The Evaluation of Caching Replacement Strategies in Future Networking

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***Abstract*— In today's context, multimedia has evolved into a feature that is indispensable on the Internet with respect to the advanced developments faced in digital media and networking technologies. Named Data Network (NDN) is one of Information-Centric Networking (ICN) architectures which is gaining increasing attention, as an important direction of the future network architecture research. This architecture is centered on content and it is worth noting that content caching plays a key role in NDN. This study focuses on highlighting certain gaps by comparing common caching strategies in the different predicted scenario of the future. In addition, a ndnSIM analysis on the performance metrics of caching replacement techniques (FIFO, LRU, LFU, ARC, and CCP) in NDN in terms of a cache hit ratio, server load, and throughput, results in rational outcomes that seem to serve. Based on the results, the CCP procedure gives the preferable end result for popularity among the presented techniques. This study would positively benefit both purveyors and users of Internet videos as it shows the presentation of various techniques with varying sizes of the content store.**

Keywords— Information-Centric Networking, Name Data Network, Future Network, Cache Replacement Strategies

I. INTRODUCTION

Content dissemination is at present the common Internet utilize case, representing the lion's share of worldwide Internet activity and growing exponentially. There has been a dramatic increase in the amount of Internet traffic resultant from content distribution in the past decade. For instance, in 2017, the traffic accounted from the video alone was 75% of the global Internet traffic, and studies have forecasted that there will be a continuous increase reaching to 82% of global Internet traffic by 2021 [1], [2]. This constant and rapid growth in the amount of Internet traffic regarding content distribution and related phenomena have been a severe challenge to the global Internet scalability. The reason for this adverse effect is partially attributed to the truth of the Internet being unsuitable for content distribution which happens to be the present major use case. This challenge evolved from the fact that the original design of the Internet envisaged its major use case as host-to-host communications. Therefore, there is a general assent that the most efficient approach to solving the problems of content distribution is by adopting globally distributed in-network caches. This is because, a diversity of add-on patches, such as Content Delivery Networks (CDNs), Mobile IP, Peer-to-Peer (P2P) overlays, and Network Address Translation (NAT), all violate, in different approach, diverse characteristics of the initial Internet architecture, noting that these were not the original design's part [2]–[5]. Information-Centric Networking (ICN) projects on the other hand have demonstrated that the yearning will before long be an accomplishment in accordance with the enormous help it has been accepting through European Union FP7 ventures, ICN Research Group (ICNRG) at Internet Engineering Task Force (IETF) and the Internet Research Task Force (IRTF) [6]. This new network architecture addresses many of today's Internet problems (content distribution efficiency, security, congestion, etc.), in order to avail users with a better communication network [7]–[11]. Be that as it may, when a network is stacking more information than what it can deal with, network congestion diminishes service quality [12]–[14]. For example, the ICN paradigm which was recently proposed has the aim of diverting from the existing Internet architecture whose major abstract is characterized by location-based on repository addresses and transmission to the architecture, whereby the location-agnostic content identifiers is the major abstract. The implementation of this paradigm has been proposed by a number of certain architectures. However, the most prominent one is known as Named Data Networking (NDN) (also addressed as CCN [15]). NDN means that every network router envisages the ubiquitous deployment of content caches [3, 16, 17]. Therefore, this study reviews and evaluates previous works on NDN architecture during the operation of cache replacement strategies.

The paper is then divided in the following manner: segment II provides a description of the Named Data Networking, section III presents the characteristics of the Operation of NDN Architecture, section IV describes cache replacement strategies, section V discusses the cache replacement strategies and problems in NDN, section VI simulation and evaluation, and section VII is the conclusion.

II. NAMED DATA NETWORKING (NDN)

NDN is characterized for offering certain enhanced features, such as, the use of data packets with content names [2], [6], [18]–[20], rather than using source and endpoint addresses. Using the communication of content name evict the necessity of application precise middleware. This is because of unique content names for communication permits routers in the tracking of packets' states, which supports a large number of functions, which is an advantage over IP routers. Still differing from IP, in NDN, all data packets are verified by the consumer and signed by its producer. The data packets are contained in itself and independent of their source of retrieval and forwarding point. These features give room for in-network content caching for achieving requests to be made and innately allow mobility of user. NDN routers, in addition, support multi-path forwarding, which implies forwarding of a user request at the same time, to multiple interfaces. Although, NDN and Internet are similar in terms of their layered hourglass architecture, there are certain functional diversities between correspondent layers [6,15,18], as displayed in Fig. 1.

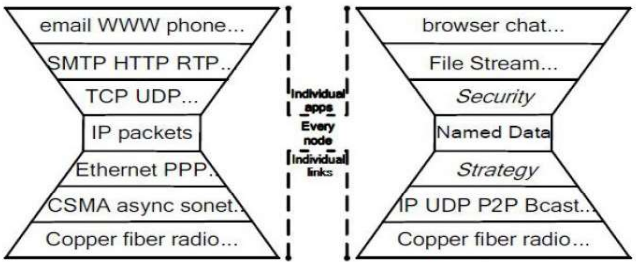

Fig. 1. Building blocks of the NDN architecture *[18]*

III. Operation of NDN Architecture

This section is linked to the diagram shown in Fig. 2. This diagram demonstrates how each NDN router maintains three data structure form. Here, the interest and data packets can be forwarded using Forwarding Information Base (FIB), Content Store (CS), and Pending Interest Table (PIT). Given these three processes, one can observe that the re-routing strategy guides the operation. Then, this re-routing strategy determines where and when to divert each of the NDN architecture's trays. For this type of situation, all the PIT Interests' stores are considered as routers. However, they were not able to fulfil the stage [13], [22]–[24]. For the majority of cases, the interesting package prompts the substance's preparatory examination through an NDN router, which in turn results in a preliminary content store examination to match the data. This is performed to restore the interest packets on their sources and the data packets on the router interface. However, if this process is not done, the router is used to lookup the name of the PIT. As such, if there are matching entries, the interest's incoming interface with the introduction of the PIT is simply recorded by the router [21, 22]. Nevertheless, if the input do not match PIT, then the router will readdress attention for the data product, which in turn is based on the FIB information, along with the strategy of adaptive forwarding router [16], [26]. This makes sure that the re-routing strategy can recover the package's longest prefix of interests. These procedures guide the NDN's Content Store and justify it as a temporary cache for the data packets that will have to be received by the router. As such, the packaged NDN data's autonomous component becomes more meaningful. It is important at any point where it has been put away incidentally in order to meet future interests [13, 16, 23].

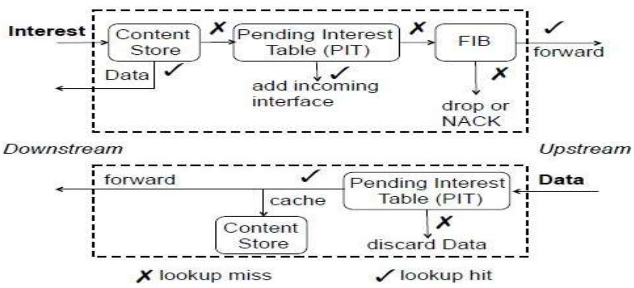

Fig. 2. Forward processing in NDN node *[13]*

IV. Strategies For Cache Replacement

A. Least Recently Used

One of the cache replacement stratagems that is easy to use and simple to understand is the strategy coined as Least Recently Used (LRU). This strategy is instigated using the concept of timestamp, and the process involves a removal of the least recently used object, that is, the object that has not been made use of in a long time. The removal initiated when the maximum size of the cache is exceeded, involves a new object being introduced in replacement of least recently used evicted [27]–[33].

B. Least Frequently Used

Another cache replacement strategy introduced in this article is the Least Frequently Used (LFU), which is a cache auxiliary strategy following the concept of removing requests. Although, in this case, the least frequently used request is removed, to be replaced by a new request in the free space available in the cache. This strategy also possesses that advantage of simplicity and ease of use, similar to LRU. The concept follows maintaining a counter for counting the frequency of the request, while replacing less frequent request with new incoming ones [28, 29, 33].

C. Adaptive Replacement Cache

The fundamental thought behind the Adaptive Replacement Cache (ARC) is to keep up two LRU arrangements of pages. One rundown, say L1, consists of pages that have been viewed just once "as of late", while the other rundown, say L2, consists of pages that have been seen at any rate twice "recently". The things that have been seen twice inside a brief timeframe have a low between entry rate, and, henceforth, are considered as "high-recurrence". ARC keeps up a reserve registry that recalls twice the same number of pages as in the store cache [34]–[36].

D. Cache Content Popularity

This cache replacement strategy known as Cache Content Popularity (CCP) is based on content popularity. To assess the quality of the cache replacement strategy, content routing is implemented by considering the remaining size of the available space in the existing cache. The process follows that after a data packet yet to be stored is received by a content router, the estimation of the transformation between the inception size of the cache and the statistical dissemination of the cached content needs to be measured to obtain the remaining space of cache size. On the basis of CCP, there will be a replacement of the content having the minimum popularity and its record in the Content Popularity Table (CPT) will be deleted simultaneously. The newly arrived content would then be cached in the Content Store (CS), at the same time setting up its own record in the CPT [37].

E. *First-In-First-Out*

Another cache additional stratagem is the First-In-First-Out strategy, with the acronym FIFO. The strategy operates by setting and maintaining a finite-size queue of tags T. Therefore, it is possible to model a solid k-way FIFO cache set S, as k-tuple cache tags, being arranged from left to right in descending order (that is, starting from last-in to first-in). Note that there will be no change in the cache set when a cache hit occurs, although a new tag is inserted at position 0 when a cache miss occurs [38].

F. *Popularity Prediction Caching*

The Popularity Prediction Caching (PPC) is lumped-level in-network caching replacement stratagem that makes predictions of how popular video chunks will be in the future. A recorded value of the popularity of content in PPC is noted and then arranged in order based on how many historical requests are made. Nonetheless, this approach of adopting statistical concepts with respect to popularity of chunk-level has its shortcomings, particularly in video applications [39].

V. Cache Replacement Strategies and Problems in NDN

The cache replacement strategies have an important role in NDN. This is because in general, replacement strategies are a significant piece of accomplishing the profoundly modern cache mechanism. This replacement strategy plays the role of removing the data parcel from the cache and makes room for new data packets entering the cache. Be that as it may, a cache cannot store the whole data packet that will be requested, based on the account of its restricted size. Accordingly, space for the new data packet is given by the cache replacement strategies [24, 36]. This applies to a cache brimming with the data packets. Consequently, the new data packet will at that point be embedded into the cache.

There are a few important factors (characteristics) of a data packet that can influence the replacement process [19], [29]:

- Recency: times of the last reference to the data packet.
- Frequency: the number of request to a data packet.
- Size: the size of the data packet.
- The cost to fetch the data packet: cost of fetching a data packet from its publisher.
- Access latency of data packet.

There can be an incorporation of all these factors into the replacement decision. Therefore, depending on these factors, the replacement strategies can be classified into four categories which are Recency-based strategies, Frequency-based strategies, Recency/Frequency-based strategies, and popularity-based strategies for NDN.

Table I presents the replacement strategy categories respectively. There are several strategies based on these factors above, and the recent replacement strategy in NDN is explained.

Note that decision timing of the cache can be founded on replacement of content and content arrival at the router. In order to initiate an improvement of the current network performance, there should be no deletion or erasing of content except in cases where the said content reaches expiration. It is however worth nothing that, when referring to caching, one can make it move one-level upstream inside the cache hierarchy. In an instance where a content request is initaited from an intermediate node which serves as a transitional hub, and there is a cached copy of the router, then in such a case, the request is fulfilled locally. This prompts the issues with respect to design, of caching strategies regarded as effective [11], [41]–[43] The cached data can optionally have a long-Freshness-Period (long-life) period before the cached data are replaced because the expiration of Freshness-Period only means that the initaitor may have initaied or created newer data [43]–[45]. This purpose is indispensable to the dissemination of information that is accessed by a large number of users, e.g., disaster-related information [43], [44], [46]–[48]. Most popular data packet get the most demands in terms of requests, while an enormous part of data packets, which are put away in the cache, are never requested in the futire and that consequentlsy makes the cache occupied [46, 47]. Data packets can hold an occupied cache in Content Store (CS) forever before some new, more common content with significantly higher hits happens. This can enable the cache to be filled by data that has been common previously but seldom used recently. So the new arrival content cannot be saved [16, 48].

Table I: Replacement Strategy Categories

Category	Brief Description	Available Replacement	Disadvantage
Recency Based Strategies	It uses recency factor to remove data packet	LRU [26, 27, 28,29,30,31,32]	Download latency of data packet
Frequency Based Strategies	It uses object popularity (or frequency count) to remove data packet	LFU [26, 29, 30]	Make occupied cache and download latency of Data packet
Frequency/ recency based	It combines both spatial and temporal locality together maintaining their characteristics.	ARC [34]–[36]	Download latency of Data packet
Popularity Based Strategy	It uses a popularity-based hit rate factor to remove the data packet.	CCP [37]	Depend on previous popularity

VI. Simulation And Evaluation

An in-depth evaluation study is presented, with the aim of quantifying how effective the other strategies by using the simulation scenario as shown in Table II.

For an illustration, consider a situation where the percentage is 30%, this denotes that if there are 10^3 unique content objects, then every node has the ability to cache 300 content objects. Note that in the real network, there is a limited number of cached contents in every node. Therefore, the concept adopted is to observe the efficiency of the cache by altering the size of the cache. Fig. 3 shows a portion of the network topology.

Table II: SIMULATION SCENARIO

Parameter	Description
Content Routers	36 nodes
Cache Size	1-10 GB
Catalog Size	1000 elements
skewness equals	Zero

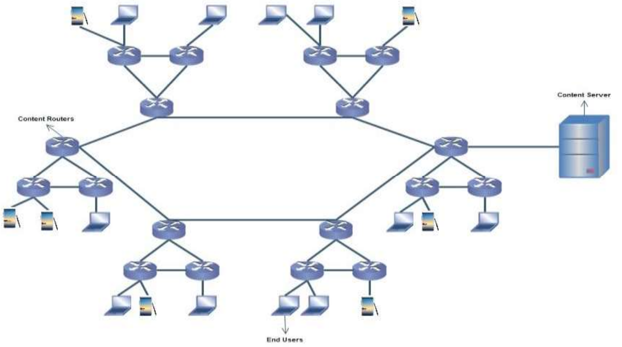

Fig. 3. The network topology

Simulator	ndnSIMv2.3 under NS-3 (see http://www.nsnam.org/).
Simulation time	400 sec
No. of Simulation	10 runs
Average Bit Rate	100 Mbps
replacement strategy	FIFO, LRU, LFU, ARC, and CCP
performance metrics	cache hit ratio, server load, and average network throughput

Fig. 4 and Table III shows the productivity of the diverse

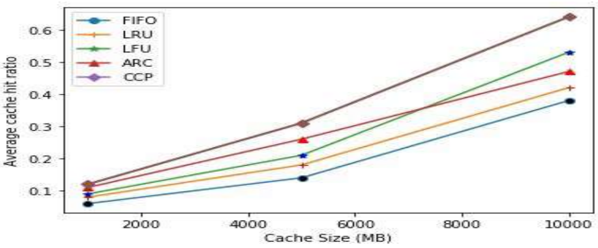

Fig. 4. Cache hit ratio

TABLE III: HIT RATE ON DIFFERENT CACHE SIZE

Cache Size (MB)			Cache Hit				
1000	5000	10000	FIFO	LRU	LFU	ARC	CCP
X			0.06	0.08	0.09	0.11	0.12
	X		0.14	0.18	0.21	0.26	0.31
		X	0.38	0.42	0.53	0.47	0.64

cache strategies for given scenario with varying sizes of the cache with respect to the determined cache hit proportion. The CCP over the LRU and LFU for all various cache size obviously shows essentially the best outcomes. Bearing in mind that cache hit proportion is generally adopted to give a decent understanding of the caching performance of the network when the data packets are distributed in a consistent way dependent on the dimensionality of the caches. Therefore,

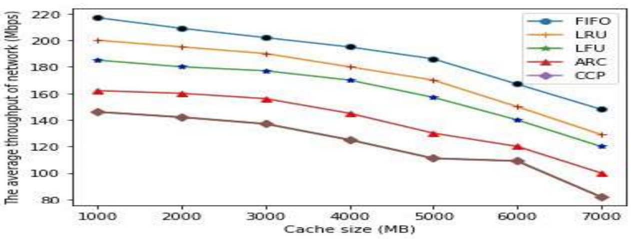

Fig. 5. Average network throughput

the small difference is a sign in a cache hit ratio.

Fig. 5 illustrate the performance of the various cache strategy in respect to the average network throughput with varying cache sizes. Likewise, the average throughput of CCP is significantly reduced compared to the situation without having to cache the network. Thus, the CCP outperforms the others (LRU, ARC, LFU, and FIFO). throughput performance

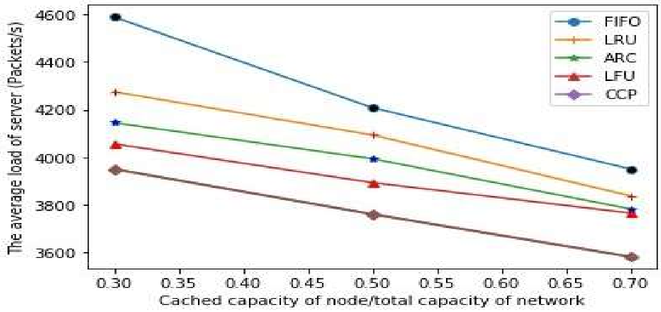

Fig. 6. Average server load

is affected by the packet-switched network congestion like a resource discussing problems which have commonly been posing an important threat to be able to attain the requirements of NDN networks and the Internet specifically.

The average server load performance of the cache strategies with different percentages of cache capability is displayed in Fig. 6. The findings show that CCP can achieve a lower load on the server than with other cache strategies. For instance, when the percentage is at 30%, the decrease in server load is approximately 7.75% in comparison with LFU. Note that the smaller the cache capability, the more obvious the ffectiveness.

VII. CONCLUSION

It is important to address how significant in-networking caching is in NDN. This is because NDN is a recently proposed network architecture for the future. Consequently, this paper exhibits its viability in contrast with traditional systems, for example, FIFO, LRU, LFU, ARC, and CCP. The simulation results show that CCP can altogether decrease of the server load, increase the higher cache hit proportion and add to an expansion in the size of the network simultaneously. Similarly, from the results obtained from the average throughput, it is evident that CCP performs more favourably than LRU, ARC, LFU, and FIFO. Consequently, future examinations intend to put into consideration the introduction of designs which will have the property of being a more intelligent cache strategy and more in addition, being adopted to more complex network scenarios with real service applications.

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