Computer Networks 123 (2017) 88–103

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet

# RISC: ICN routing mechanism incorporating SDN and community division

Jianhui Lv[a], Xingwei Wang[b,*], Min Huang[c], Junling Shi[a], Keqin Li[d], Jie Li[e]

[a] College of Computer Science and Engineering, Northeastern University, Shenyang 110169, China
[b] College of Software, Northeastern University, Shenyang 110169, China
[c] College of Information Science and Engineering, Northeastern University, Shenyang 110819, China
[d] Department of Computer Science, State University of New York, New York 12561, USA
[e] Department of Computer Science, University of Tsukuba, Tsukuba Science City, Ibaraki 305-8573, Japan

ARTICLE INFO

*Article history:*
Received 28 November 2016
Revised 26 March 2017
Accepted 9 May 2017
Available online 10 May 2017

*Keywords:*
Information-centric networking
Software-defined networking
Community division
Routing mechanism
Clustering analysis

ABSTRACT

Information-Centric Networking (ICN) is one promising architecture paradigm which is a profound shift from address-centric communication model to information-centric one. Although ICN routing has attracted much attention from researchers, there are few researches on improving it inspired by other fields. In this paper, we propose a Routing mechanism for ICN incorporating Software-Defined Networking (SDN) and Community division (RISC), by decoupling control plane from data plane and dividing ICN topology into different communities. Firstly, we propose a community division scheme based on maximal tree in order to help retrieve the content conveniently and effectively. Secondly, we place all information about contents and forwarding into the corresponding information center for the centralized management. Thirdly, we design a routing mechanism which consists of intra-community routing based on same community information and inter-community routing based on social relationship among communities. Finally, the experimental results show that the proposed RISC not only speeds up content retrieval but also outperforms existent methods.



## 1. Introduction

The current Internet has been suffering from some significant limitations such as those brought by mobility and content distribution, which are inherent and inevitable due to its address-centric communication model [1]. At present, users widely use mobile devices to generate and consume digital media contents, producing large volumes of traffic, which is hard to be undertaken by the current Internet efficiently. For example, Cisco Visual Networking Index (CVNI) predicts that the annual global mobile data traffic is expected to reach 366.8 EB by 2020 from 44.2 EB in 2015 [2], and that the could traffic in Middle East and Africa region is expected to have the highest compound average growth rate (43%) by 2020 [3]. Furthermore, most users are mainly interested in accessing the content irrespective of its physical location with the development of mobile, cloud and big data technologies. For example, CVNI predicts that mobile users are expected to reach 5.5 billion, that is, 70% of the global population, by 2020, and personal mobile devices are expected to reach 8.5 billion by 2020 [2]. Therefore, the current Internet is becoming inadequate to the newly emerging usage patterns [4].

In order to facilitate the development of Internet continuously, many countries (e.g., USA, Germany, Japan and China) have paid high attention to the design of the future Internet [5], and Information-Centric Networking (ICN) is one of the promising networking paradigms. As we know, the research of ICN has been supported by some projects, such as Data-Oriented Network Architecture (DONA) [6], Content-Centric Networking (CCN) [7], Publish/Subscribe Internet Technology (PURSUIT) [8], Named Data Networking (NDN) and its Next Phase (NDN-NP) [9]. Especially, the first NDN community meeting (2014, Los Angeles) [10], the second one (2015, California) [11] and the third one (2016, Kyoto) [12] have highlighted the importance of ICN. As a clean-state networking paradigm, ICN is a profound shift from IP address-centric communication model to information-centric one [13], where content-aware routing and in-network caching are two notable features currently considered [14]. The content-aware routing delivers Interest packets to the content provider which returns the content to the interest requester by Data packets. The main goal

* Corresponding author.
*E-mail addresses:* lvjianhui2012@163.com (J. Lv), wangxw@mail.neu.edu.cn (X. Wang), mhuang@mail.neu.edu.cn (M. Huang), shijunlingdhr@163.com (J. Shi), lik@newpaltz.edu (K. Li), lijie@cs.tsukuba.ac.jp (J. Li).

http://dx.doi.org/10.1016/j.comnet.2017.05.010
1389-1286/

of in-network caching is to cache the frequently used contents as long as possible since they are expected to be requested by other users. The cached content replicas are capable of quick response to interest requests, which reduces bandwidth usage and latency, thus improving routing efficiency. However, ICN does not properly have an efficient routing scheme for the large-scale production network, which remains one of its major issues to be solved for the future deployment. In fact, the lack of scalable routing scheme is one of the main obstacles which slows down the large-scale deployment of ICN. Therefore, the design of efficient ICN routing mechanism has attracted much attention from a lot of research communities.

Some ICN routing mechanisms have been proposed, for example, flooding [15,16] and forwarding Interest packets according to the "best" outgoing interface(s) [17–23]. However, the flooding usually overloads network, wastes network resources and reduces network performance. It is usually unfeasible in ICN to find the "best" outgoing interface(s) to forward Interest packets with network scale, time scale and Forwarding Information Base (FIB) size considered [22]. Besides, the above mentioned two kinds of routing schemes are hard to realize the global control of contents and retrieve the closest content replica. In recent years, Software-Defined Networking (SDN) has been treated as enabling the new routing scheme development [24], and it can realize the global awareness of contents effectively in the centralized management manner [25]. Furthermore, the scalability of ICN routing is also an important issue which is very difficult to be overcome by the above mentioned two kinds of routing schemes. In [20,26,27], the community division has been proposed to address routing scalability. Moreover, ICN pays attention to user interests, thus the community division based on interest similarity relation can speed up content retrieval. Based on the above statements, in this paper, we adopt the basic ideas of SDN and community division to devise an efficient ICN routing mechanism.

As we know, SDN is considered as one promising networking paradigm to overcome the limitations of the current network architectures, and it was originally conceived at Stanford University [28]. In SDN, the control is decoupled from forwarding, and the network is directly programmable according to Open Networking Foundation (ONF) [29]. On one hand, SDN breaks the vertical integration by separating control plane from data plane; on the other hand, network switches just have the forwarding function whilst controllers are responsible for managing the whole network in the centralized manner [28]. The combination of the above SDN features can improve network management, control and data handling effectively [30–33]. Especially in the industry, Yahoo, Google, Facebook, Cisco and Microsoft have paid attention to SDN development. As two networking paradigms, ICN and SDN have profound impact on the future Internet, thus introducing the ideas of SDN into ICN is becoming a hot research topic, which is also done in this paper.

The community division [34,35] can be used to improve packet forwarding efficiency in ICN routing and help retrieve the content for interest requests conveniently and effectively. In fact, Content Routers (CRs) in the same ComMunity (CoM) usually have the same or similar features (e.g., interest categories). In this case, if the content is retrieved from any CR in its CoM, there is no need to forward Interest packets to CRs in another CoM, and thus avoiding redundant interest forwarding. When and only when the content cannot be retrieved from all CRs in one CoM, Interest packets will be forwarded to CRs in another CoM. It is obvious that the community division can improve routing efficiency and reduce routing overhead. Thus, in this paper, we divide ICN topology into CoMs according to the cached contents in CRs.

This paper proposes a novel Routing mechanism for ICN incorporating SDN and Community division (RISC), which decouples control plane from data plane by introducing SDN at the same time divides ICN topology into CoMs by introducing community, and the main contributions are summarized as follows.

(i) We propose a system framework of RISC which consists of SDN controllers, CoMs and Information Centers (ICs). RISC has the control plane which consists of SDN controllers to make routing decision, and the data plane which consists of CoMs and ICs to forward packets.
(ii) In order to help retrieve the content conveniently and effectively, we propose a novel community division scheme based on maximal tree, which is one clustering analysis method, to divide ICN topology into CoMs.
(iii) In terms of each CoM, we place all information about contents and forwarding into the corresponding IC for the centralized management, which is controlled and managed by SDN controller.
(iv) We propose a new routing mechanism to forward Interest packets and Data packets, which consists of intra-community routing based on same CoM information and inter-community routing based on social relationship among CoMs.

The rest of this paper is organized as follows. Section 2 reviews the related work. Section 3 proposes the system framework of RISC. In Section 4, the clustering analysis based community division is presented. Section 5 introduces the centralized information management. The routing decision of RISC is done in Section 6. Section 7 shows simulation results. Finally, this paper is concluded in Section 8.

## 2. Related work

### 2.1. ICN routing

The routing plays an important role in ICN since it determines packet forwarding and content retrieval, thus a lot of ICN routing mechanisms have been proposed. According to what we have learnt, in [13], the flooding algorithm was firstly proposed to address ICN routing issue. Although it could guarantee retrieving the content by sending Interest packets via all available outgoing interfaces, it would cause the heavy message traffic. Therefore, in [15], a cluster-based routing algorithm was proposed to reduce interest flooding. In [16], a flooding-based route discovery mechanism was proposed by considering the relationship among chunks, where the content was divided into a number of chunks. Although [15,16] reduced overhead brought by the successive flooding to some extent, it was hard to manage the degree of flooding.

A number of routing proposals about forwarding Interest packets according to the "best" outgoing interface(s) have been studied. In [17], an adaptive interest forwarding strategy was proposed by ranking different outgoing interfaces and selecting an outgoing interface to forward Interest packets. In [18], a named-data link-state routing protocol was proposed to announce the name prefixes. It used OSPF to propagate link-state advertisements throughout the entire network, which leaded to that the corresponding route computation no longer produced just one shortest path. In [19], a greedy ant colony forwarding algorithm was proposed to provide the intelligent interest forwarding, which improved cost-efficiency and scalability for CCN. In [20], an adaptive forwarding strategy based on probability was presented. It used Ant Colony Optimization (ACO) to compute the probability of path selection and used the statistical mode to compute the timeout for retransmission. In [21], a priority-based interest forwarding strategy was designed, in which Interest packets with higher priority were forwarded prior to those with lower priority. In [22], an exploration and exploitation based interest forwarding strategy was introduced. It spanned over two extremes, i.e., the deterministic exploitation towards a known replica and the random exploration towards an unknown