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ACO-inspired Information-Centric Networking routing mechanism

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ABSTRACT

In recent years, the bio-inspired solution has been employed to address routing optimization issue intelligently without manual intervention. In this paper, we propose a novel Ant Colony Optimization (ACO)-inspired Information-Centric Networking (ICN) Routing mechanism (ACOIR) by mapping ACO into ICN. At first, we devise a content management strategy based on the storage of name prefix to help conveniently and effectively manage and provide contents. Secondly, we propose a continuous model for content concentration by considering dynamic environment to conduct interest forwarding. Thirdly, we give a computation scheme about forwarding probability with physical distance and content concentration considered to determine the forwardable outgoing interface. Finally, we propose a comprehensive routing mechanism based on probabilistic forwarding to retrieve the most suitable content copy. We evaluate the proposed ACOIR, and the experimental results demonstrate that ACOIR can obtain the optimal solution and has better performance than other methods.

1. Introduction

Nowadays, Information-Centric Networking (ICN) has been accepted as a new paradigm to indicate that information objects are more important than IP addresses. The profound fruit brought by the change of communication mode can effectively achieve content distribution and support mobility [1]. However, moving the focus from IP addresses to information objects raises ICN routing scalability issue, because the amount of contents in network is considerably enormous. Especially when non-aggregatable flat names and even hierarchical names are employed, the routing table size increases explosively [2]. Besides, it is difficult for interest request to retrieve the content copy optimally, because the routing (table) in ICN is stateless and has no adaptability brought by the usage of distributed forwarding strategy. In addition, users in ICN usually need to send new interest requests when the content cannot be retrieved. In particular, when nodes or links cannot work effectively, the re-routing problem is very difficult to be solved. In that case, the network has to need manual intervention in order to make it work normally. Many kinds of ICN routing schemes have been proposed to solve the above mentioned routing problems, for example, forwarding interest request via the so-called best outgoing interface, exploiting in-network caching capability, and even devising other routing styles based on new architectures. However, the corresponding results are not adequately effective. Given this consideration, the effective ICN routing scheme should be further designed.

Recently, the bio-inspired solution has been investigated to solve the routing optimization problem [3–5], and its research can usually be divided into three fields, i.e., system, networking and computing. Among them, the bio-inspired system is capable of adapting and learning how to react to unforeseen scenarios with emergent properties. The bio-inspired networking is capable of providing new services and applications by considering networking features. The bio-inspired computing is capable of doing some operations according to the inherent computing rules and behaviors of biology. In fact, the bio-inspired solution can overcome the above mentioned three limitations in ICN routing due to its self-evolution, self-organization and survivability [6]. Naturally, the bio-inspired ICN routing is promising and feasible. As we know, most researches on bio-inspired ICN routing focus on Ant Colony Optimization (ACO) [7]. The principle of ACO is derived from the natural ant behaviors when searching for the shortest path between nest and food source. Meanwhile, ants communicate indirectly by laying the corresponding pheromone and following the trail with high pheromone, as a result, the pheromone accumulates on the shortest path. Although ACO-inspired ICN routing has been

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proposed, its feasibility has not been analyzed in the other literatures. Then, we summarize five comprehensive explanations to illustrate the feasibility of ACO-inspired ICN routing as follows.

- "What" not "where": ICN pays attention to the content rather than IP-address, in which interest packet is used to retrieve the content irrespective of its physical location. ACO concentrates on what food is rather than where food is, in which ant is used to find the unknown food.
- Naming: ICN relies on the name-based routing, where content name is persistent, available and authentic. The food name in ACO is also unique and it exists in the natural world, thus ACO relies on food name to find the route for ant. In addition, both content types and food odors are diverse.
- Consumer-driven: In ICN, content provider does not provide the content before sending content request from interest requester; when the content is obtained, it is returned to interest requester no matter which content provider it comes from; it is obvious that ICN is the interest-driven mode. In ACO, food is not likely to be provided for ant before food request is sent, and food only needs to meet the ant's requirements regardless of which ant wants; in other words, ACO belongs to the ant-driven mode.
- Mobility: ICN supports mobility of interest requester excluding that of content; in other words, the content can be returned to interest requester no matter where interest requester moves, however, interest requester cannot obtain the content effectively when the content moves. In ACO, ants can find food by their cooperation and organization no matter where food moves, and food can be also carried to nest no matter where nest moves, which displays that ACO supports mobility of food and nest.
- Multiple resources and most suitable resource: In ICN, Content Routers (CRs) cache the multiple content copies, and they always provide the most suitable resource (*e.g.*, the closest content copy). In ACO, there are many same food sources in the natural world, and ants find the most suitable food along the shortest path in a distributed and parallel manner.

Furthermore, existent ACO-inspired ICN routing proposals only adopt computing rules of ant (bio-computing) regardless of considering ICN features (bio-system and bio-networking). In other words, they only pay attention to design and update pheromone, without considering Content Store (CS), Pending Interest Table (PIT) and Forwarding Information Base (FIB) together. Besides, their corresponding updating strategies of pheromone are discrete, which is against the actual ant behaviors. Therefore, it is considerably essential to design a comprehensive mechanism to solve the ICN routing optimization problem from the perspective of system, networking and computing in order to make modelling process accord with the actual ant behaviors better.

In this paper, we propose a novel ACO-inspired ICN Routing mechanism (ACOIR), which maps the system models of ACO into ICN, and the major contributions are summarized as follows. (i) We map ACO into ICN with environment constraint and routing scenario, and propose the system framework of ACOIR by simulating ant behaviors to retrieve the most suitable content. (ii) To help manage contents in CS conveniently and provide them effectively, we devise a content management strategy based on the storage of Name Prefix Trie (NPT). (iii) To self-adaptively conduct interest forwarding, we propose a continuous content concentration model under dynamic environment in PIT. (iv) In order to determine the suitable outgoing interface in FIB to forward interest request, we propose a computation scheme about forwarding probability based on physical distance and content concentration. (v) To retrieve the most suitable content copy with good performance, we devise the comprehensive mechanism of ACOIR based on probabilistic forwarding and further prove its covergence.

The rest of this paper is structured as follows. The related work is reviewed in Section 2. Section 3 maps ACO into ICN. Section 4 presents the proposed ACOIR mechanism. The performance evaluation is done in Section 5. Finally, Section 6 concludes this paper.

2. Related work

2.1. ACO-inspired routing solutions in non-ICN

There are some ACO-inspired routing researches in traditional networks other than ICN-alike. In [8], an intelligent routing scheme based on ACO in peer-to-peer networks was proposed. It regarded the message which was forwarded successfully as agent and further used biological procedure to forward the following packets for resource discovery. In [9], an adaptive ACO-based pheromone diffusion routing framework was proposed by introducing network information region, in which spatial and temporal network information were exchanged among adjacent routers. In [10], a clustering-based ACO scheme was proposed to handle vehicle routing problem in dynamic environment covering both random and cyclic traffic situations. In [11], an ACO-based routing scheme in optical networks was proposed to deal with Byzantine failures. It used a crankback re-routing mechanism to circumvent congestion during the light-path establishment process.

Furthermore, ACO-inspired solutions have been used to solve the energy-efficient routing problem. In [12], a self-adaptive energy saving routing mechanism based on ACO was proposed to make the Internet more energy-efficient. It heuristically solved the formulated NP-hard routing problem without any supervised control by allowing incoming flows to be autonomously aggregated on specific heavy-loaded links and switching off light-loaded links. In [13], an ACO-based approach was used to compute routing table in a decentralized manner in order to minimize the global energy consumption.

Moreover, ant-like methods have been suitable for dynamic networks such as Mobile Ad hoc NETworks (MANETs) due to the adaptability to the changing environment. In [14], an improved ACO-based dynamic source routing scheme in MANETs was proposed. It focused primarily on efficient routing by avoiding congestion and link breakage phenomena to produce high data packet delivery ratio with low end-to-end delay, routing overhead and energy consumption. In [15], an ACO-based power saving routing algorithm in MANETs was proposed to enhance adaptability and stability in reacting to node movement. According to the above, ACO has been applied to various kinds of networks.

Although [8–15] showed remarkable results, they were not designed for ICN routing optimization. In addition, their corresponding pheromone models were discrete; instead, we devise a continuous pheromone model which is closer to the ant foraging behaviors.

2.2. ACO-inspired ICN routing solutions

There have been a lot of ACO-inspired ICN routing proposals. In [16], Content-Centric Networking (CCN) architecture was extended to support service routing decision. It used a distributed scheme to gather service information based on ACO in order to deliver a service request to the best service instance. However, [16] assumed that the best service instance was known, which was against the fact that content/service provider was unknown in ICN routing. Besides, [16] neither considered content feature (type) nor had