Content Placement for Reducing FIB Size in NDN Using GA

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***Abstract*—In Named-Data-Networking (NDN), we request data by name, not IP address. At that time, request packets are sent by referring to FIB (forwarding information base) of routers. On the other hand, CDN (content delivery network) is widely used as a technology to improve the delivery quality of users in the network. We proposed reducing the FIB entry size by using CDN in the method that allocates the original content to the CDN cache server in the network from the server that publishes its content. However, the content placement on the network affects the performance of the network; therefore, it is difficult to determine the optimal placement when considering not only the FIB size but also other metrics. In this paper, we propose a method to use a genetic algorithm (GA) to not only aggregate FIB entries, but also reduce network load and improve other network metrics. Through the numerical evaluation, we show that the proposed method can reduce the FIB entry size while suppressing the load concentration of network links.**

***Index Terms*—ICN, NDN, CDN, Forwarding Information Base, FIB Aggregation**

I. Introduction

With the spread of the Internet and SNS, user-generated content (UGC) such as YouTube is increasing. In addition, with the spread of 5G communication with high speed, large capacity, and multiple simultaneous connections, the practical application of Internet of Things (IoT) is progressing in agriculture and corporate factories, and the processing of large amounts of sensor data obtained from IoT devices is necessary for their utilization. Therefore, Information-Centric Networking (ICN) [9][14] is being considered as a next-generation network for efficiently distributing content. ICN allows users to request content directly without specifying the source of the content, since delivery requests are made using the name of the content. Named Data Networking (NDN) [6][15] is the mainstream among ICNs, and this paper assumes NDN.

In NDN, packets requesting content items are referred to as *Interests*. Similar to the conventional communication method using IP addresses, NDN forwards interests to Next Hop (NH) by referring to a routing control table called Forwarding Information Base (FIB) in the router. An entry in the FIB is composed of a pair of prefix and NH. Unlike IP routers, which utilize a FIB to correlate the prefix of a destination IP address (i.e., the network address) with the corresponding output port, FIB in NDN routers operates as a matching table that associates content name prefixes with their respective output faces. The original content of NDN exists on the publisher host, and the publisher advertises the prefix of the content name to neighboring routers. When the NDN router receives a prefix advertisement, it configures the FIB such that the content requested by the user subscriber (i.e., users) is forwarded to the publisher's host. If we create entries for every possible prefix in the FIB, the memory required for the FIBs increases significantly. Therefore, aggregating FIB entries is essential to make small the memory cost of the FIB.

In the case of IP network, IP addresses have geographical locality because a certain range of addresses is assigned to each country or region by the management organization. However, in the case of NDN, the hosts of publishers who provide content from the same organization tend to be located in the same region, but the organization name is not geographically localized. Therefore, it is difficult to aggregate prefixes in the NDN FIB compared with that in IP networks.

On the Internet, CDN (content delivery network) is widely used as a mechanism to reduce the amount of traffic and the time of delivery of web content for users within the network. In NDN, contents are likely to be cached and delivered by routers near the requesting users so that the objectives of CDN are met by NDN. To effectively aggregate entries, it is desirable for content with similar names to reside on the same node, since multiple entries can be aggregated into a smaller number of FIB entries if their names contain the same string.

We have previously proposed to effectively reduce the size of the NDN router FIB by positioning the CDN as the original ICN provisioning platform and reallocating web objects. For example, for the first component of a URL, each of the top level domain (TLD), and the second component of a URL, the second level domain (SLD), we assigned them to the same CDN cache server in descending order of the number of web objects in the corresponding domain [12]. However, the original content placement location has a significant impact on the amount of traffic flowing through the network. In addition, it is desirable to place contents with the similar names to reside on the same node, but content requests are concentrated on a few nodes, which lead to link load concentration and reduced content availability when the node failures occurs. These are important from the perspective of network design and need to be taken into consideration but determining them heuristically is NP-hard and difficult.

Therefore, in this paper, we propose placing original contents that uses genetic algorithm (GA) to consider four evaluation criteria: the average FIB size, the average link load, the coefficient of variation of link load, and the content availability. We investigate content placement that reduces FIB size and improves network quality by using a GA, which is an effective approximate solution method that can be applied to any combinatorial optimization problem.

In the following, Section II explains related research. Then, in Section III, we propose content placement using GA. In Section IV, we explain the performance evaluation method and then evaluate the performance of the proposed method. In Section V, we summarize this paper and state future directions.

II. Related Works

To reduce the number of FIB entries in an NDN router, four methods have been proposed: (1) partial cache, (2) route aggregation, (3) flooding, and (4) Bloom filters.

In the first approach, i.e., partial caching, FIB entries consist of some prefixes instead of all prefixes [1][7][8]. Afanasyev et al. proposed a name resolution method that uses DNS when an entry does not exist in the router's FIB [1]. That is, when the prefix of the incoming interest does not exist in the router's FIB, the router returns a negative acknowledge to the subscriber. Then, the subscriber obtains the prefix that has the same domain as the requested content and has an entry in the router's FIB by DNS. This process resubmits the interest with that prefix name. Moreover, Detti et al. also proposed A look-and-cash approach [7]. In that case, the router caches routing information obtained from the name routing system (NRS) server in the router's FIB. This approach the size of FIB is reduced, but the name look-up procedure is required. Ghasem et al. proposed i-CDN that used CDN architecture based on information centric [8]. In this method, each group nodes announce the cached contents to each other, and make and update the FIB entry for that contents.When the content does not exist in the FIB, an Interest packet is forwarded to a higher laye in the CDN. This approach reduces the size of the FIB, but it requires nodes to notify each other of their cache contents.

In the second approach, i.e., routing aggregation, the FIB is set so that all Interests are forwarded to the same router, called the name collector (NAC) [13]. Because of the transmission of Interests within a tree topology, where the NAC serves as the root node, the necessary size of FIBs at routers is diminished. Nevertheless, this configuration results in an increase in the path stretch, specifically in the hop count associated with Interest transmission.

In the third approach, i.e., flooding, Interest is broadcast to all output sides of the router without FIB lookup [3][5]. Ascigil et al. proposed a method in which routers broadcast an interest signal, prompting neighboring routers that have cached the relevant prefix to return the corresponding router information to the requesting router[3]. Chiocchett et al. propose that non-popular contents forward Interest, while popular contents broadcast Interest without FIB [5]. Because copies of popular content are likely to be cached at many routers, the interest reaches a router that has the requested content by broadcasting Interests. However, Interests are transmitted redundantly, which can overload network links.

Finally, in the fourth approach, i.e., bloom filter, the router uses a Bloom filter at each output face to decide whether to forward each arriving interest to that output face [10][11]. By using Bloom filters, the router can make Interest forwarding decisions with a limited number of memory accesses. However, there is a possibility that interest will be transferred to the wrong output surface, and redundant Interest transmission will increase the network load.

A. FIB Aggregation Method Using LPM

As an FIB aggregation method, LPM (longest prefix matching), which is used in IP routers to reduce the size of the FIB, is applied to NDN router entry reduction [12]. To apply the LPM to NDN routers, two approaches can be considered: (1) unit of characters of URLs, or (2) unit of components of URLs. In this paper, we adopt approach (2) to reduce FIB entries. We define a component as a character string delimited by a period in the URL. For example, the URL "www.ritsumei.ac.jp" has four components consisting of "www", "ritsumei", "ac", and "jp". In NDN, the FIB prefix is the concatenation of the components separated and rearranged in reverse order, i.e., "jp / ac / ritsumei/ www". The first component of the URL is the TLD, the second component of the URL is the SLD, and the components of the URL are used as units of the LPM. We use the URL component as the unit for LPM[1].

B. FIB Aggregation in NDN by Content Relocation

We study that the aggregation effect of FIB entries is mostly obtained from TLD and SLD [12]. Then, the authors proposed a content allocation design for CDN cache servers that considers the aggregation of FIB entries focused on TLDs and SLDs [12]. For a prefix whose original content resides in the same node, the same output face is set for that content in the FIB of each node. Therefore, by allocating web objects high-ranking TLDs to the same node, the number of FIB entries can be efficiently minimized. In the extreme case, if all web objects are located on a single node, it would be possible to aggregate all FIB entries into a single entry. However, it is necessary to allocate web objects as evenly as possible to all nodes in order to reduce the amount of traffic, because the traffic load is concentrated

[1]A unit of data that makes up a webpage, consists of various items such as icons and other images, text, and advertisements.

on the nodes where all web objects are located and on the links to which they are connected. Therefore, this method limits the maximum number of web objects placed in one node to less than the upper limit B. The method shows that the content can be aggregated by about 45% when compared to the original position.

III. Proposed Method

In this paper, we propose a content placement algorithm that reduces not only the average FIB size, but also network load concentration by adapting GA to the content placement location decisions. In the GA of the proposed method, genes are designed as g node placement on the network where each content is placed. The contents are reallocated by TLD unit, because the FIB entry aggregation effect can be expected to be improved by allocating contents with the same TLD to the same node.

As described in the previous section, allocating content with a limited number of placement nodes, e.g., all web objects on one node, can lead to problems such as load concentration on the same link or unavailability of all content if a failure occurs on that node. Therefore, the optimal number of allocating nodes is derived by considering the coefficient of variation of link loads and the availability of content. TLD content with a high request ratio can cause load concentration, so the relevant content is divided into SLD units and placed so that it accounts for less than 1% of all content. We define $P_{D_1(i)}$ and $P_{D_2(d,j)}$ as the sum of the request ratios of URLs in $U_{D_1(i)}$ and $U_{D_2(d,j)}$. When P_u is the request ratio of URL u, $P_{D_1(i)}$ and $P_{D_2(d,j)}$ are obtained by

$$P_{D_1(i)} = \sum_{u \in U_{D_1(i)}} p_u \qquad (1)$$

$$P_{D_2(d,j)} = \sum_{u \in U_{D_2(d,j)}} p_u \qquad (2)$$

Furthermore, since this research uses CDN to reduce the FIB entry size by changing the distribution location of original contents, it is expected to reduce the amount of traffic within the network, which is the purpose of CDN. However, there is a problem in that distributing content increases the amount of traffic, so it is necessary to consider the average link load of the entire network should also be taken into account when placing content.

Because of these things, four quality measures are considered: E_a, the average FIB size, C_L, the coefficient of variation of link load, R_c, loss of content availability, and L_a, the average link load, The genetic fitness $A(g)$ is set based on these four indicators.

First, the proposed algorithm randomly generates an initial population. Then, for each gene in the population, we calculate the fitness of the gene $A(g)$ based on an evaluation function. To calculate $A(g)$,

When a failure occurs at node n, the reachability of originals is lost for delivery requests of ratio $R_c(n) = \sum_{x \in U_c(n)} P_x$, where P_x is request ratio of content x, and $U_c(n)$ is the content set placed at node n. Moreover, assuming a single node failure, we define the loss of content availability, R_c by

$$R_c = \max\ R_c(n). \qquad (3)$$

When one node requests a content at another node, let F_l be the set of flows on link l and f_{sd} be the flows between node s and d, the average link load L_a for all links constituting the network is obtained by the following equation.

$$L_a = \frac{\sum_{s,d \in \boldsymbol{N}} h_{sd} r_p(s) \epsilon(d)}{N_L}, \qquad (4)$$

where $r_p(s)$ is the population ratio of the requesting node s, $\epsilon(d)$ is the total request ratio for contents placed at node d, $\boldsymbol{N}$ is the set of all nodes, N_L is the number of links, and the links between nodes are assumed to be bidirectional.

We define E'_a, C'_L, R'_c,and L'_a as the normalized value of each of the four quality measures which take value between zero and unity and obtained by subtracting the minimum value and dividing by the maximum value.

$$A(g) = w_1 E'_a + w_2 C'_L + w_3 R'_c + w_4 L'_a, \qquad (5)$$

where w_1, w_2, w_3, and w_4 is the weight of each quality measure.

The content placement algorithm using GA is shown below.

1) Randomly create I initial genes for the number of contents N
2) The selection probability p_i of the ith gene is calculated as the proportion of fitness A_i, where A_i is determined by the sum S of the fitnesses of I genes
3) Select the number of genes x to be left in the next generation using the roulette selection method based on the selection probability
4) Two-point crossover based on the selected genes, then generate offspring genes of number y
5) Randomly reconfigure genes by generating mutations with a certain probability
6) Repeat the above steps for a preset number of generations G, Select the gene with the highest fitness in the last generation as the optimal placement

IV. Evaluation

This study used 12,010 web objects[2] for which distribution servers exist in the United States. Content is allocating by TLD, except for content with URL TLDs of "com" and "net". This is because these contents account for approximately 67% and 15% of the total webpage requests, respectively, and allocating them to a single node would cause load concentration. Therefore, content with the TLD "com" and "net" are divided into SLD units and allocating them to the network.

The following is a description of the evaluation conditions. Set the number of generations $G = 10$ and the number of initial genes $I = 250$, and find the node position n of the content C. The population ratio and content request ratio are calculated for each node, so we assume that each node requests content once from all nodes other than itself. The weights of each scale in the adaptability equation are equally valued with a standard value of 0.25. We are considering using this system in a single AS, so network operators who use the system set their weight freely.

For the evaluation, we use Allegiance Telecom, a commercial network topology in the United States [4] in Figure 1. We compare the results of the proposed method (Proposed) with that of the original placement (Original) without rearrangement. Original means that the content is delivered from the publisher's host without using CDNs.

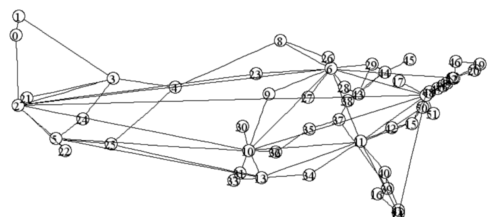

Fig. 1. The topology of Allegiance Telecom

Figure 2 shows six results: (a) average FIB size, (b) average link load, (c) coefficient of variation of link load, (d) content availability loss value, (e) maximum FIB size (E_{max}), and (f) maximum link load (L_{max}) in the original and the proposed method. The proposed method suppresses the increase in FIB entries while distributing content throughout the network, which results in reductions in the average FIB size, coefficient of variation of link load, content availability loss value, maximum FIB size, and maximum link load. In particular, the maximum FIB size was 4915 in Original, but it was 626 in Proposed, which was a reduction of about 87%.

On the other hand, the average link load of the proposed method increased by about 6% from the original. This is because the number of hops required to obtain content increased due to the content being distributed across the network as a result of load balancing. This is bad for network operators who want to reduce link load, but, but L_a can be reduced by prioritizing the weight w_2 of L_a.

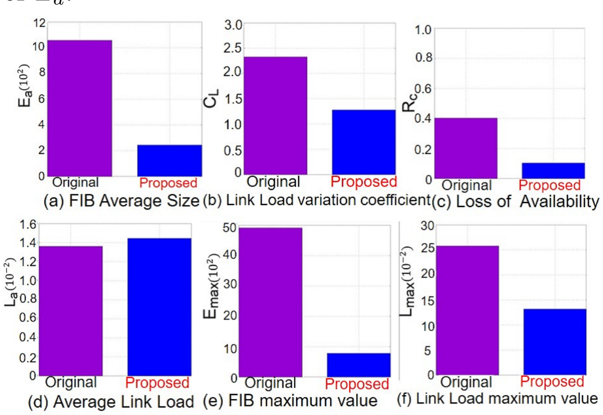

Fig. 2. The result of Proposed Method

V. Conclusion

In this paper, we proposed the GA method to replace content from the original delivery location of content using CDN in order to reduce the FIB size in the NDN architecture. The proposed method not only reduces the FIB size and improves scalability, but also reduces the network load by distributing the content.

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