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Network coding-based multisource content delivery in Content Centric Networking

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ABSTRACT

Content Centric Networking (CCN) is a new network architecture around content dissemination and retrieval. Its request–response and in-network caching mechanisms can significantly improve the network performance in reducing the transmission delay. However, the in-network caching may prevent the network coding technique from being applied into CCN because cached coded blocks may not be linearly independent to each other such that they cannot be used for responding the future requests. In this paper, we propose a novel request-specified network coding (RSNC) scheme for efficiently encoding and delivering chunks of content. In this scheme, a new Interest coding and forwarding strategy is proposed for specifying network coding requirements and getting linearly independent coded blocks simultaneously from multiple nodes. Our simulation results show that the proposed scheme achieves better performance than conventional CCN in terms of average download time, cache hit ratio, and transmission amount.

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1. Introduction

Since the primary uses of the Internet are content distribution and retrieval, the current Internet architecture which was designed for end-to-end communication between hosts is facing unprecedented challenges in many aspects. The emerging demands for security, mobility, content distribution, etc., are hard to be met by current Internet. Therefore, the concept of Information-Centric Networking (ICN) is introduced (Ahlgren et al., 2012). In ICN, routers forward packets based on content name rather than on host address. The architecture of Content-Centric Networking (CCN) proposed by Van Jacobson et al. is one of the most popular ICN architectures (Jacobson et al., 2009; L. et al., October 2010).

Communication in CCN is driven by the content consumers. To receive data, a consumer sends out an Interest packet (referred to as Interest), which carries a name that identifies the desired data. The same Interests sent by multiple consumers may meet in a node and be merged before being forwarded. Data packet (referred to as Data) takes the exact same path as the Interest that solicited it, but in the reverse direction.

In CCN, the content is cached on all nodes along the delivery path and thus has copies cached in multiple nodes. Each node can respond with a cached copy to a tree created by the Interests from a set of consumers. To increase the caching efficiency, a content can be divided into small sized chunks. In a chunk-based delivery scheme, different chunks of the same content can be delivered from multiple sources. Different chunks of the content may meet on their way to the set of consumers. Motivated by this, we introduce a novel network coding method for encoding the met blocks to reduce the transmission amount, and a novel Interest multicasting and merging method to specify the requests as well as the requirements for the specific encoding methods.

Network coding (NC) proposed by Ahlswede et al. (2000) allows intermediate nodes to encode and decode messages. Several studies have shown that the system with network coding performs much better than the system without network coding in terms of throughput, robustness, security and load balancing through real networks (Chou et al., 2003; Gkantsidis and Rodriguez, 2005). The benefits of applying network coding in CCN are illustrated in a 6-node butterfly network in Fig. 1. Two users are connected to content routers CR_5 and CR_6, and request a content containing two unit data chunks, A and B, at the same time. Each content router (CR) is assumed to have one unit cache capacity to cache only one data chunk and each link to have a unit transmission cost, where chunk A has been cached in CR_2 and CR_3, and chunk B in CR_4. Fig. 1(a) and (b) shows caching strategy and content routing with and without network coding. For CCN without network coding, User 1 receives chunk A from CR_3, and chunk B from CR_4. The cost is 4 one-hop transmissions over the network (excluding the transmission cost from CR_5 to User 1). User 2 receives chunk A from CR_2, and chunk B from CR_4. The cost is 3 one-hop transmissions over the network.

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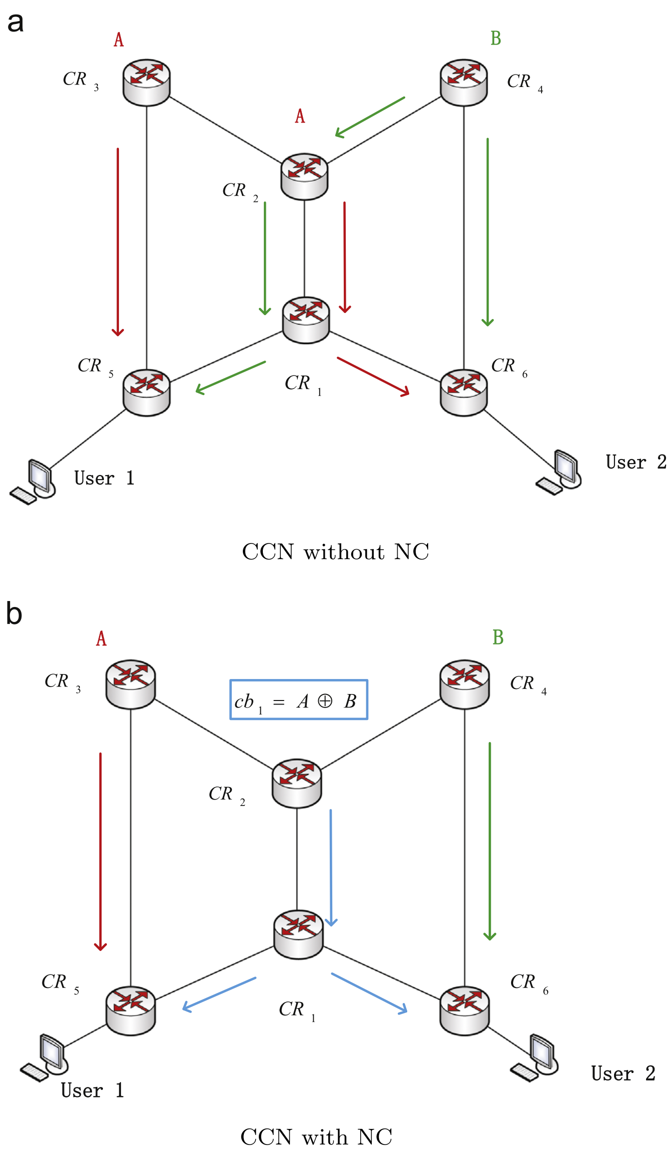

Fig. 1. An example for content request in CCN.

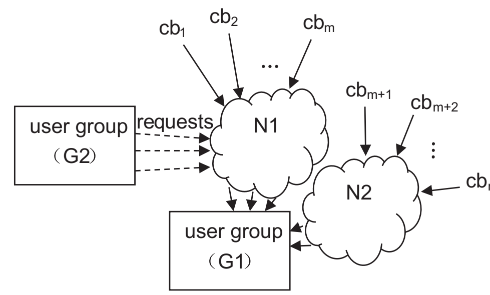

Fig. 2. An example for applying network coding into CCN.

The total transmission cost is thus 7 units. For CCN with network coding, a CR can cache a coded block of chunks. In this case, we assume a coded block cb_1, instead of chunk A, is cached in CR_2, which can be used to satisfy not only the request for chunk A, but also the request for chunk B. Then, User 1 and User 2 receive the coded block cb_1 from CR_2, based on the content delivery mechanism of CCN which is multicast along the tree formed by the requests. The transmission cost is 3 one-hop transmissions over the network. In this case, the total transmission cost is 5 units, representing a 29% improvement.

However, based on the in-network caching mechanism, a block may be cached in multiple nodes along its transmission path. The same coded block or linearly dependent blocks that were cached in multiple nodes may be provided to the same consumer in responding its multicast request. As shown in Fig. 2, when users in $G1$ obtain m coded blocks of content f from network $N1$, and (n-m) coded blocks of f from network $N2$, m' ($m' \geq m$) coded blocks encoded from $cb_1, cb2, \ldots, cb_m$ are cached in many nodes of network $N1$, and n' ($n' \geq (n-m)$) coded blocks encoded from cb_{m+1}, $cb_{m+2}, \ldots, cb_n$ are cached in many nodes of network $N2$. Suppose the number of innovative blocks (the block interested by user) is n. When users in $G2$ multicast their requests for n blocks of f, the requests arrive the network $N1$ at first. Because there is no mechanism to allow the nodes to know each other about their cached blocks and the code coefficients, they cannot globally cooperate to provide linearly independent coded blocks. Therefore, the users in $G2$ may get $t \geq n > m$ coded blocks from the nodes in $N1$. In this case, the probability of the users in $G2$ receiving linear dependent coded blocks from $N1$ is 1, instead of 2^{-8} (if the finite field size is 2^8). Therefore, the original in-network caching mechanism of CCN is not suitable for applying random network coding, if we do not introduce additional mechanisms to accommodate the network coding to CCN.

By applying network coding into CCN, multisource transfers are supported and the transmission amount and time required for getting contents are significantly reduced. Finally, we experimentally evaluate our scheme by comparing with other schemes. The simulation results show that our scheme performs much better than those schemes in terms of average download time, cache hit ratio, and transmission amount.

In this work, we assume that some content naming schemes and chunk-based routing schemes are in place. We focus on the question of "how to efficiently deliver chunks of content that are stored in different locations and requested by various users".

In summary, the contributions of this paper include:

- We design a special Interest coding and forwarding strategy for getting linearly independent coded blocks simultaneously from multiple nodes. In other words, Interests are aggregated, separated, and forwarded in every node based on the strategy that guarantees the responding coded blocks are linearly independent.
- A content delivery scheme is designed for reducing the bandwidth requirement and guaranteeing the cached blocks reusable. Original/coded blocks met in a node are encoded according to pending Interests to satisfy the downstream requests. Decoded/original blocks are cached in the node for responding the future Interest.

The rest of the paper is organized as follows. Section 2 provides a review of related works. Section 3 introduces a request-specified network coding method (RSNC) for content distribution over Content-Centric Network by using network coding. Section 4 presents the implementation of our RSNC scheme. Section 5 presents the evaluation results. The discussion about RSNC and conclusion of the paper are presented in Sections 6 and 7.

2. Related works

Content Centric Networking (CCN) is a clean-slate network architecture that aims to overcome the weakness of existing IP-based networking architecture. There are many challenges that need to be addressed for CCN to become deployed and used. Previous works on content-centric networks have mainly focused on content router issues (Aubry et al., 2015; Chen and Li, 2014),

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