A Case Study of Cache Performance in ICN - Various Combinations of Transmission Behavior and Cache Replacement Mechanism

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Abstract—**Information-centric networking (ICN) is suggested by many papers and research projects to improve network performance and enhance network resource efficiency in recent years. Moreover, in these researches, some researchers not only proposed their ideal ICN approaches but also modified the existing cache replacement mechanism to fit their ICN approaches. In this paper, we aim at investigating and quantifying the effect of the cache hit ratio with two kinds of transmission behavior, sequential and un-sequential, and three cache replacement mechanisms, FIFO, LRU, and random, in ICN. We implement several simulations with ndnSIM under NS-3 simulator. The simulation results show that LRU and FIFO are suitable for all networking applications no matter sequential or un-sequential content transmission behavior is used. Besides, the simulation results reveal that the cache hit ratios in LRU and FIFO are same when the experiment settings are with same interest packets sending rate, same experiment time, and sequential content transmission behavior.**

Keywords—information-centric networking (ICN), cache hit ratio, transmission behavior, cache replacement mechanism

I. INTRODUCTION

The variety of network applications, especially the content sharing applications and social network applications, fuel an Internet traffic explosion [1-2]. For example, end users repeatedly download the popular contents via the Internet that causes a lot of duplicated Internet traffic [3]. In order to reduce the Internet traffic in today's network, a number of content-oriented architectures, called Information-Centric Networking (ICN) [4-9], have been proposed and, in these years, ICN becomes a hot research field. The key idea of ICN is that, in computer networks, a user should focus on "what" he/she needs, rather than "where" he/she connects to and receives the data from. Two papers [10-11] showed that ICN can effectively decrease the Internet traffic because it includes a native caching function in the network. Nodes in ICN can cache the content and deliver it to the requester. Moreover, ICN can supply significant advantages for network operators and end users, such as lower the network load and faster response time for getting the content [1].

ICN redesigns the Internet architecture with named data object (DO) as the main element in the communication paradigm, instead of DO's physical location. Furthermore, ICN changes data transfer by pushing content storage and delivery at network layer by itself. There are no standard for ICN yet, so papers [4-5, 8-9] and research projects [6-7] proposed their ICN approaches, such as content-centric networking (CCN) [4], data-oriented network architecture (DONA) [5], network of information (NetInf) [6], publish-subscribe Internet routing paradigm (PSIRP) [7], content-ubiquitous resolution and delivery infrastructure for next generation services (CURLING) [8], and content network (CONET) [9].

ICN is efficient to content distribution, improves network performance in terms of minimal demand for transmission bandwidth, higher availability, and minimal delay, and has advantages on mobility and multi-homing [11]. However, some researches [1-2, 12] indicated that today's underlying Internet is end-to-end communication, and the designs of applications and services are for it. If today's applications and services are directly applied to ICN, the problems like huge traffic and long delay will occur. Thus, some papers [13-21] proposed their approaches to solve these two problems and make efficiencies of using network resources. Besides, every node in ICN has its cache to store the content, so that the cache replacement mechanism is an issue and many papers [15-18] addressed to propose their new cache replacement mechanisms. For example, M. Zhongxing et al. [15] pointed out that there has been no consensus on how to design an efficient caching scheme in ICN. Thus, they proposed an age-based cooperative cache scheme aiming at reducing network delay and publisher load for ICN. K. Katsaros et al. [16-17] proposed a MultiCache distributed caching scheme for ICN to solve huge traffic and long delay problems. MultiCache uses the already established overlay multicast forwarding state to locate an available cache. Cache availability associates with the overlay multicast forwarding state in MultiCache. Besides, cache replacement in MultiCache addresses on the advantage of the multiplicity at cache locations in an administrative domain. C. Fricker et al. [22] not only proposed a two-layer cache hierarchy but also addressed on evaluating the cache hit ratio between the four content types, web, file sharing, user generated content and video on demand. In this paper, we address on investigating and quantifying the effect of the cache hit ratio between different kinds of transmission behavior and familiar cache replacement mechanisms in ICN.

The rest of this paper is organized as follows. Section II introduces the main spirit and the basic common components of ICN and Section III presents an ICN approach, content-centric networking (CCN). Section IV shows our experiments and points out our observation. The last section concludes this paper and discusses our future works in ICN.

II. BACKGROUND

Many ICN approaches are proposed by researchers [4-5] or created in projects [6-7]. They may have different components in their structures or various algorithms for different proposes, but there are four basic components, data object (DO) [11], naming [11, 23-24], caching [11, 15, 19], and routing [11, 23-24] in these ICN approaches. In this section, we introduce these four components and their original ideas.

A. Data Object

Data object (DO) is the most fundamental component because an ICN sees the data and information as an object [11]. An object is a location in memory which has a value and is referenced by an identifier. A DO can be a document, file, audio, video, or streaming in ICN. In other words, the DO is the information that we access in the PC, laptop, and mobile device in Internet, and the DO is independent of storage location. Therefore, the DO uses its name as the identity and regardless of place, copies, and communications. Furthermore, any node in ICN can provide the DO to a user when it has a copy.

B. Naming

A naming method of an ICN is important since a DO is independent of any storage location or transport method. For example, when there are a number of DOs in an ICN, if a no good naming method is used, two different DOs will have same name. In that case, the ICN cannot identify the difference between these two DOs, and a user, called requester, may not get the object he/she really wants. Furthermore, by naming of authenticated DOs, the requester can make sure that not only the DOs come from the right publisher but also the content of DOs are same as the original. Therefore, in order to identify all DOs, an ICN needs a good naming method to generate a unique name for every DO's identity. The naming of a DO in ICN is as important as that of a host in today's Internet and the naming method should be designed to provide the integrity, authenticity, and provenance of a DO.

C. Caching

Storage for caching the DOs is an integral part in ICN. The cache is independent of Internet applications. That means the cache can record all kinds of DOs in ICN. Besides, a node in ICN has a cache no matter it is a router or an end node. With the cache, the load on the inter-operator traffic and the duplication data traffic can be reduced [15-18]. The in-networking caching is that when a requester requests a DO, any node receiving the request message can deliver the DO to the requester if it has the DO copy in its cache. Besides, a router has a cache to store the DOs, so it can maintain the traffic in the intra-domain. Due to the limitation of cache size, any cache needs a replacement policy [11, 15, 19]. When a DO arrives at a node with exhausted cache place, a cache replacement policy is employed to select a place for replacement. In order to handle the replacement policy in caching, the general replacement mechanisms can be used in ICN. There are five familiar replacement mechanisms: first-in-first-out (FIFO), least recently used (LRU), least frequently used (LFU), most frequently used (MFU), and most recently used (MRU).

D. Routing

Routing for the DOs is the last fundamental part in ICN. When the requester requests a specific DO, there are two phases for the routing. The first phase, called request route phase, is to find a node that has the DO copy and transmit the request to the node. The other, named DO route phase, is to find the routing path from the node to the requester and deliver the DO back. To achieve the routing, there are two general mechanisms in ICN and both mechanisms depend on the properties of the naming [11, 23-24].

The first mechanism uses the name resolution service (NRS) or resolution handler (RH) [5-7], which is similar to the directory server in today's Internet. First, the publisher publishes his/her available DOs to the NRS. Then, the NRS records the binding from the DOs to topology-based publishers and points the storage location in Internet. In request route phase, a requester requests the storage location to the NRS by the name of the DO. The NRS responses the storage location address, which is also called data source, to the requester. Once the requester receives the data source from the NRS, the requester requests the specific DO to the data source. After the data source receives the request from requester, it delivers the DO back to the requester in DO route phase.

The second mechanism is that the requester broadcasts his/her request message directly in Internet [4]. In request route phase, the request message is directly routed to the data source by the name of the DO, without resolving the name of the DO into the data source. When the data source receives the request from the requester, it transmits the DO to the requester from the request path in DO route phase. In this mechanism, the routing depends on the name-based routing, which uses the name prefix to route. In ICN, no matter what routing mechanisms, any node with the DO copy in its cache can satisfy the requester request in the routing path. Thus, the requester can receive faster the DO when a node with the DO copy is nearer to the requester in ICN.

III. CONTENT-CENTRIC NETWORKING

Content-centric networking (CCN) [4] is one of famous ICN approaches and many researches [1, 13-14, 19-22] simulate their proposed mechanisms in it. Thus, we choose CCN architecture to be our simulation environment and investigate our simulation results with it. CCN is generated in the CCNx project [25], designs future Internet architecture and treats content as a primitive - decoupling location from identity, security and access, and retrieving content by name. Furthermore, CCN can be deployed through middleware software communicating in an overlay over existing networks. CCN uses hierarchical naming to identify the DOs. Hence, the names are rooted in a prefix unique to each publisher. The names in CCN are used for naming information and routing purposes. Moreover, CCN provides multiple mechanisms, such as public key infrastructure (PKI) or external authority to achieve the binding between the DOs and publishers. CCN is based on content-based security which protects and trusts with the content itself. Thus, in CCN, all DOs are authenticated with digital signatures and protected with encryption.

In CCN, a communication is driven by the users' data. In order to handle the users' data, there are two kinds of packet types: interest and data packet, and three basic data structures: forwarding information base (FIB), pending interest table (PIT), and content store (CS). The interest packet is similar to the request message in today's Internet. It contains content name, selector (order preference, publisher filter, and scope), and nonce. Besides, the data packet is similar to the response message and it contains content name, signature (digest algorithm and witness), signed information (publisher ID, key locator, and stale time), and data. The FIB stores the content name and the outgoing interface with potential data source. It is used to forward the interest packet to the potential source. The PIT stores the interest packet from the requester and its incoming interface. It is used to send back the interest packet to the requester. The CS is like buffer memory and stores the DO binding to the content name.

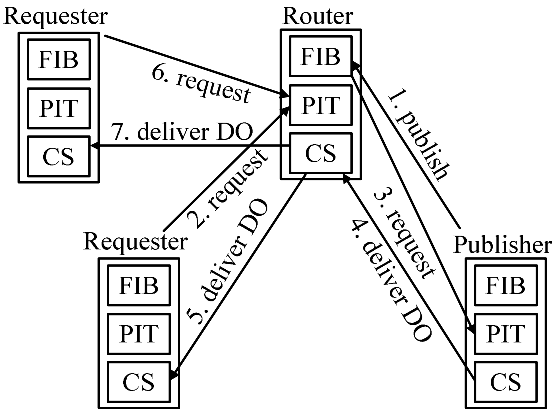


Figure 1. Overview of DO operations life cycle in CCN.

Figure 1 is an overview of DO operations life cycle in CCN. In step 1, a publisher first publishes its available DOs through the Internet. When a node receives the publish message, it will store this information in its FIB. In step 2, when a requester needs a specific DO, it will broadcast an interest packet over its available connectivity. Step 3 shows that while a node receives the interest packet from the requester, it will first check its CS in order to find the specific DO it has or not. If the node has this specific DO, it will deliver the DO to the requester from the interface where the interest packet arrived. Otherwise, the node will forward the interest packet to the potential data source depending on its FIB and store the interest packet information in its PIT. Steps 4 and 5 illustrate that the publisher delivers the DO to the requester on the reverse request path. Since CCN supports on-path caching, any node on the DO delivery path can cache the DO. In steps 6 and 7, if the node receives subsequent requests for the same specific DO, it can respond the specific DO from its cache.

IV. EXPERIMENTS AND RESULTS

In this section, we first introduce two simulators for our experiments, NS-3 [26] and ndnSIM [27]. Next, we describe our experiment environment settings for the experiments of different kinds of transmission behavior with varied cache replacement mechanisms. Finally, we not only show the results but also point out the observations to end this section.

NS-3 is a famous network simulator for Internet systems in research and development [26]. Based on NS-3, ndnSIM implements the communication model of named data networking (NDN) [28], whose architecture is much similar to CCN's. Moreover, ndnSIM has a clean and flexible structure for researchers developing their proposed mechanisms [29-33] on it. For example, B. Etefia et al. used NDN for military communication systems [29-30] and H. Yuan et al. studied content distribution with NDN [31-32]. Figure 2 shows an overall structure of ndnSIM. ndnSIM uses separate C++ classes to simulate every component and its behavior, such as interfaces of applications and network device, FIB, PIT, and CS. Besides, ndnSIM makes researchers easily modify every component with minimal impact on other components and provides helper tools to perform detailed tracing behavior of every component.

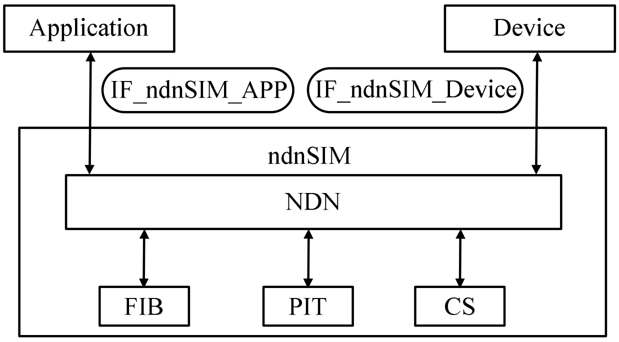
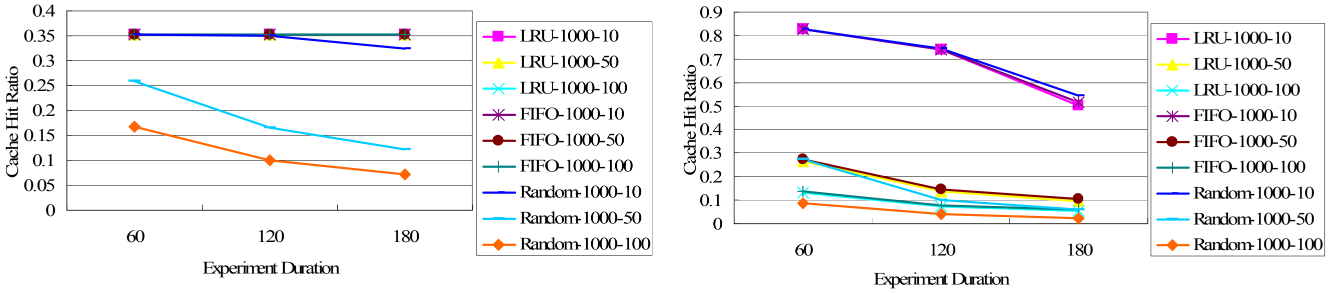


Figure 2. Overall structure of ndnSIM.

In order to investigate and quantify our research, we implemented several simulations. We generated networks to carry out the simulation environments and each environment has 10 routers and 100 nodes in the network. Each router randomly connects with other routers and every node connects with one router randomly. Besides, all routers and nodes contain FIB, PIT, and CS components. We simulated our environments with different parameters. For example, we used 100, 500, and 1000 in cache sizes of CS; LRU, FIFO, and Random in replacement policies; 10, 50, and 100 in interest packets which requester sent per second; sequential and un-sequential content in transmission behavior; 60, 120, and 180 seconds in experiment duration. In the first experiment, we simulated a networking application which delivers its content sequentially. We repeatedly simulated it with different parameters as mentioned before and calculated the cache hit



(a) Simulated result is under sequential content delivering.

(b) Simulated result is under un-sequential content delivering.

Figure 3: Relationship between cache hit ratio and interest packet sending rate.

ratio in every simulation. In the second experiment, we simulated a networking application which delivers its content un-sequentially. We also repeatedly simulated it and calculated the cache hit ratio as what we did in the first experiment.

A. Cache hit ratio decreases when interest packet sending rate increases

Figure 3 shows the relationship between the cache hit ratio and interest packet sending rate. Fig. 3 (a) is the simulated result under sequential content delivering and Fig. 3 (b) is under un-sequential content delivering. Furthermore, the LRU-1000-10 of the legend in Fig. 3 means that replacement policy is LRU; cache size of CS is 1000; and interest packet sending rate is 10.

Obviously, LRU and FIFO have better cache hit ratios than Random has in Fig. 3 (a). We also observed that the cache hit ratios in LRU and FIFO do not change acutely when the interest packet sending rate increases under the same experiment duration. While the interest packet sending rate increases from 10 to 100 under the experiment duration is 60, the cache hit ratios in LRU and FIFO only decrease from 35.17% to 35.16%. Besides, the cache hit ratios in LRU and FIFO increase when the experiment duration increases under the same interest packet sending rate. The cache hit ratios in LRU and FIFO increase 0.02% while the experiment duration increases from 60 to 180 under the interest packet sending rate is 100. However, the cache hit ratio in Random decreases acutely in both cases. The cache hit ratio in Random decreases 18.47% when the interest packet sending rate increases from 10 to 100 under the experiment duration is 60. While the experiment duration increases from 60 to 180, the cache hit ratio in Random decreases from 16.69% to 7.2% under the interest packet sending rate is 100. Only when the interest packet sending rate is 10 and the experiment duration is 60 to 120, the cache hit ratio in Random does not decrease intensely.

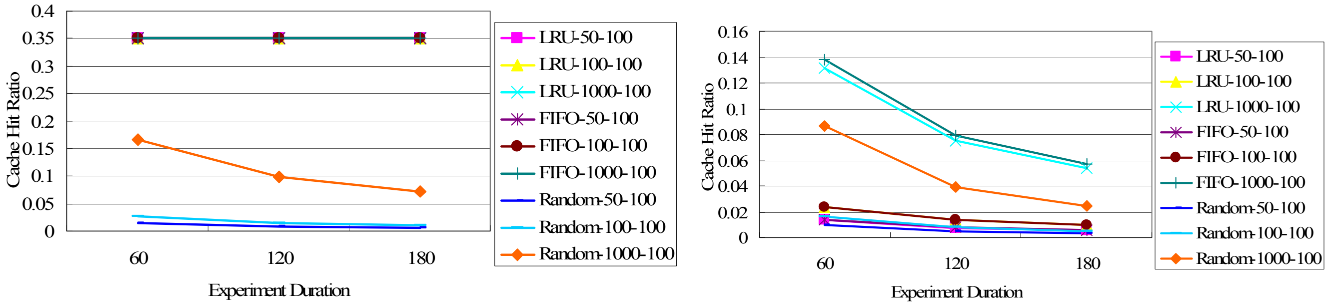
In Fig. 3 (b), we observed that Random has better cache hit ratio than LRU and FIFO have only when the interest packet sending rate is 10. While the interest packet sending rate is 10, cache size is 1000, and experiment duration is 60, 120, and 180 respectively, the cache hit ratio in Random is 82%, 74%, 54%, LRU is 82%, 73%, 50%, and FIFO is 82%, 73%, 51%. As the interest packet sending rate increases, the cache hit ratios decrease in LRU, FIFO, and Random. However, Random decreases acuter than LRU and FIFO in the cache hit ratio. For example, the cache hit ratio in Random decreases from 82% to 8% when the interest packet sending rate increases from 10 to 100 under the experiment duration is 60, but LRU and FIFO only decrease from 82% to 13%. Moreover, LRU and FIFO have better performance in cache hit ratio than Random when the cache size is 1000 and interest packet sending rate is 50 to 100 under the experiment duration is 60 to 180 according to Fig. 3 (b). Due to the Fig. 3, we conclude that the cache hit ratio decreases when the interest packet sending rate increases no matter the replacement policy is LRU, FIFO, or Random under the same experiment duration.

B. Cache hit ratio increases when cache size increases

Figure 4 illustrates the relationship between the cache hit ratio and cache size. Fig. 4 (a) is the simulated result under sequential content delivering and Fig. 4 (b) is under un-sequential content delivering. Besides, the meaning of legend in Fig. 4 is as the same as Fig. 3.

Clearly, the cache hit ratios of LRU and FIFO are higher than Random in Fig. 4 (a). We noted that not only the cache hit ratio of LRU is equal to FIFO but also the cache hit ratios are constant when the cache size increases under the same experiment duration and interest packet sending rate. Thus, we infer that the cache size does not affect the cache hit ratios of LRU and FIFO under sequential content delivering. The cache hit ratios of LRU and FIFO are 35.15%, 35.17%, and 35.17% respectively when the experiment duration are 60, 120, and 180. Moreover, we observed that when the experiment duration increases, the cache hit ratios of LRU and FIFO increase a few but not many. However, the cache hit ratio of Random varies acutely when both the cache size and experiment duration increase in Fig. 4 (a). While the experiment duration increases, the cache hit ratio of Random decreases. For example, the cache hit ratio of Random decreases 9.5% when the experiment duration increases from 60 to 180 under the cache size is 1000 and interest packet sending rate is 100. The cache hit ratio of Random increases as the cache size increases. When the cache size increases from 50 to 1000, the cache hit ratio of Random increases 15.25% under the experiment duration is 60 and interest packet sending rate is 100. However, no matter how the cache hit ratio of Random increases, it is still lower than LRU and FIFO a lot.

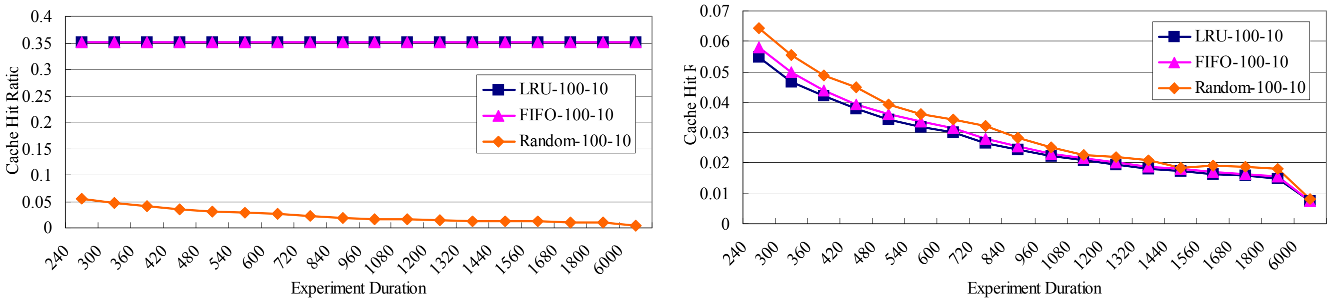
In Fig. 4 (b), we observed that LRU and FIFO still have better performance than Random under the same conditions. For instance, when the cache size is 1000, interest packet sending rate is 100, and experiment duration is 120, the cache hit ratio in LRU is 7.53%, FIFO is 7.95%, and Random is 3.94%. Besides, we noted that the cache hit ratios in LRU and



(a) Simulated result is under sequential content delivering.

(b) Simulated result is under un-sequential content delivering.

Figure 4: Relationship between cache hit ratio and cache size.



(a) Simulated result is under sequential content delivering.

(b) Simulated result is under un-sequential content delivering.

Figure 5: More simulations about different parameters.

FIFO are not the same under un-sequential content delivering. As the cache size increases, the cache hit ratios increase in LRU, FIFO, and Random. For example, the cache hit ratio in LRU increases from 1.35% to 13.14%, FIFO increases 12.38%, and Random increases from 0.95% to 8.62% while the cache size increases from 50 to 1000 under the experiment duration is 60 and interest packet sending rate is 100. Besides, the cache hit ratios in LRU, FIFO, and Random decrease when the experiment duration increases. The cache hit ratio in LRU decreases 7.73%, FIFO decreases from 13.76% to 5.72%, and Random decreases 6.17% as the experiment duration increases from 60 to 180 under the cache size is 1000 and interest packet sending rate is 100. According to the Fig. 4, we conclude that LRU and FIFO fit for the networking application which delivers its content un-sequentially.

C. More simulations about different parameters

According to the Fig. 3 and Fig. 4, we find another phenomenon. The cache hit ratios of LRU and FIFO may not exceed 35.2% under sequential content delivering in our simulations. In order to prove our supposition, we implemented other simulations. We set 100 in cache sizes; 10 in interest packet sending rate; LRU, FIFO, and Random in replacement policies; sequential and un-sequential content in transmission behavior; and from 240 to 6000 seconds in experiment duration. Figure 5 shows the simulation results and the meaning of legend in Fig. 5 is as the same as Fig. 3.

In Fig. 5 (a), although the cache hit ratios of LRU and FIFO increase as the experiment duration increases, the cache hit ratios is still not exceed 35.2%. We think the reasons for this phenomenon are that transmission behavior is sequential content delivering and network topology we generated. However, the cache hit ratio of Random decreases continuously in the same case. Thus, we infer that 35.2% is the upper bound for the cache hit ratios of LRU and FIFO under sequential content delivering in our simulations. In Fig. 5 (b), no matter how experiment duration increases, Random always has better performance in cache hit ratio than LRU and FIFO as the interest packet sending rate is 10. This is the only situation which the cache hit ratio of Random is higher than LRU and FIFO.

V. CONCLUSIONS

ICN is a new research area and it has been attention within the networking community. Besides, usage partially moves away from host-centric to information-centric. The underlying idea of ICN is that “what” is being communicated is more important than “who” is communicating. In this paper, we simulated several experiments and proposed the experiment results for cache hit ratio between different kinds of transmission behavior and familiar cache replacement mechanisms in ICN. According to the experiment results, we find that only when the networking application delivers its content un-sequentially and the interest packets sending rate is 10, Random has better cache hit ratio than LRU and FIFO. Otherwise, LRU and FIFO have better performance than Random under sequential and un-sequential content delivering. Thus, we conclude that LRU and FIFO fit for the networking application which delivers its content sequentially and un-sequentially. The experiment results also reveal that the cache hit ratio in LRU is equal to FIFO when the experiments have same interest packets sending rate and experiment time under sequential content delivering.

However, we think there are still some studies of cache in ICN for the future researches. Since the cache size in a node is limit, if the cache size is too small, the cache hit ratio will be low and the cache replacement will execute many times. On the other hand, if the cache size is too large and there are not many DOs, the memory will be wasted. In both two cases, the cache works inefficiently. Moreover, the cache needs to be updated when the publisher modifies or deletes the DO. The ICN approach needs to ensure that the requester does not receive the old or incorrect DO. In our future works, we will model the relationship between cache size and cache replacement policy. Besides, we will try to find out the balance in cache size and cache replacement policy according to transmission behavior.

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