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Information-centric networking with built-in network coding to achieve multisource transmission at network-layer

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ABSTRACT

As one of the most promising future Internet, Information-Centric Networking (ICN) is attracting more attention. However, the previous works which have achieved either single-source transmission or low-efficiency multisource transmission did not fully exploit the potential of underlying its in-network caching opportunities. We propose Information-Centric Networking with Built-in Network Coding (ICN-NC) where in-network caching can be collaborated with network coding to achieve multisource transmission at network-layer. In ICN-NC, due to network coding, partitioned caching and parallel transmission with multiple data sources can be achieved. Moreover, four schemes are proposed to address the key challenges of ICN-NC: Firstly, a novel signature scheme ensures that signature scheme can be compatible with network coding. Secondly, a communication scheme based on piggyback technology ensures that the number of returned Coded Message (CM) is exactly matched with the desired number. Thirdly, we propose a forwarding plane separated from routing plane to observe the network state, such as network failure, link transmission performance and distribution of CM, where a strategy of forwarding Interest ensures that the probability of returned CM being linearly dependent is low. Fourthly, an acknowledgement mechanism ensures that the choice of Interest exploration direction is reasonable and adaptive. Finally, experiment results shows that ICN-NC can improve transmission efficiency, caching efficiency and robustness compared to original ICN and IP.

1. Introduction

The Internet currently suffers from lack of mobility support, scalability and security vulnerability *etc*. As a result, a clean-slate architecture design paradigm has been suggested to build the future Internet by the research community [1,2].

In recent years, various research programs aimed at the design of the future Internet have been set up in different countries. However, Information-Centric Networking (ICN) is increasingly being accepted as the most promising architecture [3].

Moreover, content distribution and retrieval are dominant Internet applications today. Thus, there is a significant demand to transform the Internet from a simple “host-to-host” packet delivery paradigm to a more diverse paradigm built around the content and users instead of the machines.

To address above challenges, some dedicated systems, such as Peer-to-Peer (P2P) and Content Distribution Networks (CDN), now are deployed. Through leveraging caching, they mirror content in several locations in order to bring frequently requested content closer to where it is consumed.

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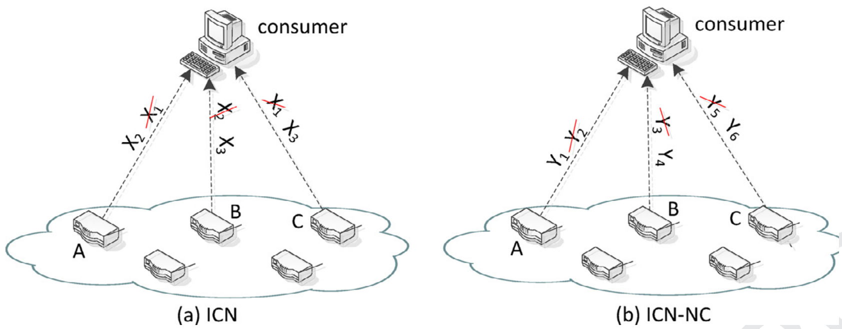

Fig. 1. An example for multipath transmission.

However, P2P and CDN based overlay network are deployed at application layer. They cannot observe the network state, such as underlay topology and demand of user. As the result, they suffer from some problems, such as the mismatch between logical topology and physical topology, the mismatch between pre-planning of CDN network and actual dynamic demand of user. Though some traffic optimization schemes are proposed [4], unfortunately, they cannot be directly translated to ICN.

Different from P2P and CDN, each node in ICN can cache passing content for further use. Moreover, the content becomes an independent which gets rid of address constraint. It can be routed and forwarded at network layer without worrying about loop, and cached by any node. These above mentioned schemes can spread the content quickly in the network, namely, there are lots of data sources, which include content provider (content server) and all intermediate nodes caching desired content, for the consumer of content.

However, in the original ICN proposal (referred to as ICN in this paper), the consumer only uses the first returned content, and any subsequent copies will be discarded when multiple data sources respond to the Interest. Redundant traffic introduced by these replicated copies wastes network resources, worsens the communication performance by saturating the network bandwidth, and increases the economic costs if usage-based charges are used. Worse, this does not fully exploit the potential of the underlying multiple data sources opportunities. In the network environment with multiple data sources, this scheme only can achieve a single source transmission.

As far as we know, little work is done on multisource transmission at network-layer [5].

In order to achieve parallel transmission and better transmission performance by fully utilizing the potential of these redundant data sources, this paper brings network coding [6] and ICN together to achieve multisource transmission at network-layer, called Information-Centric Networking with Built-in Network Coding (ICN-NC).

Due to PIT[1] (Pending Interest Table) recording communication state, the demand of consumers can be observed. Due to the forwarding plane separated from routing plane, the supply of resource (Coded Message, CM) and link transmission performance can be observed. Through the matching among them at network-layer, ICN-NC can address problems suffered by P2P and CDN, and then achieve better network performance.

The design of ICN-NC is inspired by the theory of random network coding where source node and intermediate node do network coding, and then linear combination of content distribute in the whole network. Moreover, transmission of contents can be path and even host independent as long as the consumer retrieves enough independent linear combinations eventually by any path. On the other hand, thanks to ICN, where connectionless communication model decoupling content from location. Thus, there are a nice fit between random network coding and ICN. Besides, in-network caching leveraged by ICN can store more independent linear combinations of content. Such nice fits can naturally bring better network performance.

Considering the scenario in Fig. 1, the consumer wants to retrieve $\{X_1\ X_2\ X_3\}$. In Fig. 1(a), A, B and C cache $\{X_1\ X_2\}$, $\{X_2\ X_3\}$ and $\{X_1\ X_3\}$ respectively. In Fig. 1(b), A, B and C cache $\{Y_1\ Y_2\}$, $\{Y_3\ Y_4\}$ and $\{Y_5\ Y_6\}$ respectively, where Y_i $(i = 1,2,\ldots,6)$ is a linear combination of the $\{X_1\ X_2\ X_3\}$. Obviously, the same cache space is consumed for two cases. However, two architectures offer different network performance under the same scenario:

(1) ICN-NC can improve robustness of network. If the first message is lost on each path due to some path failure or congestion policy, In ICN (Fig. 1(a)), the consumer broadcasts three Interests to A, B and C to retrieve $\{X_1\ X_2\ X_3\}$, but X_1 is unavailable unless there is a feedback loop to the consumer. Contrary, in ICN-NC (Fig. 1(b)), the consumer can decode the $\{X_1\ X_2\ X_3\}$ from received $\{Y_1\ Y_4\ Y_6\}$ which contain enough linear combinations.
(2) ICN-NC can improve transmission efficiency. If message losses do not happen, in ICN, the consumer broadcasts three Interests to require X_1, X_2 and X_3 respectively, then there are three copies among six returned messages. However, in ICN-NC, $\{Y_2\ Y_3\ Y_5\}$ are enough for the consumer and then $\{Y_1\ Y_4\ Y_6\}$ will not be transmitted. ICN-NC can complete its retrieval task with fewer transmissions and consequently with faster speed. Ideally, ICN-NC's transmission efficiency is 100% higher than ICN's.

The key contributions of this paper are: (1). We exploit the combination of ICN with network coding to achieve multisource transmission at network-layer. ICN-NC, a novel

[1] In ICN, PIT keeps track of Interests that have been already forwarded.

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