N-hop Content Store-based Caching Policy and Routing Protocol for ICN

Thanh Dinh
Soongsil University, Seoul, Korea
thanhdcn@dcn.ssu.ac.kr

Younghan Kim
Soongsil University, Seoul, Korea
younghak@ssu.ac.kr

ABSTRACT

One of ICN's main advantages is that content can be retrieved from the content store (CS) of intermediate nodes, instead of original servers. However, CS information is not considered in the data plane of current native ICN routing protocols (i.e., in NDN and CCNx) in which Interest packets are forwarded mainly using forwarding information base (FIB). FIB is built based on name prefixes registered by content producers, lists next hops to name prefixes and use that information to forward Interests towards the producers. CS information at a node is used only to check the availability of the requested content at the local node on the routing path toward the producers, not to route Interest packets. This paper highlights the importance of CS information in routing and proposes N-hop CS-based caching policy and routing protocol. The main ideas are that based on the caching storage capacity and expected network performance, the caching policy encourages to cache popular content objects within N hops from consumers. The routing protocol exploits CS information of N-hops neighbors to route Interest packets toward nearby nodes which have the requested content, instead of toward producers.

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1 INTRODUCTION

Content-centric caching and replication have shown significant benefits to improve the performance in Content Delivery Networks (CDNs) and Peer-to-Peer (P2P) which are the first attempts to exploit availability of cheap storage and processing capabilities for efficient content retrieval. Despite the advantages of P2P and CDNs, their performance and acceptance are limited due to the operations at the application layer, the commercial administration and technologies boundaries which they apply [4].

Information-centric networking (ICN) is proposed to address shortcoming of the traditional end-to-end communication model and of CDNs as well as P2P networking by designing a network layer protocol which focuses on information dissemination and retrieval. In ICN, routing operations are executed based on content names. The key features of ICN are in-network caching and content-aware routing. One of the main advantages of ICN is that content can be retrieved from the content store (CS) of intermediate nodes, instead of original servers. However, CS information is not considered in in the data plane of current native ICN routing protocols (i.e., in NDN and CCNx) in which Interest packets are forwarded mainly using forwarding information base (FIB). FIB is built based on name prefixes registered by content producers, lists the next hops to name prefixes and use that information to forward Interests towards the producers. CS information at a node is used only to check the availability of requested content at the local node on the routing path toward the producers, not to route Interest packets.

In the literature [4], several caching-aware searching and routing protocols were proposed [2]. RFW is based on random walks. INFORM is a dynamic forwarding mechanisms based on Q-learning. iNRR is based on flooding. However, most of them use a separate content replica discovery, thus resulting in a high overhead for the whole processes. Neighbor-indexed forwarding mechanisms like CATN, SCAN, and intra-AS [4] were also used. However, those mechanisms are either designed for edge networks only or utilize a global index exchange which incurs high overhead and limits the scalability. In addition, the forwarding mechanisms like SCAN are designed to work in parallel with IP routing, without IP-overlay routing they cause unstable communication and large control overhead. They cannot be directly utilized as a native CS-aware routing for ICN.

This paper highlights the importance of CS information in routing. We propose N-hop CS-based caching policy and routing protocol (NCSR) for the better exploitation of CS to improve the content-based routing performance. The main ideas are that based on the caching storage capacity and expected network performance, the caching policy encourages to cache popular content objects within N hops from consumers. The routing protocol exploits CS information of N-hops neighbors to route an Interest packet toward a nearby node having the requested content, instead of toward the producer. NCSR is a complement implementation on the top of NDN forwarding daemon (NFD) [1].

2 NCSR

Fig. 1 shows our design for NCSR forwarding engine as NDN's forwarding engine adapted with the neighbor content store (N-CS) table. A N-CS table at a router consists of counting bloom filters (CBF) [3]. A CBF is used for an interface, as a compact set representing lists of content names cached in content stores of the router's neighbors corresponding with the interface, namely a neighbor CBF. In NCSR, each node advertises its CS information to

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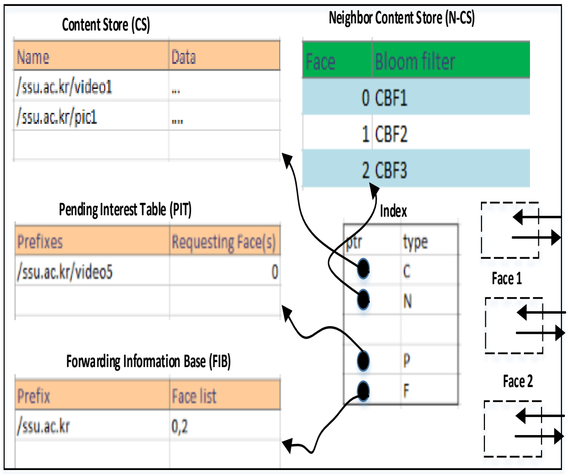

Figure 1: NDN's forwarding engine adapted with N-CS table

N-hop neighbors. We use CBFs for storing and exchanging content name lists, instead of the full lists of content names, because bloom filter (BF) is a space-efficient random data structure supporting the membership queries. In addition, we use CBF instead of the standard BF because CBF are represented by an array of m-bit counters supporting the deletion of elements. This feature is required because content can be added and deleted from CSs. Local CS information of a router is also summarized using a CBF, namely a local CBF. Note that all CBFs have the same size.

Why N hops?: In NSCR, only N-hop neighbor CSs are considered due to the following reasons. First, for efficiency, the networks should exploit cached contents which are stored within a limited number of hops from consumers, nearer than from the original servers. Second, with the exponential increase of the number of contents, maintaining CS information exchange globally is very high overhead and may be infeasible. Third, current limited-size bloom filters can maintain an acceptable high accuracy within a limited number of elements, so N-hop neighbor CS information is used to ensure the usefulness and accuracy of the bloom filters. A great number of elements' or global CS information storage is infeasible or inefficient as it results in the high false positive rate problem for BFs. Fourth, N hops allow the network operators to provision their network performance expectation and cache management for reducing the network core load based on the storage capacity.

Summary of CS information exchanges: Local CBF at a router maintains a name list of contents cached at the router and is updated when a content is added or deleted. Each router advertises its local CS information summary through a compressed local CBF to N hop neighbors only. Upon receiving an advertisement of its neighbor from an interface, the receiver merges the received CBF with the CBF corresponding with the incoming interface in its N-CS table. The advertisement is performed in periodic mode and event-driven mode which is triggered by some predefined events.

Summary of N-hop caching policies: We reuse the content popularity-based cache replacement [4] and adds additional N-hop caching policies as follows. With a limited remaining caching capacity, a router decides to cache a new popular content only if the content has not yet cached within its N hops. The reasons are 1) no benefit and storage wasting when two nearby nodes cache the same content 2) to bring diversity of popular contents into N-hop regions to increase the number of Interests that can be satisfied within N hops.

Summary of N-hop forwarding: Upon the arrival on an Interest packet, a router R first checks its local CS. If the requested content is cached in the local CS, R responds with Data messages. If not, R checks its PIT table. If the PIT table doesn't contain the Interest, the Interest is added into its PIT table. R then checks if the hop count to original servers obtained from FIB is smaller than N, the Interest is forwarded based on FIB for efficiency. If not, R then matches the requested content name in its N-CS table. If the requested content has not cached within N hop neighbors, it forwards the Interest packet to the next hop using FIB like in NFD. If the requested content name exists in a CBF of an interface in the N-CS table, R adds a hop counter to the Interest and forwards the Interest to next hops through the corresponding interface until it is satisfied by CS of a neighbor. At each hop, the hop counter is increased by 1. In cases of errors once the requested content is not found within N hops from R or its name is not found at one of the next hops, a fall-back recovery is performed by sending a notification ACK back to R. FIB-based NFD forwarding is then executed at R. The above operations are processed recursively until the Interest is satisfied.

3 CONCLUSION AND ON-GOING WORKS

This work is in early stage. We plan to find the optimal N and optimal bloom filter size based on the storage capacity of routers, the content distribution, and expected performance. Based on that, we complete designing the protocol with optimized CS information exchanges and provisioning features for network operators. We also consider a dynamic N for different kinds of content and priorities. We are conducting the implementation of NCSR in NDN and plan to test the protocol using our Network Function Virtualization (NFV) infrastructure.

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