PAPER

Multi-ISP cooperative cache sharing for saving inter-ISP transit cost in content centric networking

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SUMMARY Content-Centric Networking (CCN) has an in-network caching mechanism, which can reduce the traffic volume along the route to the destination host. This traffic volume reduction on the transit link can decrease inter-ISP transit cost. However, the memory space for caching in CCN routers is small relative to content volume. In addition, any initial access to the content requested by a user must use the transit link, even when a nearby CCN router outside the route has the cached content. In this paper, we propose a method of cooperative cache sharing among CCN routers in multiple ISPs. It aims to attain a further reduction in the inter-ISP transit cost by improving the cache hit ratio. In the proposed method, the CCN routers share the memory space for caching of non-overlapping cache content. We evaluate the proposed method by simulation experiments using the IP-level network topology of actual ISP, and show that the inter-ISP transit traffic can be reduced by up to 28% compared with normal caching behavior of CCN.

key words: *Content-Centric Networking, in-network caching, cache sharing, inter-ISP transit cost*

1. Introduction

Content-Centric Networking (CCN) [1] is an architecture which routes packets based on content name, as compared to the current Internet which uses identifiers that indicate the location of the content holder, that is, the IP address. End users can request content by the content name without being aware of the location of the content holder.

In-network caching is one of the important features of CCN. In CCN, the content that traverses the CCN routers is cached in the memory space of CCN routers called as the *Content Store* (CS). CCN routers do not forward requests for cached content to the next hop router, and instead return the cached content to the end host who requested the content. Because of this caching mechanism, CCN can reduce the traffic volume for repeatedly requested content and also provide shorter response times for users.

Reducing the traffic volume by using the caching mechanism in CCN has a positive effect on the monetary cost of ISPs. In general, ISPs have transit links for ensuring connectivity to the whole Internet. The monetary cost of a link (referred to as the transit cost below) is generally determined by the amount of traffic traversing the link. In CCN, when the CCN router that has the requested content cached in the ISP to which the end user belongs, no transit cost is incurred. In a situation that the content is not originated in ISP, it means the CCN can reduce transit cost through employing the caching mechanism. The reduction in the transit cost increases as the cache hit ratio increases. In general, higher hit ratios can be achieved by introducing larger storage. However, the memory space in the CS is relatively small compared to the amount of content required by the end users because the CS is located in the router and should offer shorter access times compared to end-host-based caching mechanisms like Web proxy servers. According to [2], when DRAM memory is used, it is expected that each CCN router may have a CS size of only about 10 GB.

Peering links are the other kind of inter-ISP links, and are used for traffic between inter-connected ISPs as a link for reducing transit cost. In most cases these require no monetary cost for traffic that traverses them except for that of the physical link equipment. We believe that there is a potential benefit for ISPs connected by peering links to decrease transit cost by sharing the caches of the CCN routers and accessing the cached content from each other. Although this kind of cooperative caching mechanism was proposed in [3], the authors presented only a rough sketch and gave no concrete methods for realizing the idea.

Here we propose a method of cooperative cache sharing among multiple ISPs for improving the cache hit ratio for effectively reducing the transit cost. In the proposed method, cached contents are shared among the CCN routers of the cooperating ISPs. The CCN routers share their CSs without the cached content overlapping. A request packet for cached contents is forwarded to a CCN router which has the content, even when it is not located on the route to the original content holder. This enables the cache hit ratio to be improved. We introduce a mechanism for keeping consistency among the caches of the ISPs since cache misses cause extra traffic on the transit links of the cooperating ISPs. We also designed the system to balance the network traffic to cached content between cooperating ISPs to ensure fairness between the ISPs by controlling the amount of cache for cache sharing. We evaluate the performance of the proposed method by simulation experiments using the IP-level network topology of actual ISP. From the evaluation results, we show that the proposed method can reduce the transit cost effectively compared with the normal CCN caching mechanism.

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2. Background

2.1 Content-Centric Networking [1]

A CCN router is constructed of three main components, which are the pending interest table (PIT), Forwarding Information Base (FIB), and CS. The PIT maintains a list of request packets that are waiting for content. The FIB is a routing table for forwarding request packets to the source of requested content. The CS is a memory space that caches the content traversing the router itself. The packets in CCN are categorized into two types, which are Interest packets and Data packets. Interest packets represent requests for content, and Data packets are the data chunks of the corresponding content.

A brief overview of packet forwarding in CCN is as follows. First, the end host generates an Interest packet for a content and sends it to the neighboring CCN router. The CCN router that receives the Interest packet refers to its own FIB, and then forwards the packet to the appropriate neighbor CCN router. Repeating this process on the CCN routers, the Interest packet reaches the host which has the requested content. The host that receives the Interest packet divides the requested content into a number of Data packets and returns them to the end host along the reverse path that the Interest packet traversed. The CCN routers on the path also cache the Data packets as content chunks in their CSs. The CCN router returns the cached chunks to any Interest packets that request the cached content chunks. Due to this in-network caching mechanism, CCN limits the traffic volume for repeatedly requested content and provides quicker responses to users.

2.2 Related works

In CCN, there are the two kinds of architecture. One has a mechanism such as routing protocols in the IP [1], the other based on a name resolution service of contents likes the DNS [4, 5]. In the other words, the two kinds of CCN architecture target different layer of the Internet, respectively. The present paper mainly focuses on the former one.

[6-8] proposed methods for improving the efficiency of in-network caching in CCN. The method in [6] provided a way for the CCN routers on a route to cache without overlap. The method in [7] distributes the content chunks along the route in a probabilistic manner. The method in [8] chooses a route by the hash value of content name to disperse load of content caching over the CCN routers. All [6-8] intended to utilize the cache on the route efficiently, and they cannot utilize the cache outside the route to the original content holder.

[9] exhibits the two types of caching strategies in CCN, which are coordinated/non-coordinated manners between CCN routers, and evaluated a theoretical performance of these strategies. However, no practical method was given in [9].

The method proposed in [10] considers cache utilization, including outside of the route to the original content holder, and assigns the content to be cached by each CCN router according to the request popularity of the content and the CCN routers collaborate on caching. However, when we use the method in [10] among multiple ISPs in a cooperative manner, the balancing of network traffic becomes a problem that was not considered in [10]. Additionally, the cached content name table called *AIB* has a possibility of cache misses resulting from its construction method, then transit link policy violations can occur as mentioned in Section 3.

To the best of our knowledge, there is no efficient method for cache sharing among multiple ISPs. Therefore, in the present paper, we propose a method for realizing this kind of cache sharing.

3. Challenges of cache sharing

3.1 Challenges for cache sharing

3.1.1 Advertisement of cached content among CCN routers

One possible way to advertise cached content names is to extend OSPFN [11]. OSPFN is a routing protocol developed for CCN, which is based on OSPF. However, OSPFN's flooding-based advertisement mechanism may bring an explosion of control messages since the cached content is replaced frequently due to the small CS size. To limit the message volume to a feasible area, we need to tune the frequency of advertisement carefully.

3.2 Challenges for inter-ISP traffic

Assuming that the problems in Subsection 3.1 are overcome, we consider two ISPs that are interconnected by a peering link and that share cached content to reduce their transit cost. Based on [1], the straightforward method of packet forwarding by the CCN router that receives an Interest packet is as follows:

- If the requested content exists in its own CS, the CCN router returns the cached content.
- Otherwise, the CCN router looks up the advertised content names in other CCN routers, and forwards the Interest packet to the appropriate CCN router when the content name exists.
- If there is no cached content in its own CS or in the CSs of other CCN routers, the CCN router forwards the Interest packet to the source of the requested content.

When we assume this behavior, the following problems emerge.

3.2.1 Traffic imbalance between ISPs

When the requested content is located at a CCN router in a

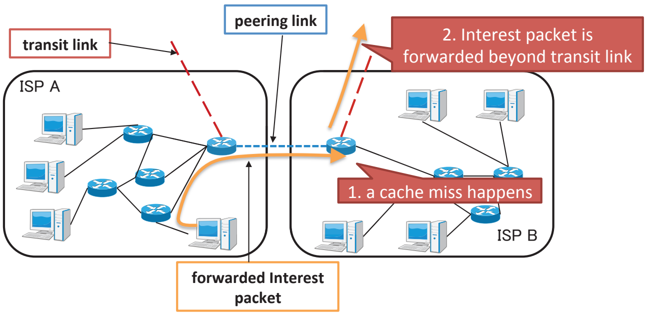


Fig. 1 Free-riding problem due to cache miss

cooperating ISP, the Interest packet and the corresponding Data packets traverse the peering link. Therefore, an imbalance in the traffic may happen due to differences in cache hit ratios and request frequencies between the ISPs. Excessive imbalance of traffic on peering links may break the peering relationship between ISPs. A mechanism for ensuring the fairness of traffic volume between ISPs is then required in cache sharing among multiple ISPs.

3.2.2 Packet handling from other ISPs

When a CCN router in the ISP forwards an Interest packet to the cached content in a CCN router in the cooperating ISP and a cache miss occurs due to cache inconsistency, there are two ways to handle the Interest packet for the ISP where the cache miss is occurred: 1) dropping the Interest packet, 2) forwarding the Interest packet to the original content. When the ISP chooses the former way, the response time to the requester of the content increases. For the case of latter way, the transit link of the ISP is used by an Interest packet generated by a user belonging to a different ISP. Furthermore, since the Data packets traverse the reverse route of the Interest packet, the Data packets also use the same transit link. This means that although the purpose of cache sharing is to reduce transit cost, the ISP may incur additional transit cost due to the traffic generated by customers of other ISPs, which we call the *free-riding problem* depicted in Figure 1. Then, we should maintain the cache consistency when using cache sharing among multiple-ISPs.

4. Proposed method

The proposed method consists of three main components and one additional components. The main components are as follows:

- Advertisement of cached content among CCN routers
- Cache management and decision about which content to advertise
- Forwarding of Interest packets according to advertised information

The additional component is specifically for cache sharing among multiple ISPs:

- Balancing traffic to ensure fairness between ISPs

4.1 Network model

We assume the network model as depicted in Figure 2. The network consists of the networks of a number of ISPs, each of which is constructed from a number of CCN routers. Each CCN router has a unique name for identification by other CCN routers. The behavior of CCN routers follows [1], where OSPFN is used as the routing protocol. ISPs are interconnected by transit or peering links. A transit cost is incurred when traffic traverses transit links. We refer to routers interconnected by inter-ISP links as *edge routers*.

4.2 Advertisement of cached content

We divide the advertisement of cached content into two parts for *intra-ISP sharing* and *inter-ISP sharing*. This partitioning enables decreasing and balancing the network traffic between ISPs as described later. An advertisement message has two fields, which are the content name and the name of the CCN router holding the content. Note that when a CCN router removes a content from its shared cache, the corresponding advertisement message includes the removed content name. For intra-ISP advertisement, all CCN routers including the edge router advertise the cached content to all other CCN routers in the ISP by utilizing OSPFN. By conducting the communication for inter-ISP cache sharing at the edge CCN routers, the additional traffic for inter-ISP cache sharing do not consume the bandwidth of the intra-ISP network. For inter-ISP advertisement of cooperating ISPs, two edge routers interconnected by a peering link choose the cached content to be shared, and advertise the content to each other. Each edge router then advertises the content names from a cooperating ISP (we refer to this type of ISP as a *partner ISP* in the remainder of this document) to all other CCN routers in that ISP in the same manner as for intra-ISP advertisement. When balancing the network traffic between cooperating ISPs, the ISPs conduct negotiations to decide contents to be share. The details are described in Subsection 4.5.

OSPFN has a mechanism for advertising the locations of content. Because the advertisement mechanism in OSPFN utilizes a simple flooding mechanism, it is not reasonable to generate advertisement messages on each change in the cached content shared by a CCN router. Therefore, in the proposed method, each CCN router advertises cached content at regular intervals of T_{intra} for intra-ISP sharing, and T_{inter} for inter-ISP advertisement.

Importantly, when a CCN router receives an advertisement message, the router replies with an acknowledgement to the source router of the message. When a content is withdrawn from cache sharing, the CCN router that has the content does not remove the content from its cache until receiving the acknowledgements from all CCN routers. By this acknowledgement mechanism, we can maintain consistency

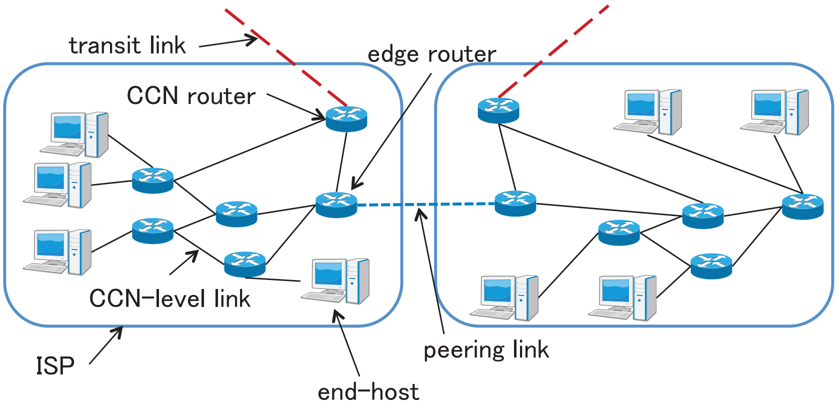


Fig. 2 Network model

of the cached content among cooperating CCN routers. This means that the proposed method enables avoiding cache misses completely, and the problem described in Subsection 3.2.2 is thus overcome.

4.3 Cache management

There are many methods for cache management of Web content in the literature. Since most of them utilize least frequently used (LFU) or least recently used (LRU) [12], we also use LFU or LRU as the basis of CS cache management in the proposed method. The details of the cache management mechanism are as follows:

- Each CCN router manages its own CS according to the LFU or LRU algorithm. The content in the CS is always sorted by access frequency or last access time.
- Each CCN router chooses the content in the CS in order of LFU/LRU rank so that the total size is within K. Note that K is a parameter for determining the amount of cached content to be shared. The router then advertises the changes of shared content. Once the CCN router has advertised the content, it does not remove the advertised content from its CS until the next advertisement is completed.
- When an advertisement is received from another CCN router, the CCN router removes the advertised content if the content exists in its own CS. When the CCN router also has advertised the same content, it keeps or removes the content according to the hash values of the combination of the content name and the router name. This hash-based decision maintains the uniqueness of the cached content holder among all corresponding CCN routers. The content is kept by the CCN router whose hash value of the name is larger, and the other router removes it.
- When a CCN Data packet traverses a CCN router, in addition to the basic caching behavior, in the proposed method, the CCN router checks cache sharing status and does not cache the Data packet when it is already cached in another cooperating CCN router.

content A	Router B1
content B	Router B2
content C	Router A1
⋮	⋮

Fig. 3 Sharing content table (SCT)

By the above mechanisms, we can avoid overlap of cached content among cooperating routers, which results in efficient usage of cache memory and improvement of the cache hit ratio.

4.4 Packet forwarding according to advertised information

Each CCN router keeps a list of advertised content with the names of the CCN routers that are the sources of the corresponding advertisements, which we call a *sharing content table* (SCT) showed in Fig. 3. Each CCN router handles an incoming Interest packet as follows:

1. According to the normal behavior in CCN, the CCN router looks up the content requested by the Interest packet in its own CS. If the CS has the requested content, the router replies with it.
2. When the requested content does not exist in its own CS, the router looks up its own SCT for the requested content. If the corresponding entry is found, the router transfers the Interest packet to the router described in the SCT entry, whether or not the destination CCN router is located in the own ISP or in the partner ISP.
3. Otherwise, the router transfers the Interest packet by the normal forwarding behavior in CCN.

4.5 Balancing traffic between ISPs

One possible situation when using the above-mentioned mechanisms is that the traffic between two cooperating ISPs becomes unbalanced due to differences in the request frequencies for content cached in each ISP. Unbalanced network traffic is a serious problem for ISPs even when they are interconnected by a peering link. Therefore, in the proposed method, we maintain the traffic balance between ISPs by regulating the number of content to be advertised to partner ISP for cache sharing by the negotiations between the edge routers in two ISPs. The detailed algorithm is as follows.

We assume that the access frequencies of content from an ISP and a partner ISP are separately monitored by both ISPs. For increasing the number of shared content, the following process is conducted at the edge routers of the cooperating ISPs. In what follows, we assume ISPs A and B are cooperating and that ISP A initiates the process. Three parameters are utilized: P_{sum} is the amount of content to add for sharing at once, Δ_P is a value for tuning P_{sum}, and α is a parameter for deciding the acceptable difference in access frequency between the ISPs.

Step 1 ISP A chooses candidate contents from the cached but not shared contents so that the total access frequency falls within the range of $P_{sum} \pm \alpha$ and informs ISP B of the content names.

Step 2 When ISP B receives the content names from ISP A, ISP B also selects candidate contents from the cached but not shared and not informed by ISP A contents so that the total access frequency becomes $P_{sum} \pm \alpha$, and informs ISP A of the content names. When ISP B cannot provide such content because there are no contents that meet the condition, ISP B sends a message to ISP A to reject the negotiation.

Step 3 When the exchange of content names is successfully completed, both ISPs A and B advertise the additional content names to be shared to CCN routers in each ISP and finish the process.

Step 4 When ISP A receives the denial message, ISP A decreases the value of P_{sum} by Δ_P and restarts the negotiation (return to Step 1).

On the other hand, when the difference in access frequencies between both directions, denoted by P_{diff}, becomes larger than P_{th}, the ISP that has the larger access frequency than the other ISP initiates the following process.

Step 1 ISP A chooses candidate contents from the cached and shared content between the ISPs so that the total access frequency falls within the range of $P_{diff} \pm \alpha$, and advertises the withdraw of the selected contents to ISP B.

Step 2 ISP B forwards the withdrawn advertisement messages to CCN routers in its own network.

5. Evaluation

5.1 Evaluation environment

For evaluation, we construct a network topology that consists of two ISPs' network. We utilized the AT&T network topology, which was obtained from the CAIDA database [13]. The number of nodes and links in the AT&T topology are 82 and 124, respectively, and we assume each node corresponds to a CCN router. We regard the network topology as a single ISP topology, and assume that two ISPs have the identical topology. We refer to two ISPs as ISP A and ISP B in the remainder. The CCN router that has the highest degree is called the edge router, and two ISPs that are interconnected to each other by a peering link between their edge routers. Each ISP also has a transit link at the edge router for ensuring connectivity to the entire Internet. We adopt shortest path routing between all CCN router pairs, and each CCN router has full routing entries for forwarding Interest packets for all contents in network. When the two ISPs adopt the inter-ISP cache sharing, we refer to the cooperative ISP of each ISP as the *partner ISP*.

We assume that the CCN mechanism including the proposed method is applied to video streaming services such as YouTube [14]. The original content server is located outside the two ISPs. According to [15], the request frequencies to content follow the Zipf distribution with a skew parameter of 0.668, and the cooperative ISPs share their request frequencies information. The number of unique contents is set to $10,000$. The content sizes follow a uniform distribution up to 150 MB. The size of CS at each CCN router is set to 500 MB and LFU is utilized for the cache replacement algorithm, with all CSs in the CCN routers initialized to empty when the simulation experiment is started. In CCN, content is divided into a number of chunks and each chunk has a unique name. However, the advertisement of cached content in the proposed method every chunk generates heavy overhead. So, in the evaluation, the advertisement is conducted every whole content to simplify. This simplification is based on a fact that, in general, when a content is downloaded by end user, the all chunks of the content is requested. In other words, it is rare case that only a part of chunks are cached in the CCN router.

We use the total volume of traffic traversing the transit links of the two ISPs as the evaluation metric, which we call *transit traffic* below, since the Interest packets that request uncached content and the corresponding content data both traverse the transit links. We also show the ratio of Interest packets for which the requested content is cached and is returned by a CCN router in the ISPs, which we call the *cache hit ratio*. Using these metrics, we exhibit the comparison results between the normal CCN, the proposed method without and with the inter-ISP cache sharing. Additionally, we confirm the behavior of the proposed method by assessing the traffic volumes on the transit and peering links, access frequency from each ISP to its partner ISP, average hop-count to reach the contents.

In each ISP, $250,000$ Interest packets are generated for one simulation experiment, each of which is received by a randomly selected CCN router. We conduct 10 trials for each simulation experiment and calculate the average values for each metric. Note that although we also calculated the standard deviations, we omit it because the standard deviations for all metrics are too small. Since the simulation experiment progresses by generating Interest packets sequentially, the unit of T_{intra} and T_{inter} are represented by the numbers of generated Interest packets. We set the parameters as follows: $T_{intra} = T_{inter} = 10$, $P_{sum} = 0.02$, $P_{th} = 0.05$, $P_{dup} = 0.01$, $\alpha = 0.001$, $\Delta_P = 0.005$, $K = 400$ MB.

5.2 Evaluation results

5.2.1 Basic behavior of the proposed method

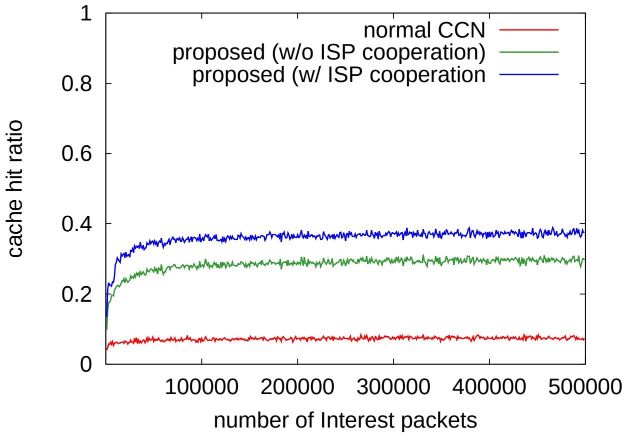
Figures 4(a) and 4(b) show the changes in the cache hit ratio and the transit traffic, respectively. The x-axis of these graphs is the number of generated Interest packets. Note that increasing x-axis value indicates the progress of the simulation experiment. From Figure 4(a), we can observe that at the beginning of the simulation experiment, the cache hit ratio increases rapidly, and becomes stable as the simulation progresses. This is because the simulation experiment starts with empty caches and the number of cached contents increases as the simulation progresses. The cache hit ratio in the normal CCN is approximately 0.09 at peak. On the other hand, when using the proposed method, it reaches 0.31 and 0.39 without and with inter-ISP cache sharing, respectively. This result indicates the cache sharing avoiding overlaps by the proposed method improves the cache hit ratio significantly. In addition, the cache hit ratio when using inter-ISP cache sharing increases rapidly at the beginning of the simulation experiment comparing to the case without inter-ISP cache sharing. This is because the obtained contents by the customers in both ISPs are cached without overlapping. This property of the proposed method indicates an additional advantage to cache contents quickly as well as improving the cache hit ratio.

From Figure 4(b), we can confirm that the transit traffic is greatly decreased by introducing the proposed method, even when we do not utilize inter-ISP cache sharing. When we use inter-ISP cache sharing, the degree of reduction is further advanced. Comparing the traffic volume generated by the last 50, 000 Interest packets in the simulation experiment, we see that the proposed method can decrease the transit traffic by 21% and 28% without and with inter-ISP cache sharing, respectively.

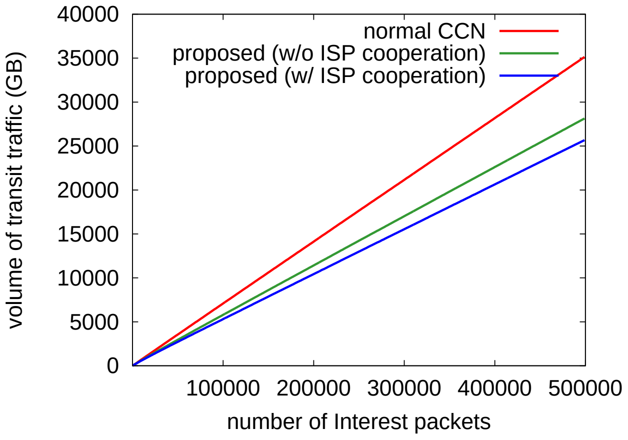
The cache sharing among multiple ISPs is equal to the extension of the CSes on CCN routers in semblance except for increase of traffic volume in intra-ISP networks. In the light of that the transit cost is a heavy burden for ISPs, the incentive to utilize the proposed method must be large.

5.2.2 Overhead by SCT packets

Almost all SCT packets are only about addition/withdraw advertisement of a single content. Here, we assume the size of SCT packet as 170 Bytes (128 Bytes for content name, 4 Bytes for CCN router name, 18 Bytes for IP header). Figure 5 shows that at the beginning of the simulation experiment, the SCT messages are generated at high rate. After that, the volume of SCT messages per unit time are stable. For the case with the inter-ISP cache sharing, observed SCT packets is 208 packets for last 50, 000 Interest packets in the evaluation. The traffic volume generated by these SCT packets is 35.4 KBytes every link between the CCN routers.



(a) Cache hit ratio



(b) Transit traffic

Fig. 4 Basic behavior of the proposed method

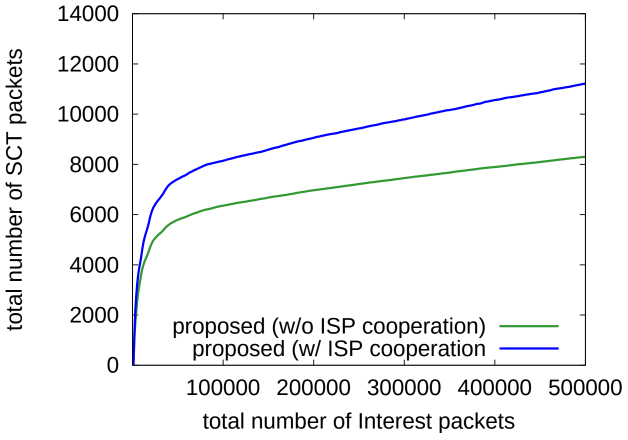


Fig. 5 Advertisement overhead by SCT messages

It is clearly low-level traffic volume for recently ISPs' network.

5.2.3 Inter-ISP traffic by the inter-ISP cache sharing

The transit traffic generated by the last $50,000$ Interest packets is $3,439$ GB for the case with normal CCN. When we conduct the proposed method, the values are $2,732$ GB and $2,491$ GB without and with inter-ISP cache sharing, respectively. Meanwhile, the traffic load on the peering link with inter-ISP cache sharing is 505 GB, which is larger than the reduction volume from without inter-ISP cache sharing, that is 241 GB. This is because when using inter-ISP cache sharing, the cache hit ratio in each ISP's network declines while the whole cache hit ratio increases, that leads the increase in the inter-ISP traffic. However, in general, the cost to utilize transit links is higher than that of peering links, and so the inter-ISP cache sharing has significant benefits for reducing the ISP's cost.

To confirm the inter-ISP traffic balance between cooperating ISPs, for each ISP, we calculate the request frequency to the cached contents in the partner ISP, where the whole request frequency of each ISP is one. The request frequencies from ISP A to ISP B and from ISP B to ISP A are 0.164 and 0.184, respectively, at the end of simulation experiment. We also conducted a simulation experiment where the request frequency of ISP B is a half of ISP A. For this case, the total request frequencies of two ISPs are 0.114 and 0.142. For both results, the differences between the two ISPs are within the threshold $P_{th}(= 0.05)$. The amount of traffic volume between the ISPs from ISP A to ISP B is 254GB, and from ISP B to ISP A is 251GB. Therefore, we conclude the proposed method with inter-ISP cache sharing can maintain the inter-ISP traffic balance.

5.2.4 Hop-count to reach contents

We calculate the average hop-count between a CCN router which first receives the Interest packet and a CCN router which returns the requested content, by assuming the hop-count beyond the transit links is 13.5 hops, according to [16]. The calculated average hop-counts are 14.5, 12.2, and 11.6 hops for normal CCN, the proposed method without and with inter-ISP cache sharing, respectively. From the results, we can observe that the average hop-count when the proposed method is introduced decreases compared with normal CCN by 2.3 and 2.9 hops with and without inter-ISP cache sharing, respectively. Therefore, we conclude the proposed method can provide a faster response to end users compared with that provided by normal CCN.

5.2.5 Influence of contents popularity distribution

To investigate the influence of content popularity distribution, we set the skew parameter of the Zipf distribution to values from 0.5 to 1.0 at intervals 0.1. Higher parameter values represent that the access frequency of content is more heavily biased. In such a situation, we can expect high cache hit ratios with small cache storage, which results in reducing the transit traffic. Conversely, when the access frequency follows the Zipf distribution with a smaller skew parameter, we need larger cache storage in order to reduce transit traffic effectively. Figure 6 shows the transit traffic reduction from the traffic volume without any caching mechanism for various skew parameters. From the figure, we observe that the proposed method can achieve a considerable reduction in transit traffic compared with normal CCN for all settings of skew parameter value. From a comparative viewpoint with the normal CCN, when the skew parameter is small, the proposed method is highly effective. When the skew parameter is 1.0, the transit traffic reduction by the proposed method with inter-ISP cache sharing is 2.04 times from that of the normal CCN. For the case when the skew parameter is 0.5, this value becomes 5.50. In an environment where the skew parameter is small, the caching mechanism must cache a number of contents to reduce transit traffic effectively, so this result shows the cache sharing without overlaps by the proposed method works efficiently.

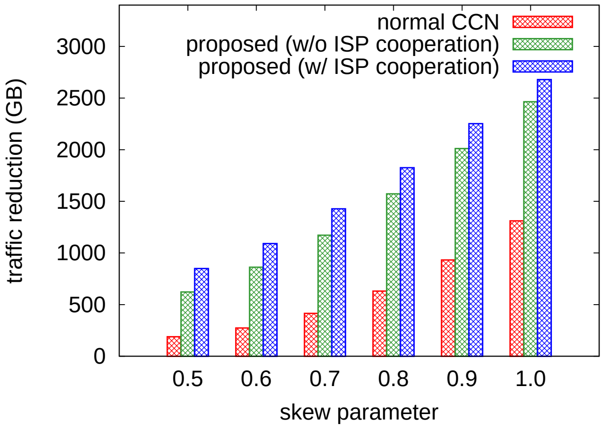


Fig. 6 Influence of the skew parameter of the Zipf distribution

6. Discussion

6.1 Relationships between total amount of content and CS size

We discuss here about the effectiveness of inter-ISP cache sharing. We assume the contents follow the Zipf low with skew parameter 0.668 based on [15]. The potential cache hit ratio $P(x)$ can be calculated by the following equation:

$$P(x) = \sum_{k=1}^{x} \frac{1/k^s}{\sum_{n=1}^{N} 1/n^s} \tag{1}$$

where N is the number of unique contents requested by end users, s is the skew parameter, and x is the number of contents that can be cashed in the CCN routers without overlapping. Here, we assume that $N = 10,000$ as the same in the evaluation. When an ISP (referred as ISP A) caches 20%

of total contents in own CSes of CCN routers, the cache hit ratio can potentially reach 0.570, which can be calculated by Eq. (1) with $x = 2,000$. Using the same calculation method, If another ISP (referred as ISP B) that has the peering link between ISP A caches the same amount of contents as ISP A and shares it with ISP A (i.e. $x = 4,000$ in Eq. (1)), the cache hit ratio improves by 0.158 at a maximum. In another case where each ISP can cache 40% of total contents (i.e. $x = 8,000$ in Eq. (1)), the improvement by the inter-ISP cache sharing is 0.198, which is relatively smaller than the case of 20% in light of they share the twice amount of cached contents. Indeed, it indicates the performance of proposed method to reduce transit traffic becomes to decline. However, as long as each ISP does not caches 100% of total contents, the improvement of cache hit ratio exists for certain, it is a motivation to introduce the proposed method.

6.2 Guide for parameter settings

T_{intra}, T_{inter}

We can decrease the convergence time of cache sharing by setting these parameters to smaller values, where the convergence time means the time to reach the state where the memory space for cache sharing has been filled by contents and advertised these among the CCN routers. On the other hand, the instantaneous overhead of the advertisement becomes large. These parameters should be set in accord with this trade-off relationship. Note that, when the content caching process is converged, T_{intra} and T_{inter} can be set relatively large for the purpose to suppress the computation overhead by advertising SCT.

P_{sum}, Δ_P

P_{sum} is the parameter that indicates the amount of contents to put in the inter-ISP cache sharing at once. When it is large, the negotiation between the ISPs for deciding which contents to be shared is difficult to reach agreement. However, P_{sum} gradually decreases by Δ_P every time the negotiation fails, so P_{sum} is not so sensitive to the performance of the proposed method.

P_{th}

This parameter is an acceptable difference between total access frequencies to each other's cached contents, which is decided by negotiation between the cooperating ISPs.

K

This parameter affects the number of unique contents that can be cached in the ISP(s) linearly. Then, it should be decided according to the amount of unique contents that required by the end users in the ISP(s).

6.3 How handling crash of CCN router

Some existing methods can be utilized to detect crash of CCN routers such as the keep-alive mechanism in OSPF, bidirectional forwarding detection [17], and just monitoring link up/down. After detecting a crash of CCN router, we can avoid requests to the crashed router with following method: the CCN router that detects the crash advertises the withdrawn messages of the cached contents in the crashed CCN router to all other CCN routers.

7. Conclusion

In this paper, we proposed a method of cooperative cache sharing among CCN routers in multiple ISPs. The main idea of the proposed method is relaxing the limitation of the current CCN architecture that only caches on the route to the original content holder are utilized for content access. Through the evaluation assuming two actual commercial ISPs adopt the proposed method, we confirmed the additional reduction by up to 28% compared with that of normal CCN.

The proposed method in this paper can be deployed by a type of Information-centric Networking approaches that has in-network caching mechanism on the routes, such as DONA [4] and NetInf [5], with a minor change. That is applying the advertising mechanism in the proposed method to the name resolution service in [4, 5]. Another type that caches only at the cache server on ISP can introduce the part of the proposed method, which is the component for inter-ISP cache sharing.

We will also try to develop an advertisement mechanism with hierarchical architecture such as OSPF's route exchange between routers. That is, the route exchanges are executed by flooding within a limited area, and for inter-area route exchange, the boundary router advertises aggregated routing information to the other boundary router. By adopting this mechanism, the proposed method may achieve the scalability to number of contents, computing resource of CCN routers, and link capacity. We intend to design a method for parameter tunings to achieve best performance of the proposed method.

References

[1] V. Jacobson, D.K. Smetters, J.D. Thornton, M.F. Plass, N.H. Briggs, and R.L. Braynard, "Networking named content," Proceedings of CoNEXT2009, pp.1–12, Dec. 2009.

[2] D. Perino and M. Varvello, "A reality check for content centric networking," Proceedings of the ACM SIGCOMM workshop on Information-centric networking, pp.44–49, Aug. 2011.

[3] S. DiBenedetto, C. Papadopoulos, and D. Massey, "Routing policies in named data networking," Proceedings of the ACM SIGCOMM workshop on Information-centric networking, pp.38–43, Aug. 2011.

[4] T. Koponen, M. Chawla, B.G. Chun, A. Ermolinskiy, K.H. Kim, S. Shenker, and I. Stoica, "A data-oriented (and beyond) network architecture," SIGCOMM Comput. Commun. Rev., vol.37, no.4, pp.181–192, Aug. 2007.

[5] C. Dannewitz, "NetInf: An information-centric design for the future Internet," Proceedings of 3rd GI/ITG KuVS Workshop on The Future Internet, May 2009.

[6] L. Zhe and S. Gwendal, "Time-shifted TV in content centric networks: the case for cooperative in-network caching," Proceedings of ICC 2011, pp.1–6, June 2011.

[7] I. Psaras, W.K. Chai, and G. Pavlou, "Probabilistic in-network caching for information-centric networks," Proceedings of the second edition of the ICN workshop on Information-centric networking, pp.55–60, Feb. 2012.

[8] L. Saino, I. Psaras, and G. Pavlou, "Hash-routing schemes for information centric networking," Proceedings of the 3rd ACM SIGCOMM Workshop on Information-centric Networking, pp.27–32, 2013.

[9] Y. Li, H. Xie, Y. Wen, and Z.L. Zhang, "Coordinating in-network caching in content-centric networks: Model and analysis," Distributed Computing Systems (ICDCS), 2013 IEEE 33rd International Conference on, pp.62–72, July 2013.

[10] S. Guo, H. Xie, and G. Shi, "Collaborative forwarding and caching in content centric networks," Proceedings of the 11th international IFIP TC 6 conference on Networking - Volume Part I, pp.41–55, May 2012.

[11] L. Wang, A.K.M.M. Hoque, C. Yi, A. Alyyan, and B. Zhang, "OSPFN: An OSPF based routing protocol for Named Data Networking," Tech. Rep. NDN-0003, NDN Technical Report, July 2012.

[12] S. Romano and H. ElAarag, "A quantitative study of recency and frequency based web cache replacement strategies," Proceedings of CNS 2008, pp.70–78, 2008.

[13] CAIDA, "Backbone data." available at `http://www.caida.org/tools/visualization/mapnet/Data/`.

[14] "YouTube." available at `http://www.youtube.com/`.

[15] X. Cheng, C. Dale, and J. Liu, "Statistics and social network of YouTube videos," Proceedings of IWQoS 2008, pp.229–238, June 2008.

[16] A. Fei, G. Pei, R. Liu, and L. Zhang, "Measurements on delay and hop-count of the Internet," Proceedings of IEEE GLOBECOM 1998, Nov. 1998.

[17] D. Katz and D. Ward, "Bidirectional forwarding detection," June 2010. available at urlhttp://tools.ietf.org/html/rfc5880.

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