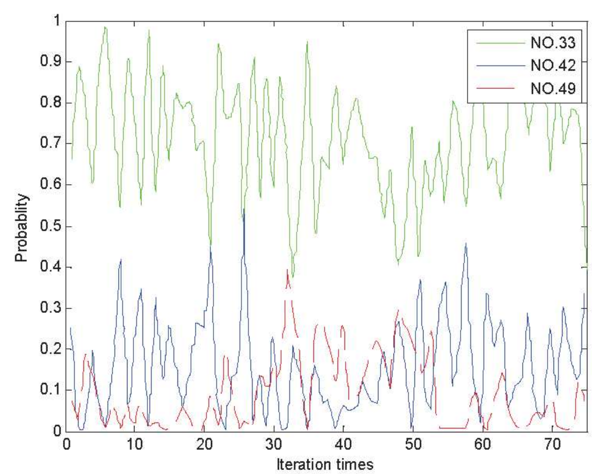

Fig. 8: Simulation of convergence results for SoCCeR

4.3 Load Simulation of Content Source Server

If less source server receives interest packet, it indicates more requests obtain content from agent service node to reduce the load of source server. The receiving content request of source server, that is, the number of interest packets is taken as load indicator for simulation. There are totally 5 times and their average value is taken as the final result. Figure 10 shows the comparison of four

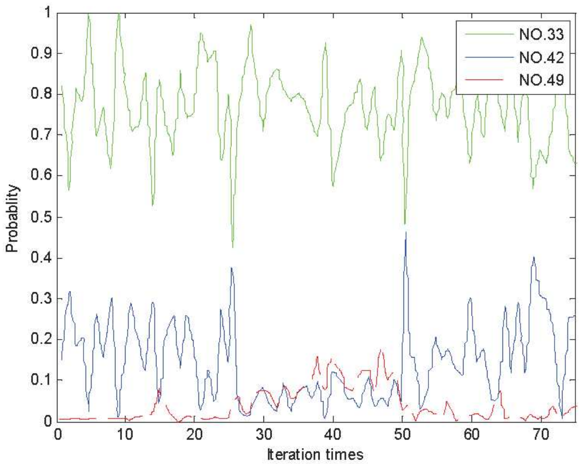

Fig. 9: Simulation of convergence results for CAACO

algorithms on load performance of content source servers. We can see that the source server is the heaviest in FF, because if transmits the interest packets to all service nodes. RF is approximate to SPF on performance: the interest packets are sent to single service node to reduce load of source server. However, received interest packets of CAACO source server is the least because the algorithm accumulates content request to make more requests service for agent node, which further reduces the load of source server. Compared to SPF, the source server load reduces about 41%.

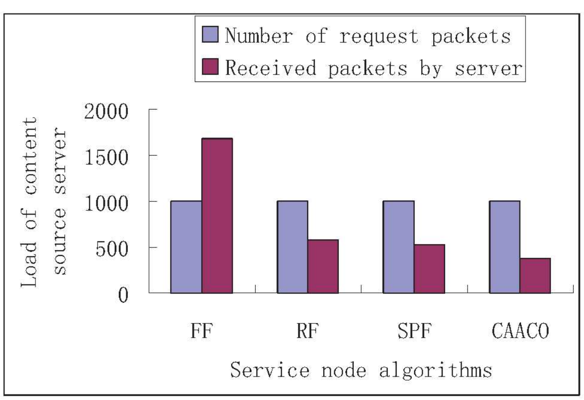

Fig. 10: Load of content source servers

5 Conclusion and Future Work

In the solution of CCN routing optimization, different content activities in network is introduced to analyze and control ants agent with distribution of content activity. In specific, for content items with higher activity, there exists higher probability for nodes to choose them as destination of searching path of ants agent. To get different paths of node with higher activity, it will promote the optimal path of practical selection on real data packet in network, which is more approximate to absolute optimal path. Therefore, by corresponding control with the content activity distribution taken by ant agent as instruct, the routing optimization algorithm can be effectively improved. Secondly, by the modification of calculating formulas of ant current colony algorithms and introduction of adaptive pheromone updating formula, the convergence of existing ACO is improved. Simulation experiment shows that CAACO has 4% reduction in average time delay, for the shortest strategies taking the least number of hops as server node selection. The load on source server is also reduced about 41%.

The distribution law of different content activity in content center network remains accurate assessment. As is discussed in the paper, current academia has only qualitative analysis on content activity in network and there are few analyses in quantitative assessment. However, CCN is still developing and there is not any large-scale implementation environment which also brings difficulty to provide quantitative assessment on content activity in real network environment. In addition, since there are many defects of ACO itself, in further research, we will focus on the content activity distribution in real network environment and combine ACO with other intelligence optimization algorithms, such as genetic algorithm, to find better routing solutions.

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