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ndnSIM-Based Performance Analysis of Interest packets' Expiry and RTT-Oriented Caching Strategies in NDN

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Abstract

Efficient caching in Named Data Networking (NDN) is crucial for increasing content retrieval performance and reducing network latency. Traditional caching strategies rely on heuristic-based content popularity estimation, which lacks adaptability to dynamic network conditions. In this paper, we proposed cache replacement strategy that is based on expiry time of interest packet from Pending Interest Table in short PIT-EXP and selective cache based on retrieval time i.e. RTT-Cache. Our methods achieved real-time network interactions to dynamically adjust caching policies without requiring prior knowledge of content distribution. Experimental results demonstrate that how integration of selective cache in PIT information named as RTT-Cache &PIT-Exp, cache replacement technique significantly improves cache hit ratio and reduces latency compared to without using selective cache i.e. PIT-Exp cache replacement strategy in real data traffic, under limited cache space, simulated by ndnSIM simulator. This research paper discussed on how combination of PIT and Forwarding information based caching are useful to enhance the cache hit ratio and reduce the latency under limited cache size, that is useful to take decision during replacement of data item from memory.

Keywords: Selective Caching, Cache Replacement, PIT, RTT, Named Data Networking, ndnSIM

1. Introduction

Named Data Networking (NDN) is a next future generation internet architecture that provides the option to the host-centric communication paradigm with a data-centric approach. In NDN[1], data item is retrieved by names like string request other than host locations where intermediate routers can cache data for fulfill the same requests in future, reducing retrieval delays and improving network efficiency. However, determining which content to cache and for how long remains in memory is a critical decision. There are two types of cache replacement strategies (i) static cache replacement strategy (ii) dynamic cache replacement strategy. The example of static cache replacement strategies like FIFO, LRU, RR, LFU out of which LRU perform better, It evicts the least recently requested one [2]. Traditional caching strategies estimate content popularity using predefined rules or historical access patterns and lack of the adaptability towards network traffic that's why we need to optimize caching decision. With care of adaptability in caching we proposed the expiry time based cache replacement technique (i.e. PIT-EXP) based on PIT table. In which during cache memory full, evicts the data item from content store which has minimum expiry time of corresponding interest packet, also we used the selective cache which is based on round trip time of interest in forwarding information with PIT-EXP replacement named as RTT-Cache & PIT-EXP to analyze the its performance. The Objective of this paper is to tell the importance of PIT table of NDN in order to use the real data in cache replacement strategy. This paper is organized as follows, System overview in section-2. Literature Review in section-3. Materials and Methods in section-4. Result and discussion in section-5. Conclusion and future research direction in section-6 and at last Bibliography & References in section-7.

2. System Overview:

The main architecture of Named data network is centered on the concept of content-centric networking, where data is retrieved based on its name rather than its location. NDN is basically has seven components.

1) Interest Packet 2) Data Packet 3) Consumer 4) Producer 5) Pending Interest Table (PIT) 6) Forwarding Information Base (FIB) 7. CS (Content store)

Where an interest packet is a request as same as Uniform Resource Locator (URL) made by set of string in which specific data content is mention. Data packet is made of name of data-item and actual data payload with content signature which is going too delivered. Consumer is a node who generates the request for content in terms of interest packet. Producer is a node who produces the content payload. Each intermediate routers maintain three data structure PIT,FIB and CS where PIT is table which maintain pending request of consumer[3]. FIB is table which provide the information of forwarding the request to next hop. CS is a memory or works as cache memory where data is stored or cached for fulfilling the request locally without forwarding the request to the original data producer[4].

As in fig (1) shows the basic architecture of NDN where the consumer sends its request for data to producer with the help of routers. The CS resides on routers caches the incoming data content from producer so that for the same request in future it can provide to the consumer directly without forwarding to producers[5].

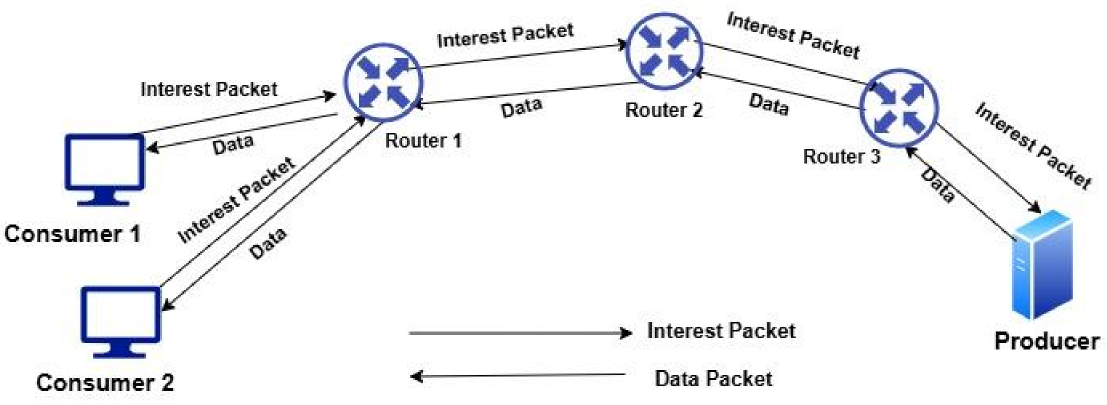

Fig. 1. Basic NDN Architecture

2.1 Working of Caching in NDN:

The given below Fig. 2, shows the working of NDN in which when a consumer wants to particular piece of data, it sends an interest packet containing the name of the desired data into the network. The router, which has memory in the form of CS (content Store) checks whether the data which was requested by the consumer is available in the cache. If yes, the router retrieves the data content from the CS and sends it back to the consumer, significantly reducing latency. If the content is not available in the cache, the same interest packet is forwarded through the FIB table to locate the producer that holds the requested data. Before forwarding the same interest to the next Hop, the router writes the pending interest details in the PIT (Pending Interest Table), allowing it to track the interests that are still in waiting [6]. This mechanism ensures that once the data is retrieved from the producer, all waiting consumers can receive the content simultaneously, further optimizing network efficiency and resource utilization. After maintaining the PIT, the router forwards the interest based on the FIB to the next appropriate hop, ensuring that the request reaches its destination promptly. This process not only enhances data retrieval speed but also minimizes unnecessary traffic across the network, contributing to a more streamlined and responsive communication system[7].

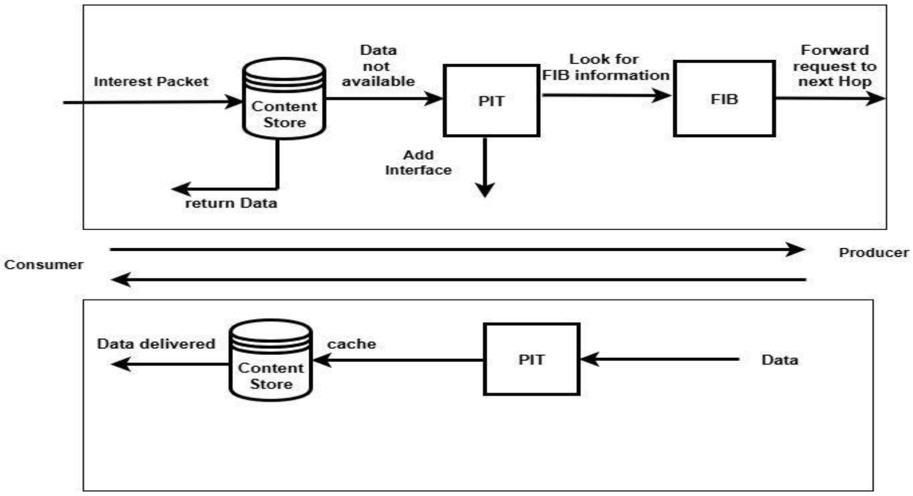

Fig. 2. Caching Procedure [7]

3. Literature Review

There so many traditional approaches of cache replacement strategies are available like RR (Random Replacement),Least Recently Used (LRU),Least Frequently Used (LFU), First in first out (FIFO)[8]. The main limitation of above approach is that they are static which are not capable to handle the caching decision in named data networking. In the paper [9], the author used graph neural network approach for caching and shown that GNN based caching has higher Byte hit ratio (BHR), Cache Hit Ratio (CHR) and lowest Average Latency Time(ALT).In the paper[10] author proposed The Apriori algorithm based caching which is used to forecast the upcoming data to be requested in near future and accordingly it maintain the cache. In the paper [11], authors used the FIB table proposed DFRC policy introduces a novel approach by evaluating the retrieval time of content using Forwarding Information Base (FIB) table information. Moreover, many researchers do not consider features from the PIT table of router in cache decision-making process, leading to suboptimal performance in high-traffic networks. This gap in the current literature motivates my research to develop the methods which take the cache decision based on data of PIT table.

4. Materials and Methods

$i^* = \arg\min_{i \in S} T_i^{\exp}$ (i)	$E(i) = \begin{cases} 1, & \text{if } i = i^* \\ 0, & \text{otherwise} \end{cases}$ (ii)

The PIT table's information maintain by the each routers between consumer and producer. It maintains the data related to pending request like interest name, face-id, nonce, timer and nackedid. This parameters explained as The detail of these PIT fields are explain below

(i) Interest Name: This field represent the all unique unsatisfied requests generated by consumer that are still awaiting corresponding data packets. (ii) Face-ID: the face fields is basically come in both records in-record and out-record (a) in-record Face and (b) Out-record Face where in-record Face tells about the interfaces from which the interest packet is generated and Out-record Face that tells about the interfaces through which interest packet forwarded for to get the data packet. The key point is that same Interest packet can be generated with the multiple Face-ID. (**iii**) Nonce: Nonce is a random number assigned to an interest packet. Its main purpose is to distinguish duplicate interests with the same name in the network. (**iv**) Timer: Each PIT entry contains one timer, the expiry timer. This timer is used by forwarding the pipe lines. It execute when the pit entry expires. When the in-record expiry time has expired the corresponding interest request has been deleted from PIT entry. The interest which has minimum Expiry time means the consumers requested data is less in demand. (v) NackedId: The NackedId field indicates that the last outgoing Interest packet has received a NACK (Negative Acknowledgement) from the upstream node [12]. In our approach the data item to be evicted based on minimum expiry time of corresponding Interest packet whenever memory cache is become full because such data is less in demand ,this eviction is known as PIT-EXP, as per fig. 3 where T_i-exp represents the expiry time for data i. We can denote equation1.

when new Data item D_k arrives and the cache is full the item is evicted from content store based on minimum Interest expiry time. The eviction indicator function defined as equation2.Where i denote the index of Data item currently present in the cache and i* represents the index of data item selected for eviction i.e. the item whose corresponding Interest has minimum expiry time. Also the second approach is based on Round trip time between the events, Interest packet generation and reception of corresponding data. It means cache the data into the content store only when RTT is less than of average RTT of all data item received so far, because large RTT means data was likely fetch from distant node, more congested path, this caching strategy known as RTT-Cache as per fig. 4. The mathematical representations are written as follows. Let Di represent the ith data packet received by the router , and let RTTi corresponding round trip time measured between the interest transmission and Data reception. The average round trip time of all previously received data packets is defined as equation three and the caching decision variable C_i defined as equation four.

$$\overline{RTT}_{i-1} = \frac{1}{i-1}\sum_{k=1}^{i-1} RTT_k \quad \text{(iii)}$$

$$C_i = \begin{cases} 1, & \text{if } RTT_i < \overline{RTT}_{i-1} \\ 0, & \text{otherwise} \end{cases} \quad \text{(iV)}$$

Where in equation two $C_i = 1$ represents that Data packet permitted to store into content store, while $C_i = 0$ means not to catch the data packet.The proposed strategy runs with tree topology in ndnSIM simulator as shown in Figure 5. The simulation parameters are given in table 1.

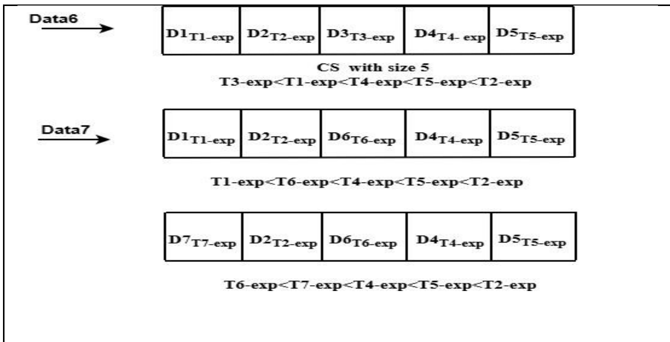

Figure 3. Working of PIT-EXP

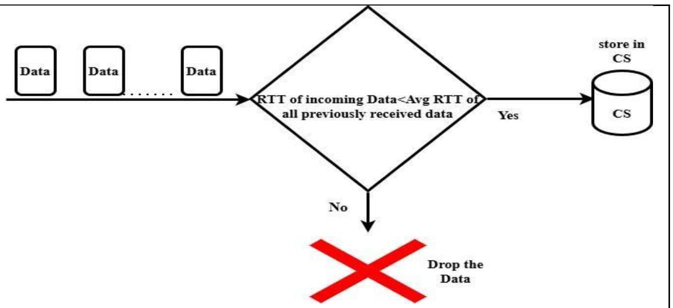

Figure 4. Working of RTT-Cache

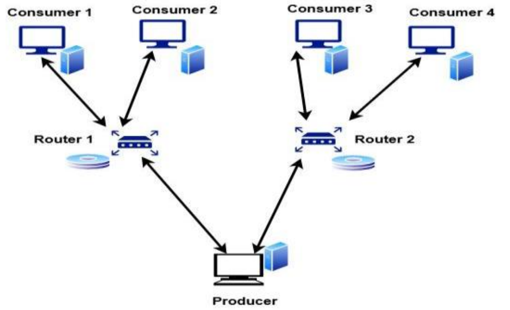

Fig. 5 Tree Topology

Parameter	Value
Request Rate	100
CS size	10/20/30/40/50/60/70/80/90/100 (Entries)
Cache Strategy	PIT-EXP, RTT-Cache & PIT-EXP
Forwarding Strategy	best-route
Simulation Time	100 s
Nodes	7

5. Results and Discussion:

The results obtained after the simulation are presented in the table 2 below in three parts 2.a, 2.b and 2.c.

PIT-EXP Cache Replacement Technique (Eviction based on minimum Expiry) [Table 2.a]										
Time\CS	**CS-10**	**CS-20**	**CS-30**	**CS-40**	**CS-50**	**CS-60**	**CS-70**	**CS-80**	**CS-90**	**CS-100**
0s -10s	23.20	34.86	43.81	51.26	57.43	63.35	66.18	68.06	69.27	69.48
10s -20s	24.45	38.04	49.28	58.24	66.80	74.48	79.22	83.21	86.36	87.99
20s - 30s	24.34	38.17	49.45	58.94	67.49	75.31	81.04	86.03	89.80	92.03
30s - 40s	24.36	38.17	49.51	59.09	67.70	75.68	81.83	87.50	91.53	93.99
40s - 50s	24.34	38.11	49.49	59.30	67.90	75.64	82.02	88.10	92.38	95.20
50s - 60s	24.38	38.25	49.68	59.51	68.18	75.80	82.38	88.61	93.07	95.97

60s - 70s	24.36	38.28	49.79	59.57	68.34	75.91	82.55	89.01	93.46	96.45
70s - 80s	24.48	38.43	49.93	59.74	68.49	75.96	82.62	89.26	93.77	96.82
80s - 90s	24.43	38.34	49.84	59.77	68.46	75.98	82.67	89.44	94.01	97.15
90s - 100s	24.36	38.30	49.74	59.60	68.29	75.93	82.64	89.60	94.20	97.41
Average	24.27	37.895	49.052	58.502	66.908	74.404	80.315	85.882	89.785	92.249

Table 2. Calculated Results

5.1 Results in Terms of CHR and Latency:

RTT-Cache & PIT-EXP Cache Replacement Technique [Table 2.b]										
Time\CS	**CS-10**	**CS-20**	**CS-30**	**CS-40**	**CS-50**	**CS-60**	**CS-70**	**CS-80**	**CS-90**	**CS-100**
0s -10s	28.14	40.21	47.94	53.33	57.87	60.77	63.16	64.11	64.66	64.62
10s -20s	32.55	45.91	55.84	64.03	70.82	74.69	78.64	81.60	84.12	85.53
20s - 30s	33.07	47.13	57.41	65.49	72.09	77.15	81.21	85.31	88.02	90.85
30s - 40s	33.63	47.50	57.95	65.98	72.77	78.04	82.64	86.94	90.33	93.33
40s - 50s	33.77	47.55	58.03	66.26	73.02	78.63	83.21	87.85	91.72	94.76
50s - 60s	33.65	47.76	58.20	66.48	73.32	79.14	83.70	88.27	92.25	95.68
60s - 70s	33.61	47.92	58.35	66.60	73.41	79.28	83.91	88.70	92.75	96.30
70s - 80s	33.82	48.08	58.55	66.78	73.58	79.45	84.07	89.09	93.23	96.78
80s - 90s	33.87	48.05	58.49	66.78	73.62	79.48	84.29	89.35	93.54	97.15
90s-100s	33.96	48.05	58.48	66.67	73.59	79.52	84.38	89.39	93.83	97.44
Average	33.007	46.816	56.924	64.84	71.409	76.615	80.921	85.061	88.445	91.244

PIT-EXP					**Latency**		**[Table 2.c]**			
Latency	**CS-10**	**CS-20**	**CS-30**	**CS-40**	**CS-50**	**CS-60**	**CS-70**	**CS-80**	**CS-90**	**CS-100**
Average Latency (µs)	3478.654	2426.952	1781.344	1333.329	988.298	715.5236	492.1767	290.4458	155.1506	59.91185
RTT-Cache & PIT-EXP					**Latency**					
Average Latency (µs)	2751.553	1936.165	1470.003	1135.311	874.8592	652.5934	472.5085	310.9523	170.2037	62.59256

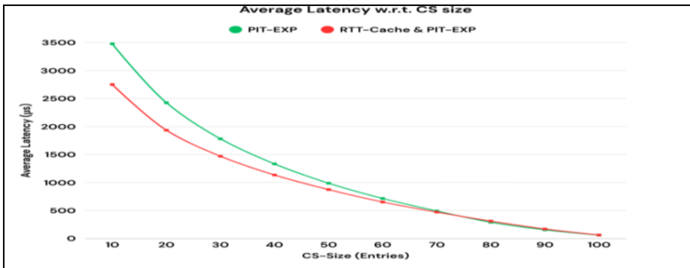

Figure. 7. Graph of Average Latency w.r.t. CS-Size of PIT-EXP and RTT-Cache & PIT-EXP

Average Latency: As per table 2.c**,** The Latency data clearly tells that RTT-Cache & PIT-EXP consistently provides lower latency from CS-10 to CS-70.Onwards CS-80 to CS-100 the PIT-EXP provides slightly lower latency than RTT-Cache & PIT-EXP. Same depicted in figure 7.

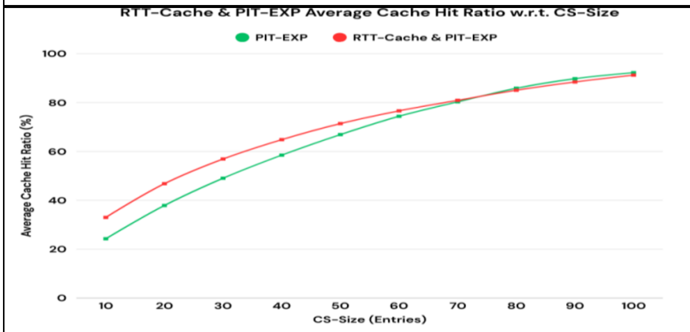

Figure. 6. Graph of Avg. Cache Hit Ratio w.r.t. CS-Size for Strategies of PIT-EXP and RTT-Cache & PIT-EXP.

Cache Hit Ratio (CHR): As per table 2.a & 2.b, The Cache Replacement strategy RTT-Cache & PIT-EXP outperforms PIT-EXP from CS-10 to CS-70. At CS-10 to CS-50 RTT awareness helps to store the data which having lower retrieval latency. Onwards CS-80 to CS-100 PIT-EXP outperforms RTT-Cache & PIT-EXP. It indicates that Expiry based eviction is work good when there is sufficient cache memory and it also indicates that under limited cache space selective cache based replacement performs better. Same depicted in figure 6.

6. Conclusion and Future Work

The Pending Interest Table maintains the records of pending interest in named data networking. PIT contains various parameters in each entry which divided in terms of in-record and out-record like Face-id, expiry time, nonce and arrival time. In this manuscript our approach used only expiry time of interest packet and we got good result in terms of cache hit ratio and Latency when we have enough cache space and we also found that round trip time based selective cache is useful to enhance the cache hit ratio of PIT based cache replacement under limited cache space. Further research can be on the combination of various parameters of PIT with forwarding decision to further optimize caching strategies in NDN.

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