A Feasibility Check for Utilizing Multiple Paths in Content-Centric Networking

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ABSTRACT

Content-Centric Networking (CCN) re-designs the Internet architecture in a clean-slate manner. Benefits of CCN have attracted research communities to develop novel schemes to enhance a performance of original CCN architecture. In CCN, a content file consists of multiple chunks, and thus if a user retrieves content chunks from multiple paths, a content retrieval time will be substantially reduced. However, there have been less efforts on CCN transport mechanisms, especially, a multi-path data transmission. In this paper, we focus on a feasibility of retrieving chunks from multiple content holders to reduce the content retrieval time in CCN. First, we explore the design space of retrieving multiple chunks from multiple places over multiple paths. Finally we suggest an efficient method to realize the multi-path transmission concept by mitigating a side effect that can degrade content retrieving performances.

1. INTRODUCTION

Over the last few decades, the Internet has grown up rapidly and a paradigm of the Internet usage has changed. The Internet was used to connect remote hosts for host-centric usage; however, the Internet is now mainly used for obtaining contents. Current Internet traffic mainly consists of content retrievals, such as video services or a P2P file sharing [1]. This trend brings up a gap between the host-based Internet architecture and data-retrieving usage patterns. Due to the gap, inefficient content delivery (e.g., duplicated content transmission for the same popular content) becomes an increasingly serious problem. To address the problem, there have been lots of efforts to redesign the Internet architecture in a clean-slate manner [2, 3]. Content-Centric Networking (CCN) [3] is one of such efforts with a new perspective.

CCN has a few remarkable characteristics. First, a content file is fragmented into multiple chunks. Second, networking is performed by content names (at a chunk unit) since content names are used as identifiers of content (i.e., route-by-name). Third, users can trigger data transmissions by issuing Interest packets. With a content name, a user sends a request packet called *Interest* that includes the name of content chunk. Then the corresponding data packet called *Data* is retrieved from somewhere in networks without any information about its location. In the CCN research community, many researchers have investigated on mechanisms about caching, routing, and forwarding [4, 5, 6, 7]. One of interesting studies reveals that *Interest forwarding strategy* is an important factor that significantly affects a performance of CCN in terms of content retrieval time [4]. However, relatively little attention was paid to the Interest forwarding and congestion control mechanism utilizing multi-path for further performance enhancement.

In this paper, we focus on the feasibility of Interest forwarding mechanisms that utilize multiple paths to reduce the content retrieval time. Contributions of our work are summarized as follows: (i) investigating what issues make it hard to achieve multi-path data transmission in CCN, (ii) comparing two alternatives to realize multi-path concept in CCN, and (iii) suggesting an efficient design to achieve multi-path data transmissions.

2. RELATED WORK

Recent works [5, 6, 7] have focused on finding the closest content copies to improve a content delivery performance by revising an Interest forwarding mechanism. INFORM [5] introduces a hop-by-hop dynamic request forwarding to discover ways towards temporary copies through the best performing interface. In [6], authors propose an adaptive forwarding scheme by recording RTTs of PIT entries. Based on the measured RTTs, the proposed scheme defines forwarding policies of all interfaces in FIB entries. However, above works do not guarantee to utilize multiple paths in parallel since the Interest forwarding is decided based on hop-by-hop information, not end-to-end information.

3. DESIGN CONSIDERATIONS

When we try to transfer data over multiple paths in CCN, a challenging issue in CCN is that "a content name is an identifier of content and used for routing". In CCN, content files are retrieved by using content names without using any locators. In other words, subscribers just send Interest packets with content names, while they do not care about the locations of contents. Without the knowledge of locations, how can we forward Interest packets to multiple places over multiple paths? To deal with this problem, we compare possible design alternatives and choose a proper option for the

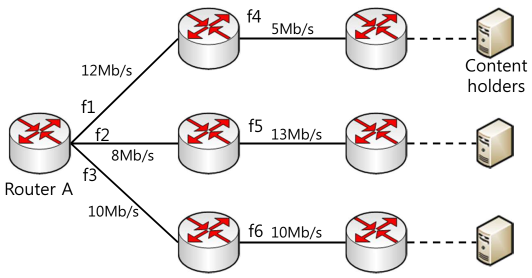

Figure 1: The case of a local optimum is illustrated.

multi-path data transmission. We assume that a router already has the information of multiple paths (or interfaces) to the requested content.

3.1 Naive approach: Hop-by-hop approach

A naive way to achieve the multi-path data transmission in CCN is spreading Interest packets at intermediate routers. That is, each router forwards an Interest packet to one of possible multiple interfaces (to the content holder(s)). Thus consecutive Interest packets for the same content are forwarded to multiple interfaces at each router towards the content holder(s). As a result, Interest packets that reach at the content holder(s) may have traveled over multiple paths. Because decisions of forwarding Interests over multiple paths are made by intermediate routers, and paths are determined in a hop-by-hop manner, we call this forwarding mechanism the *hop-by-hop* Interest forwarding.

3.2 Limitations of hop-by-hop approach

With the hop-by-hop Interest forwarding, we do not need any additional features at Interest headers or subscribers. A router may choose the link of the best throughput within its one-hop range, because it can know the conditions of links connected to its one-hop neighbors. However, there are two major problems. One is an overhead of measuring, storing and updating RTT information at all intermediate routers in networks. Another problem is called the *local optimum problem*, and it may decrease end-to-end throughput. The hop-by-hop Interest forwarding provides one-hop best throughput but does not guarantee end-to-end best throughput. This means that the hop-by-hop Interest forwarding can lead only to the local optimum problem. The limitation of the local optimum problem is explained with the following example.

Figure 1 shows the local optimum problem. Let us assume that Router A has Interest packets to be forwarded and it is connected to next-hop routers via interfaces $f1$, $f2$, and $f3$. With the hop-by-hop Interest forwarding mechanism, Router A chooses $f1$ for its outface since $f1$ has the highest available bandwidth among its direct links (12Mb/s). However, the end-to-end bandwidth is 5Mb/s because $f4$ becomes a bottleneck. So, $f1$ can be the best outface among its one-hop neighbors from Router A's viewpoint, but not from a global perspective. The best interface considering end-to-end throughput is $f3$, which can provide 10Mb/s end-to-end bandwidth.

3.3 Enhanced solution: End-to-end approach

We define the end-to-end Interest forwarding as follows. *Subscribers will decide where to forward Interest packets.* When there are Interest packets to send, a subscriber decides which paths will be selected for forwarding them. Intermediate routers just forward Interest packets over the interface chosen by the subscriber. In this way, forwarding Interests to multiple paths is decided by a subscriber, not by intermediate routers. The end-to-end Interest forwarding locates the overhead of storing additional states (i.e., path information) at subscribers. However, it can address the problem of local optimum. If a subscriber can store RTTs of multiple end-to-end paths, she can always send Interest packets to the best interface with a network-wide perspective. For example, in Figure 1, the subscriber can make Router A choose $f3$ since it knows the network-wide path conditions. Thus, we can achieve the fastest data transmission over the end-to-end path.

Until now, we explained design considerations about the Interest forwarding mechanism over multiple paths in CCN, and presented two possible alternatives. In particular, we compared the hop-by-hop Interest forwarding and end-to-end Interest forwarding. We will provide suggestion and concluding remarks in the next section.

4. CONCLUSIONS

In this paper, we explored design considerations for the multi-path data transmission in CCN. Based on the considerations, we suggest the end-to-end path selection mechanism for CCN multi-path content delivery. While the hop-by-hop path selection will be likely to choose a local optimum path, an end-to-end path selection by a user will choose the best end-to-end path. Also, the overhead of keeping track of multiple paths is shifted from routers to users in the latter approach. In the future work, we will substantiate the end-to-end multi-path transmission mechanism for CCN.

5. ACKNOWLEDGMENTS

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