In-Network Guidance for New-Generation Content Distribution

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Content distribution will be one of main applications in future networks. To realize the concept of Space Decoupling, which is supported by the fact that users have only to acquire desired contents irrespective of where they are located, we developed effective technologies to retrieve and transfer cached contents efficiently by exploiting in-network guidance functions. In this paper, we introduce the main results of our research project in terms of both content retrieval and content transfer.

1 Introduction

Right from the beginning, the Internet has been developed as a means of supporting point-to-point communication. However, currently its role has greatly widened as a basic platform for implementing content delivery services. Content delivery services such as CDN or P2P have undergone changes, and have now developed into such forms where the source of contents, from where the content is obtained, is not disclosed to the users. Still, networks that support content distribution maintain location oriented basic designs such as specifying the content acquisition destination in the IP address. The users are interested per se in the content itself and not in location information such as where the content is located. Based on such a content-oriented viewpoint, we carried out research on cache networks using in-network guidance, with the aim of implementing the concept of Space Decoupling—to weaken the strong location-oriented linkage between the content sever and the user—, while taking into consideration the operational efficiency of the network.

In this research, Breadcrumbs[1] is used as the base technology (Fig. 1). Breadcrumbs is the in-network guidance technology wherein, when the user requests content, the router within the network autonomously guides the content request towards the location of the requested content based on the information that the router manages by itself. In Breadcrumbs, when content is downloaded, a pointer that indicates the download path of the content, called a breadcrumb (hereinafter referred to as "BC") is left in the router. After that, if the request for content sent out in the network encounters a router with the appropriate BC while it is being forwarded to the content server using normal IP forwarding, then the content request will subsequently be forwarded in a hop-by-hop manner, in accordance with the BC. The content saved in the router cache, which is the route not on a default path (a path from the user to the server), could possibly be hit by the in-network guidance system that uses BC, so Breadcrumbs is an excellent method for flexibly discovering content in the cache network.

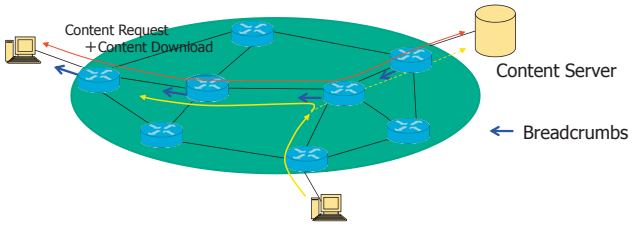


Fig. 1 In-network guidance technology: Breadcrumbs

This paper describes the research and development on a new content delivery technology using in-network guidance technology for two phases of content delivery: content discovery, and content transmission. Section **2** describes an efficient location ID selection technique, in which load balancing function is introduced for mapping content ID and location ID, that are considered as prerequisites for the in-network guidance. Section **3** describes an efficient method for implementing content discovery through in-network guidance, by having multiple in-network guidance systems and controlling them in an autonomous and distributed manner. Section **4** describes a platform for discovering/acquiring/using network resources by applying in-network guidance technology in dynamic discovery of network resources including content. The research results in Sections **2** to **4** were implemented in a prototype, and those aspects whose validity and operability were verified on JGN-X are described in Section **5**.

2 Load-balancing content location mapping control technology

This section introduces the research conducted by Kobe University on Mapping Server with Cache-location Resolution (MSCR). In MSCR, in-network guidance is performed by mapping the server location and cache location from the content ID.

MSCR provides functions for resolving the location of the content server from content ID. The user terminal which requested this solution acquires the content, and as its result, it is expected that the content will be cached in the route leading up to that user terminal. MSCR proactively guides the content request to the content cache, by saving the location of that user terminal as the Prospective Cache Location (PCL), and responding to the subsequent content request with this PCL in addition to the server location. By this, there is a high possibility of the cached content being discovered, and most likely that the load on the backbone traffic and content server will be reduced.

2.1 Content acquisition flow

Content acquisition flow by MSCR is shown in Fig. 2. The user terminal for content acquisition requests the content location resolution (1) from the MSCR server. When the MSCR server receives the content ID/location resolution request, it responds to the content request terminal with the location of the content server, and with (multiple) PCLs from the solution request history (2). The content request terminal that receives the response sends the content request (3). This content request will be forwarded to PCLs, as well as server location (3). In case the desired content is discovered in cache midway, the content will be forwarded to the content request terminal from there (4). In case the content is not discovered in any of the PCLs, the content request will be forwarded to the content server.

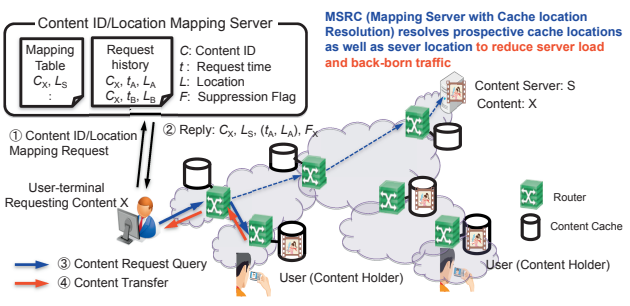


Fig. 2 Content Acquit ion Flow using MSCR

2.2 Review and summary

In this research, we first reviewed earlier studies on MSCR. Reference [2] proposed the MSCR method, and described the performance evaluation obtained through simulations conducted from the viewpoints such as how many PCLs should be saved and how long they should be saved, and which and how many PCLs should respond to the content request terminals. In Reference [3], focusing on the fact that MSCR is capable of estimating the popularity of the content from the content ID/location resolution history, MSCR with Cache Suppression (MSCR/CS) was proposed, with added functions for controlling the excess generation of cache containing highly rated content and the unnecessary caching of unpopular content, and the performance of this proposed method was evaluated. In Reference [4], Variable PCL (VPCL) was proposed. Focusing on the fact that there is a high possibility that the more unpopular the content, the more likely its PCL is invalid, VPCL was designed to maintain invalid cache locations less frequently, by making the number of PCL saves vary according to the content popularity, and thereby reducing the number of hops till the content request discovers the desired content. The performance of this proposed method was evaluated through simulations.

2.3 Variable PCL save system

Through simulation experiments, we compared the Constant PCL (CPCL) system, where a constant number of PCLs are saved, vs. the VPCL system, where the number of PCLs to be saved varies based on the content popularity estimation results.

In the simulation, a three-tier topology made up of Tier-1, Tier-2 and Tier-3, consisting of a total 1,020 routers, is used considering Tier-1 as the core network. Cache is found in the access router only, and its capacity is five contents. In the CPCL system, six PCLs are saved uniformly across the board for each content. In the VPCL system, six PCLs are saved for the content with the highest estimated content request rate, while the number of PCLs to be saved for other content is reduced relative to the estimated content request rate. Both systems respond to the request with four PCLs that are considered to be close to the content requesting terminal in terms of the number of hops.

Table 1 shows the simulation results. Here, IP denotes the conventional system of acquiring content only from the content server based on the IP. Local Cache (LC) represents a system of acquiring content from the content server, or from the local cache of the access router connected to

Table 1 Simulation results about IP, LC, and MSCR

Scheme	SDR (%)	RCTR (%)	AQH
IP	100	100	11.2
LC	99.8	99.9	11.2
MSCR-CPCL	46.2	92.2	26.9
MSCR-VPCL	41.8	91.6	17.7

SDR: Sever Download Ratio, RCTR: Relative Core-network Traffic Ratio, AQH: Average Query Hop

the user terminal. Evaluation was made in terms of the server acquisition rate, relative core traffic rate, and average number of query hops. Server acquisition rate is the proportion of content acquired from the server, expressed as percentage, and the smaller this value, the lower the server load. Relative core traffic rate is the relative volume of traffic, compared to the traffic flow in the core network in the IP system, expressed as percentage, and the smaller this value, the smaller the core traffic volume is considered to be. The average number of query hops is the average value of the number of hops sent by the content request until the acquisition of content, and the smaller this value, the faster the content will be found (hereafter, "query" may be used when appropriate as a term to indicate the content request message itself). From the simulation results, it can be understood that compared to the IP system and the LC system, MSCR reduces both server load and relative core traffic rate. On the other hand, in the MSCR system, the average number of query hops increases, because content requests are guided to cache. There is a high probability that content with low popularity has had its cache replaced by another content and has become invalid, and compared to the VPCL system, in the CPCL system, where a constant number of PCLs are saved, there is a high probability that such invalid PCLs are included in items to be responded to, leading to an increased number of query hops and a high probability of the requested content not being found in the cache. Hence, it is believed that the VPCL system reduces the server acquisition rate, while also reducing the average number of query hops.

3 Distributed content delivery control technology

In this section, we describe the research and development on Multiple Breadcrumbs[5] conducted at Kansai University. In the original Breadcrumbs, the most recent direction in which the content has been transferred is saved as BC, and as opposed to that, Multiple Breadcrumbs aims at increasing the probability of finding content by using some older BCs as well. As research related to in-network guidance technology, the researchers at Kansai University have analyzed the practical deployment of Breadcrumbs[6][7], and proposed Storage Aware Routing[8] as a time axis direction content delivery scheduling technique, in addition to the Multiple Breadcrumbs described in this paper.

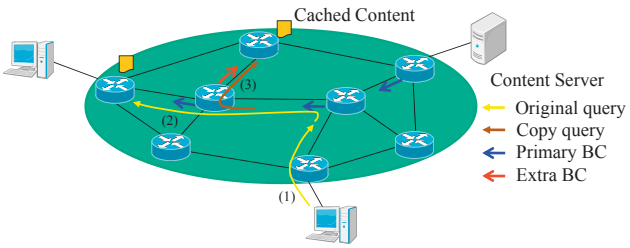


Fig. 3 Basic procedure in Multiple Breadcrumbs

3.1 Multiple Breadcrumbs

Breadcrumbs always records only the most recent guidance information (BC) as guidance information for content saved by each router, and discards all the rest. One of the reasons for using only the most recent content download direction is the high probability that the content in that direction has been cached. However, there is a possibility that usable cache, or guidance information that can lead us to cache in shorter hops than the most recent guidance information, has been included in this discarded guidance information. Here, we investigated Multiple Breadcrumbs as a system using the most recent guidance information in combination with past guidance information.

On specifically investigating Multiple Breadcrumbs, we followed the operation of the original Breadcrumbs, while referring to the guidance information used in conventional Breadcrumbs, i.e. the most recent guidance information, as Primary BC, and any guidance information older than that as Extra BC, separately. For the Primary BC direction, guidance is always performed, because it is believed that there is high probability of acquisition of content. In case of the Extra BC direction, which is old information, a query is duplicated and sent depending on probability, instead of always performing guidance.

Figure 3 shows the basic operation of Multiple Breadcrumbs. In the figure, (1) shows the flow until a content request by user A encounters the Breadcrumbs router, (2) shows the flow of the original query guided by Primary BC, and (3) shows the flow of a duplicated query guided by Extra BC. When the content request sent by user A occasionally reaches the BC router, it is guided in

the direction of BC as shown in (1). In the case of multiple BC routers, operation similar to that of the regular Breadcrumbs is performed, by performing guidance with probability 1 for Primary BC (2). Moreover, for Extra BC, cache search is performed by performing guidance of the content request with probability p ($0 \leq p \leq 1$) for each respectively.

3.2 Finding content using Multiple Breadcrumbs

With Multiple Breadcrumbs, there is a possibility that multiple contents can be discovered by guiding the content request to multiple directions where caches may exist. Performance improvement in content transfer is expected to be achieved by selecting an appropriate download destination from among the multiple discovered contents. Hence, we proposed a Throughput Sensitive selection method, where items with the highest throughput at the time of download are selected from among the multiple discovered contents.

Figure 4 shows a specific example of the Throughput Sensitive selection system. It shows a case of a control packet returned on routes (1) and (2), indicated by red lines, from each of the multiple contents discovered with Multiple Breadcrumbs. The numbers on each link denote active flow numbers. The maximum active flow number on the route is four on route (1), and five on route (2). When the bandwidth of all links is equal, route (1) is selected because it has higher throughput.

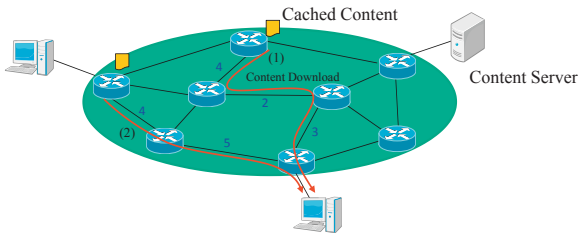


Fig. 4 Throughput Sensitive content selection in Multiple Breadcrumbs

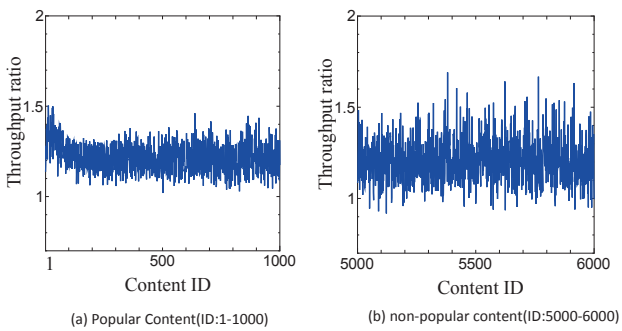


Fig. 5 Throughput improvement by Multiple Breadcrumbs

We conducted performance evaluation of the Throughput Sensitive selection method, applying a Barabási-Albert (BA) topology model with 1,000 routers created by BRITE, wherein 5,000 users and 50 servers are connected to the routers selected randomly from among the 1,000 routers. The number of contents was taken as 10,000, and the content request from the user was assumed to follow the Zipf distribution. Furthermore, the guidance probability for Extra BC was taken as $p = 1$. Figure 5(a) and (b) show characteristics of throughput improvement ratios of popular content and unpopular content, respectively. Throughput improvement ratio is the ratio that represents how much improvement can be seen in the throughput, when the Throughput Sensitive selection method is used in Multiple Breadcrumbs, compared to the throughput obtained in the regular Breadcrumbs. Multiple content search is available for popular content, so it is to a certain extent obvious that throughput ratio will have improved. However, a very interesting result that emerged was that the throughput for unpopular content, for which multiple content search is not completely available, also showed similar improvement. You may refer to Reference [5] for details, but we found that avoiding heavy load links by selecting the high throughput route of popular content leads to lowering the link load on the acquisition route of unpopular content that can be acquired from the server alone, thereby leading to improvement in the throughput of not only popular content but unpopular content as well. Thus, efficient resource investment is possible in a network with Multiple Breadcrumbs.

4 Dynamic discovery and usage technology for generalized resources including content

This section explains the details of the research conducted at Osaka Prefecture University. The research details are broadly divided into the following three subsections.

4.1 R&D on sophisticated distribution method of in-network guidance information

We established Breadcrumbs-Scoping framework for adaptively regulating the distribution of BC information. In the Breadcrumb+ (BC+) method[9], an explicit deletion process of BC Trail and a mechanism for preventing route loop is included. In the Active Breadcrumbs (ABC) method[10], the guidance information of own-content is proactively

distributed around cache. In the earlier methods including Breadcrumbs+ (BC+) and Active Breadcrumbs (ABC) that we had previously proposed, guidance information was created and utilized uniformly in every transit node for all the content. In contrast, in this research, with the aim of further improving performance, we proposed a new framework, Breadcrumbs-Scoping framework (BC-Scoping framework) that limits the scope of creating guidance information under constraints based on an optional index[11]. In this research, corresponding to the two types of indexes, "Network Domain (D)" and "Content Popularity (P)," we respectively designed the specific proposed methods, BC-Scoping (D) and BC-Scoping (P), and evaluated them quantitatively. With regard to BC-Scoping (D), the results of the performance evaluation in two-level network model showed that the acquisition rate from the same domain increased approximately five times in comparison to the existing IP method (Fig. 6). Also, compared to the IP method, the packet quantity traversing an upper level domain reduced in the BC+ method and the ABC method by around 28% and 36% respectively when BC-Scoping (D) is not applicable, and the quantity further reduced in both methods by around 45% when BC-Scoping (D) was applicable (Fig. 7). Thus from the above, it is understood that the BC-Scoping method accelerated local content acquisition and reduced traffic inside the network. Also, as a result of the accelerated content acquisition in the lower level domain, the ISPs operating lower level domains can expect reduction in the transit charge they would have to pay for upper level domains, because the amount of traffic transferred via transit connection will decline.

On the other hand, in the case of BC-Scoping (P), the operation frequency of BC table in each router reduced by 2/3 compared to the existing BC method (Fig. 8). Here, the BC+ (rate) method in Fig. 8 is the method where the creation of BC Trail and cache is stochastically curtailed at the same rate as BC-Scoping (P) method. Also, regarding table lookup cost, the results show that for a single table lookup process in BC+ method, the frequency is 0.186 times in BC Scoping (P), and 1.324 times in BC+ (rate) method. Thus, the proposed method achieved reduction by 4/5.

Next, by upgrading the ABC/BC+ methods and expanding the search and distribution scope of the existing one-dimensional guidance information to be two-dimensional, and also by generalizing the search/distribution scope from line to plane, we proposed a Generalized ABC method in which the query more proactively comes in contact with the guidance information and is guided towards cache. We carried out a basic experiment using the prototype wherein the software of User side Flooding method of query which is a part of the Generalized ABC method was implemented. Specifically, from the results of the experiment conducted by building a 3×6 grid and Japan Photonic Network (25 nodes) in a form to interconnect the virtual machines

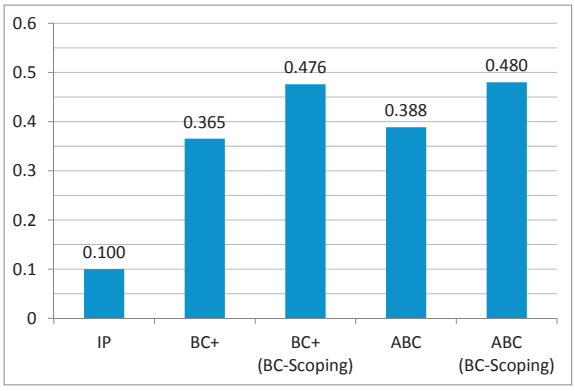


Fig. 6 Comparison of content acquisition rate from same domain as users in each method

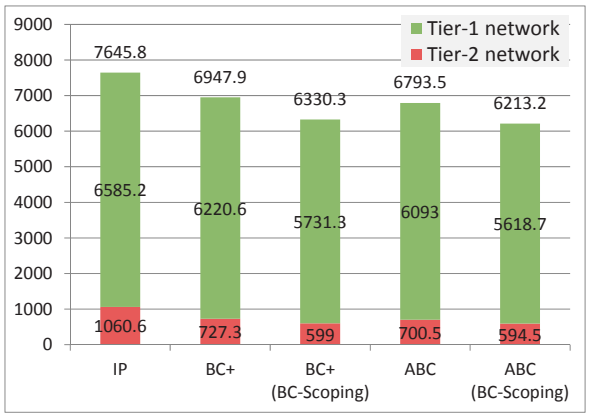


Fig. 7 Comparison of total volume of packets inside Tier-1/Tier-2 network in each method

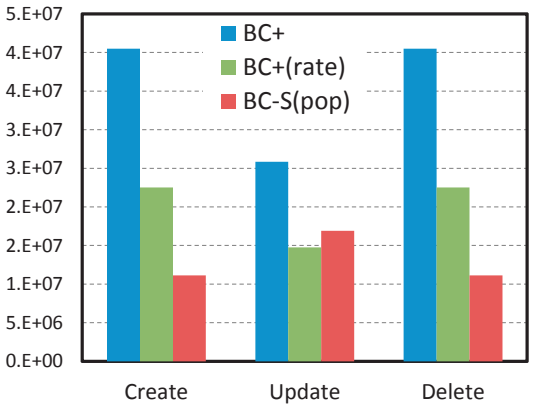


Fig. 8 BC entry operation counts

in a server workstation, we confirmed a further reduction in the number of hops[12]. In cooperation with NEC, we also performed a wide area prototype demonstration experiment regarding the methods we proposed, namely, BC+, ABC, and BC-Scoping on Domain.

4.2 Development of technology for enabling efficient discovery/acquisition of general resources

Through the application of the Breadcrumbs method, we developed Resource Breadcrumbs as a platform for discovery and acquisition of general resources such as computational resources and memory resources[13]. Figure 9 shows an overview of Resource Breadcrumbs. Specifically, in addition to (Spread) RBC, the basic method in which each supplier distributes their guidance information to the periphery (spread), we proposed En-Route RBC that registers RBC entry along the lines of the return route from the supplier. The former achieved 1/3 or fewer hops via request (Fig. 10), and approximately half the number of hops between suppliers and users (Fig. 11), compared to normal server-client type resource acquisition. Also, with the latter, similar performance was obtained with distribution scope reduced by one or more hops, compared to a simple RBC method. Also, we proposed Selection of Proximal Supplier (SPS) that selects the resources to be utilized so that the suppliers of the resources used in the same request come closer to each other, and successfully reduced the distance between suppliers by up to approximately 50%.

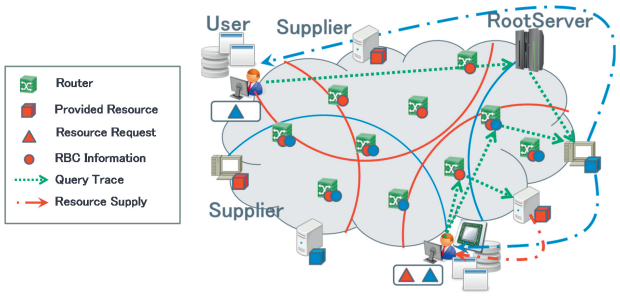


Fig. 9 Outline of RBC method

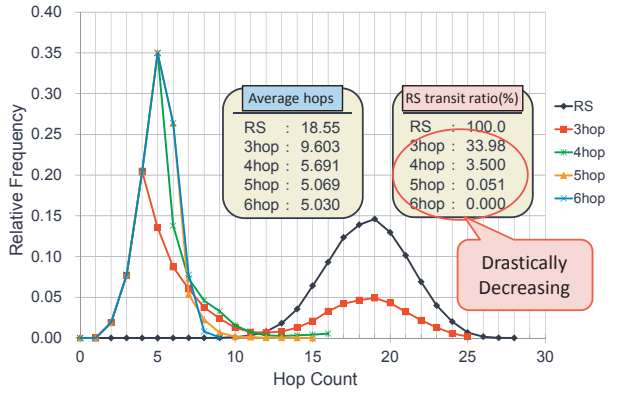


Fig. 10 Probability distribution of hop counts until query message for content request reaches target resource

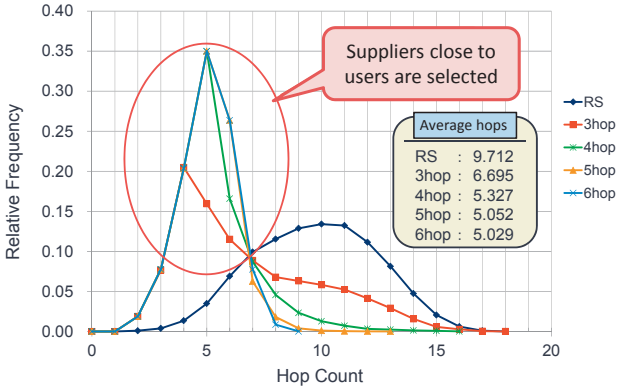
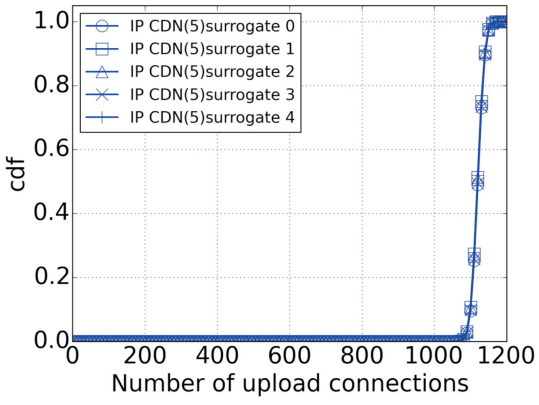
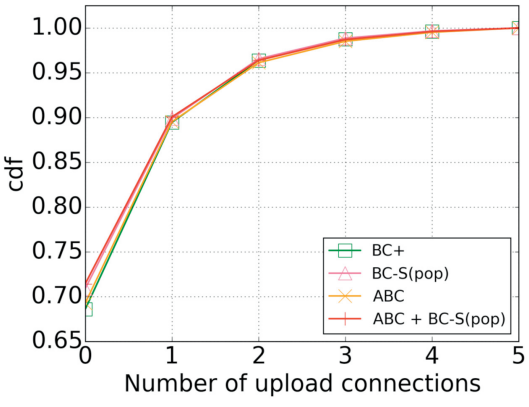


Fig. 11 Probability distribution of hop counts between user and selected supplier



(a) Each surrogate (CDN)



(b) Each user (BC-related methods)

Fig. 12 CDF of upload connections

4.3 Quantitative Comparative Evaluation of CDN Approach and BC-related Approaches

After making a model of the existing content distribution network (CDN), we performed a quantitative comparison of its characteristics vs. the various BC-related approaches. For the comparative evaluation, we focused on Akamai[14], which is the most widely used CDN, and constructed a CDN model with a simplified DNS redirection mechanism. From the result of the comparative evaluation conducted in an environment with standard total cache storage capacity in the network, the advantage of BC-related approaches over CDN became clear, particularly from the viewpoint of the network load balance. In the assumed environment, the processing capacity needed for each user in the BC-related approaches was calculated as approximately 1/2,500 of the CDN surrogate (data center).

The specific considerations for this point based on the numerical results are given below. Figure 12(a) shows the cumulative distribution function of the number of upload connections in each surrogate in the CDN approach. Each of the total five surrogates installed in the network boots up with 1,100 connections. This is the effect of distribution of load between the surrogates using the DNS redirection technology. On the other hand, in the BC-related approaches, the maximum number of upload connections is set to five, but the maximum limit was hardly ever reached (Fig. 12(b)). The average values in each of the BC-related approaches (BC+, BC-S (pop), ABC, ABC + BC-S (pop)) were 0.47, 0.44, 0.47, and 0.44 respectively. Also, in this simulation, each connection has a speed of 5 Mbps, so the load on the surrogates in terms of the bandwidth was 6 Gbps at the maximum, and in terms of the work load, on average there were 1120.83 connections, with 1,200 connections at the maximum. In contrast, in the BC-related approaches, the work load averaged 0.44 to 0.47, and 5 connections at the maximum. Considering the averages, in this simulation, the processing capacity required by each user was about 1/2,500 of the surrogate (data center).

We further assessed the synergy effect when CDN and BC+ approaches co-existed and operated together. It became clear that, by the combined use of CDN and BC+ approaches, the surrogate usage rate was reduced by up to 3/4.

Through the above results, we achieved the improvement of the Breadcrumbs approaches and successfully established the general resource finding and fetching technology. Next, besides developing a better system to be proposed, we plan to expand the approach considering interface with the current CDN or data center, etc., and expand the approach with the main focus on actual application cases such as big data analysis.

5 Demonstration test in network virtualization testbed

This section describes the prototype implementation and the demonstration tests conducted by NEC. In particular, we developed the Breadcrumbs network guidance technology and its expanded approaches such as BC+, Active BC, BC Scoping, Hop-aware BC, MSCR and guidance between heterogeneous NWs. We conducted the demonstration test on the network virtualization testbed of JGN-X. The purpose of this demonstration test was to verify the effectiveness of the combined use of expanded approaches whose effectiveness was already confirmed by simulation.

Figure 13 shows the structure of the slice generated on the virtualization platform. One VM for the router and one VM for both the users and content server were arranged on each VNODE in Otemachi, Hakusan, Sendai, Hokuriku, Nagoya, Osaka and Fukuoka, so a total 14 VMs were connected as shown in the figure. The resources were divided using LXC, and one content server and four users were operated on one VM.

1,000 contents were arranged in the content server of each point. To avoid bias in popularity of the contents, the contents were arranged by round robin in each content server by the order of popularity. Popularity distribution was done by using Zipf Mandelbrot distribution (s=0.8, q=3). Each user requested content once in one second, by the probability based on the popularity. This continued for 1,800 seconds. The domains shown in the figure were used

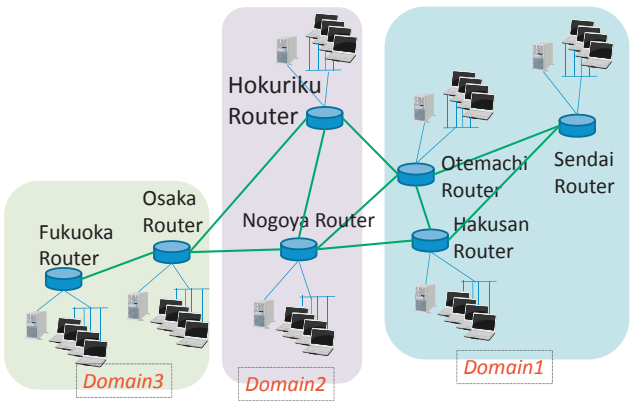


Fig. 13 Experiment topology

when BC Scope was used. Table 2 shows the parameters used for evaluation. We evaluated performance achieved when several expanded approaches were combined and used. The combination patterns were of ten types from IP to ALL, as shown in Table 3. We conducted tests three times using each approach and took the average result.

Figure 14 shows the cache hit rate of each pattern. While the cache hit rate was 16.5% when only the cache from the shortest route was used, it was 38.9% when guidance through Breadcrumbs (BC) was performed, showing an improvement of 12.4 points. Moreover, it was confirmed that the hit rate could be raised up to 41.7% by using MSCR and ABC. However, when BC Scope was used, the cache hit rate was between 32.1–33%, below the level when only BC was used. This was because the scale of the evaluated topology was small and the BC's network configuration is different from the hierarchical network configuration assumed for BC Scope. BC Scope is favorable in terms of the network load or the hop count described later, which have a trade-off relationship. As for which index should be given priority, it depends on the network operator's policy, so one cannot say that any index is generally appropriate.

The average query hop count when BC Scope and ABC were combined was 3.0 hops, which was the shortest. That was 5% shorter than the result of 3.18 hops when only BC was used. This is due to the synergy effect of both the effect of guidance to the adjacent cache saving node by ABC, and the effect of prevention of guidance to the farthest node by BC Scope. Also in the case of "ALL" (using all the expanded approaches), the hop count was 3.13, which was better than the result when only BC was used. Average hop count of content response (download) was held to less than 3 hops by using the expanded approach; this compares to IP (3.5), Cache (3.13) and BC (3.05), so the expanded approach fetched content from closer nodes. The test had a small

Table 2 Evaluation Parameters

Router Cache Size	50 contents
User Cache Size	50 contents
Breadcrumbs Tf	45 sec
Breadcrumbs Tqf	30 sec
Content size	1 Kbyte
ABC Lifetime	60 sec
PCL Lifetime	60 sec
Link Bandwidth	50 Mbps

Table 3 Combination of methods

	cache	BC	ABC	BC Scope	MSCR
IP	×	×	×	×	×
cache	○	×	×	×	×
BC	○	○	×	×	×
ABC	○	○	○	×	×
BCScope	○	○	×	○	×
MSCR	○	○	×	×	○
ABC+BCScope	○	○	○	○	×
ABC+MSCR	○	○	○	×	○
BCScope+MSCR	○	○	×	○	○
ALL	○	○	○	○	○

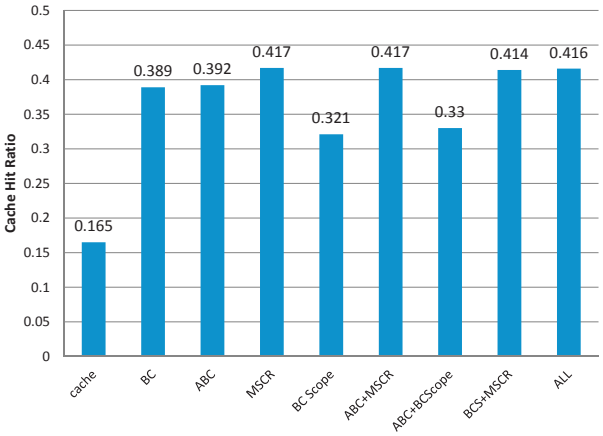


Fig. 14 Cache hit ratio

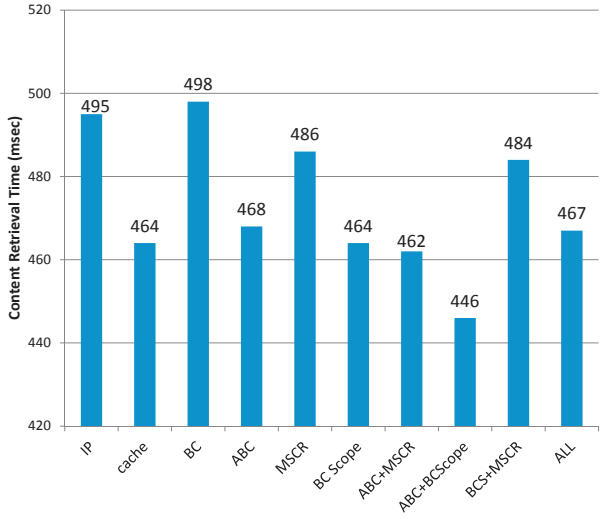


Fig. 15 Content retrieval time

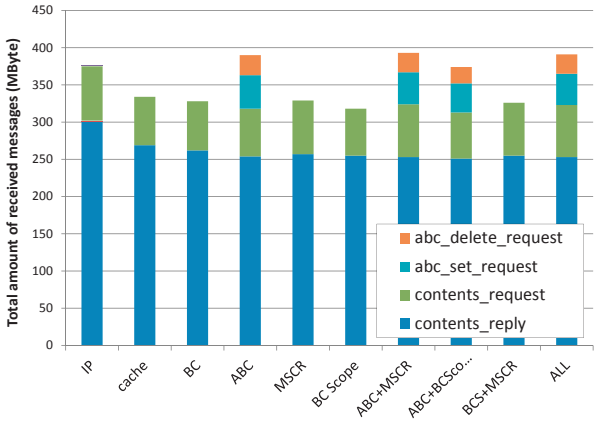


Fig. 16 Total amount of received messages (Mbyte)

topology, so no major differences were found in the hop counts from the different combinations of the approaches.

Figure 15 shows the average time users take to fetch content. Average content fetch time for users tended to be longer because of query guidance when only BC was used. Also, even when MSCR was used, fetch time was longer as there were more cache mistakes. From the viewpoint of fetch time, ABC+BC Scope was the fastest at 446 ms, 10% shorter than when only using BC (498 ms).

Figure 16 shows the total bytes of messages received by all routers. Most traffic was content replies (contents_reply). By using the expanded approach, content download hop count decreased, and the send/receive bytes of content replies also reduced. Queries (contents_request) also had some amount of difference arising from the hop counts. In the pattern using ABC, ABC control messages were added, such as "abc_set_request" for distributing ABC to the next node, and "abc_delete_request" for deleting ABC when the cache disappears. In this test, content size was 1 KB, and the larger the content size, the difference in contents_reply messages was also proportionally greater. On the other hand, the ABC control message and query were not related to the content size, so with the increase in content size, the network load of IP, cache and BC also increased, and their total was larger than the pattern using the expanded approach. Thus we can conclude that the expanded approach is also more effective in terms of network load reduction. Also, it was considered that even the control load of ABC could reduce by adjusting the distribution parameters of ABC to appropriate values.

This demonstration test conducted in the live environment enabled us to confirm that the combined use of ABC, MSCR and BC Scope is effective for improving the cache hit rate, reducing the fetch time, and reducing the network control load.

6 Conclusion

By adopting the viewpoint of effective use of network resources for content delivery, which is expected to be the main application in the new generation network, we worked on research and development regarding both content discovery and content forwarding, with the purpose of achieving Space Decoupling. Using the network guidance technology known as Breadcrumbs as the base to actively engage the network in content delivery, it is possible to achieve content delivery that is beneficial to both users and the network, i.e. improvement in content acquisition throughput for users, and efficient application of cache for the network through the reduction of traffic in the network. Research and development is currently progressing world-wide, and even in Japan, committees such as the Technical Committee on Information-Centric Networking established by IECI are more active. In the field of research on content-centric networking, the knowledge on efficient application technology of cache network for achieving Space Decoupling obtained in this research is expected to be used widely.

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References

1. E. J. Rosensweig and J. Kurose, "Breadcrumbs: efficient, best-effort content location in cache networks," Proc. of IEEE INFOCOM 2009, pp.2631–2635, Rio de Janeiro, Brazil, June 2009.
2. H. Kawabata, K. Hashimoto, T. Inamoto, Y. Takaki, C. Ohta, and H. Tamaki, "Content/location mapping with cache-location resolution for in-network guidance," Proc. of the Fourth International Conference on Advances in Future Internet, Roma, Italia, pp.1–6, Aug. 2012.
3. H. Kawabata, T. Onizuka, Y. Takaki, C. Ohta, and H. Tamaki, "A study on cache suppression control according to content popularity for in-network guidance," Proc. of ACM the 9th International Conference on Emerging Networking Experiments and Technologies (CoNEXT2013), Student Workshop, pp.39–41, Santa Barbara, USA, Dec. 2013.
4. Takaki Onizuka, Naomi Kataoka, Yumi Takaki, Chikara Ohta, and Hisashi Tamaki, "A Study on Management of ContentID/Cache Location based on Estimation of Content Popularity for In-network Guidance," IEICE Technical Report, Vol.114, No.477, NS2014-239, pp.361–366, March 2015. (in Japanese)
5. Hideyuki Nakajima and Miki Yamamoto, "A Study on Download-Node Selection Method in Multiple Breadcrumbs," IEICE Technical Report, Vol.114, No.206, NS2014-93, pp.85–90, Sept. 2014. (in Japanese)
6. T. Tsutsui, H. Urabayashi, M. Yamamoto, E. Rosensweig and J. Kurose, "Performance Evaluation of Partial Deployment of Breadcrumbs in Contents Oriented Networks," in Proc. Fifth International Workshop on The Network of The Future(Future Net V), IEEE ICC 2012, pp.7386–7390, Ottawa, Canada, June 2012.
7. K. Ikkaku, Y. Sakaguchi, and M. Yamamoto, "In-Network Guide Performance in Wireless Multi-Hop Cache Networks," in Proc. The 16th Asia-Pacific Network Operations and Management Symposium (APNOMS 2014), Hsinchu, Taiwan, Sept. 2014.
8. S. Yamashita, T. Yagyu and M. Yamamoto, "Time Dimensional Traffic Engineering with Storage Aware Routing," IEICE Trans. on Commun., Vol. E97-B, No.12, pp.2641–2649, Dec. 2014.
9. Masayuki Kakida, Yosuke Tanigawa, and Hideki Tode, "Breadcrumbs+: Some Extensions of Breadcrumbs for In-Network Guidance in Content Delivery Networks," IEICE TRANSACTIONS on Communications, Vol.J94-B, No.10, pp.1283–1292, Oct. 2011. (in Japanese)
10. M. Kakida, Y. Tanigawa, and H. Tode, "Active breadcrumbs: adaptive distribution

of in-network guidance information for content-oriented networks," IEICE Trans. Commun., Vol.E96-B, No.7, pp.1670–1679, July 2013.
11. M. Kakida, Y. Tanigawa, and H. Tode, "Constraint-based distribution method of in-network guidance information in content-oriented network," Proc. of Sixth International Conference on Advances in Future Internet (IARIA AFIN 2014), pp.39–47, Lisbon, Portugal, Nov. 2014.
12. C. Michard, Y. Tanigawa, and H. Tode, "User-side flooding for query distribution in Breadcrumbs-based content-oriented network and its experimental evaluation," Proc. of APSITT 2015, 3 pages, Colombo, Sri Lanka, Aug. 2015 (Accepted).
13. H. Tode, K. Nishii, and Y. Tanigawa, "A participating fine-granular cloud computing platform with in-network guidance," Proc. of IEEE ICC 2014, SAC-CC-03, 6 pages, Sydney, Australia, June 2014.
14. J. Dilley, B. Maggs, J. Parikh, H. Prokop, R. Sitaraman, and B. Weihl, "Globally distributed content delivery," IEEE Internet Computing, Vol.6, No.5, pp.50–58, 2002.

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