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A Survey on Caching in Named Data Network

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***Abstract*—** To replace the present host-driven IP-based Internet architecture, Content-Centric Networking (CCN) is considered as conceivable substitution and is been developing worldwide. In CCN, the content name rather than IP address of host becomes the primary entity. Content is in this manner decoupled from its location. In addition to other things, this allows the cache to be ubiquitously present. One of the famous examples of CCN is Named Data Networking (NDN). To satisfy the incoming request for data, every node in NDN is permitted to have its own local cache. For productive huge scale content dissemination, NDN is been made a decent architecture because of this. This paper focuses on various caching techniques and explains many of them briefly. NS-3 based Named Data Networking simulator named as ndnSIM is used to assess proposed scheme.

***Keywords*—** NDN, CCN , CS, FIB, PIT, ndnSIM, NS-3

I. Introduction

Over the years many efforts have been made to develop a suitable architectural replacement for today's IP-based Internet architecture. This new architecture is been designed to increase the growth rate of the Internet and efficiently satisfy present needs. Specifically, a remarkable effort is made to give enhanced mobility, expandability and well-organized content distribution. Moreover, powerful security is the major design requirement of these architectures.

Named Data Networking (NDN) [1], is one of the Future Internet architecture [2] is an example of Content-Centric Networking (CCN) [3]. In CCN, uniquely defined names of content rather than the respective IP address play a role of primary entity.

1) Caching Features in ICN:

- **Caching transparency:**

Application dependent frame-work intends to be for one specific traffic class as conventional cache frameworks are closed, e.g., Web, Peer-to-peer or Content delivery network (CDN). Web content pursues domain-based naming convention, in spite of the fact that Web caching depends on open HTTP convention. Two duplicates of a similar object in various domains have diverse names. Objects are coherently isolated by domain limits in caching framework. A peer-to-peer application is a closed framework as it utilizes exclusive protocols.

- **Cache Ubiquity:**

In ICN, caches are omnipresent and have no fixed cache points. These factors add challenge to the scientific analysis and modelling of the caching framework, furthermore make explicit coordination difficult to accomplish. Contents are proactively pushed and duplicated to edge servers in CDN, which systems, for example, redirection and DNS resolution, so as to guarantee global accessibility of the data duplicates depends on earlier information of accessed request and structure of the network. The framework depends on systems, for example, redirection and DNS resolution, so as to guarantee global accessibility of the data duplicates.

- **Cache contents granularity:**

Most ICN proposition utilizes the strategy of cutting vast documents into smaller self-identifiable pieces, and performs cache tasks on the unit of pieces. The cache contents are divided according to change of popularity, independent reference presumption failure and proficient utilization of the cache space.

2) NDN Overview:

NDN mainly emphasizes large-scale content distribution. NDN consumers a request for the chunk of data by the unique name was given to it rather than using the IP address of the host which is providing contents. The network itself is responsible for finding the most similar copy of the contents and sending the data back to requesting consumer efficiently. One of the important features which are enabled by NDN is detaching the contents from its location and making it available all over the network. A random amount of cache is given by NDN router that is able to store forwarded data for the future request. Figure 1 shows the Hourglass architecture [1] of the present (a) and NDN (b) architecture.

NDN is a pull-based model, where the data or contents are pushed into the network only when consumer requests for particular data. NDN supports two types of object packets, i.e. they are Data and Interest object [4] also known as Data and Interest packet. Every content packet consists of names (probably in human-readable format), digital signature signed by the content producer and payload. The hierarchical structure is used to generate unique names which consist of one or more components. In NDN, each component is separated by '/' symbol, In NDN, each component is separated by '/' symbol, for example, /NDN/com/toi/sports/secondpage. Large parts of contents are divided into fragments, e.g., fragment 5 of tom's photo could be named /instagram/tom/photo1.jpg/5.

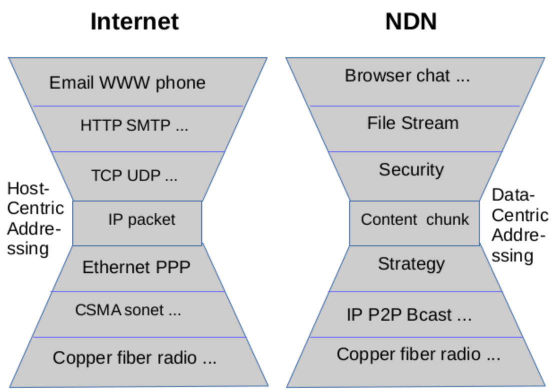

Fig. 1: Hourglass Architecture

NDN network consists of data publishers, data producers and data consumers. In-network caches and forwarders also called as the Content store is handled by CCN-X. In NDN network, Forwarding Information Base (FIB) [4] comprises the names of content rather than IP addresses. The forwarder consists of a strategy layer, so as to forward the Interest packet through an optimal path. To determine the correct return path for Content Objects to follow and integrate similar Interest packet, Pending Interest Table (PIT) [4] stores data about Interest packet with an end goal to avoid sending many similar packets.

There are three sections in the paper, section I describes the fundamentals of the paper as the requirement of the architecture and its basics. Section II discusses the various techniques used for caching which are three main types i.e. cache placement, cache replacement and cache management. Section III concludes with a summary of the paper.

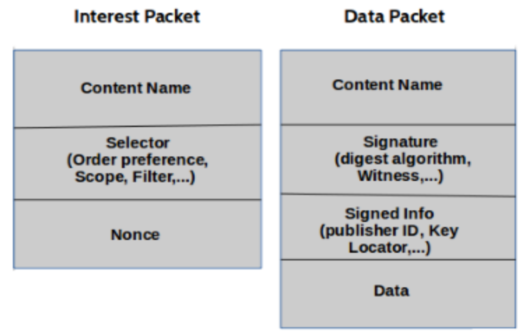

Fig. 2: NDN Packets

II. RELATED WORK

Many researchers have worked on different caching techniques, caching does not restrict to storing of data; it also deals with the placement of cache, replacement of cache and managing cache. Some of the algorithms are discussed below:

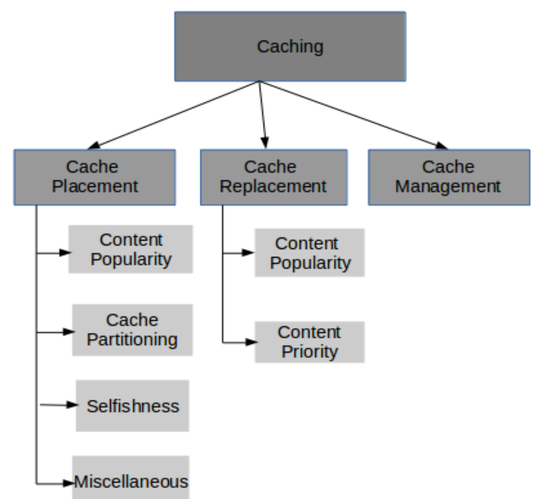

Fig. 3: Caching Strategy

1) Cache placement

To propagate in the network efficiently, contents need to be cached in the router. Hence, cache placement plays an important role when it comes to storage of content. Content placement is done on the basis of below four mentioned parameters.

a) **Content Popularity:**

Li et al. [5] proposed a new efficient caching scheme for ISPs is been developed, so as to increase the inter-ISP traffic saving. Coordinated caching algorithms are proposed in the NDN network, which can help to determine cache placement along the forwarding path. Following algorithms are used in it. First is Bottom-up caching algorithm, according to popularity measure every node makes its own popularity decisions and collaborates all the request stats of its sub-tree. The decision is made from end-nodes to nodes upward and to the root. Second is Top-Down caching algorithm, Deletion Tracking (DelTrack) [5] table is created. The ObjectID is added which is decided to be cached locally to DelTrack table by current node and sends that table to its entire child node. Then the children nodes will delete the record from DelTrack table and then makes the caching decision depending on record table of local request. Third is Bridging caching algorithm, is combination of both bottom-up and top-down, taking advantage of both.

NDN consist of functionalities for effective content distribution like name-based routing and inbuilt caching. Presently, caching in NDN is also a primary topic especially for an ISP with multiple gateways. Wu et al. [6] proposed this method for the primary goal of decreasing inter-ISP traffic, for multiple gateways and multipath routing, Effective Multi path Caching scheme which is popularity based coordinated caching strategy is developed. The incoming request status is not known initially and the request rate and during a particular time period the request rate is stable.

Li et al. [7] suggested a method that mainly focuses on to reduce the average access delay and inter-ISP traffic. Popularity-driven caching schemes [8], [7] is been developed which will place the replicas in caches dynamically in coordinated fashion. Three techniques are used, they are, first is Top-Down Caching, where for every object each nodes make caching decision according to its popularity of object, which subtrees collectively decide. Second is similar to first approach with Bottom-Up approach. Third is AsympOpt Caching combines the advantages of both.

Yeh et al. [9] discussed the framework consist of two planes i.e. Actual plane and Virtual Control plane. Actual plane handles Interest and Data Packet while Virtual Control plane deals with rate of client request for Data object in the network. To reach network load balancing through dynamic caching and forwarding, VIP in virtual plane implements distributed algorithm, which cause the increase in user request rate that can be fulfilled by NDN network. Cho et al.[10] introduces WAVE, having similar feature like 1) Popularity-based 2) Simple 3) Decentralized 4) Incrementally deployable. It provides content caching scheme. In it many pieces of data can be cached according to the popularity of content. In this scheme, the amount of data chunks that is to be cached in downstream node is suggested by upstream node, which will increase gradually if request count is increased. Chunk caching algorithm [10] is used in WAVE, and there are three important decisions to be made: what data to cache, which data to replace, and where the data needs to be cached.

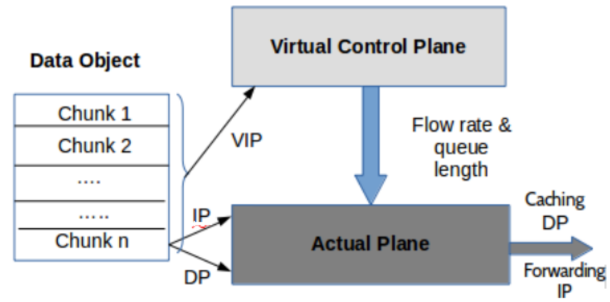

Fig. 4: VIP Framework

b) **Selfishness:**

Laoutaris et al.[11] contributed to obtain object placement schemes that 1) can take care of local service under greedy local object placement when compared with local services to every node once, 2) don't get affected from ill-treatment problems, optimizing the social utility using inbuilt centralized strategy and 3) do not need complete information at each node. It is a criteria efficient algorithm for getting a stable scheme mentioned above.

Laoutaris et al. [11] considered that each node in the network is selfish, contents can be cached at each node in the network and its goal is to reduce its own access time for fetching the contents from its local cache or by accessing its neighboring caches. If these nodes are getting benefited by caching and sharing data, then and only then the nodes in network will co-operate with it. Hu et al.[12] put forward the formal definition for NSCC is given as follows, if we possess a collection of selfish nodes in “NSCC group” [12] and a collection of m unit objects then access pattern of node i can be given as rik, i.e. the rate at which node i requests object k. Ths NSCC makes use of CCNx library and runs on application level. NSCC node could be placed anywhere in the system also it is similar to proxy. The NSCC node is placed on the route from user to Internet by simply configuring the routing in system. No further changes are needed to other NDN nodes and the hidden CCNx.

c) **Cache partitioning:**

Storage in NDN network is crucial entity which is very limited, that needs to be taken care of, and handle with efficiency. It considers two scenarios with different motives: decreasing overall miss ratio and balancing fairness in miss ratios among traffic classes. Rezazad et al.[13] considers differentiating NDN traffic into multiple classes as well as determine how an NDN router’s content store can be divided among these classes. It shows how dynamically; this partitioning can be done using the Buffer Miss Equation.

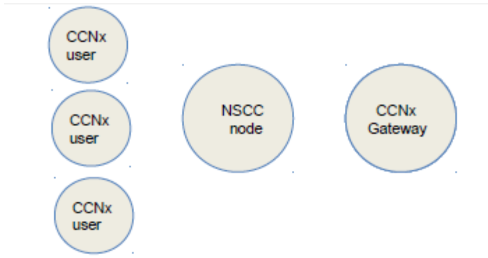

Fig. 5: NSCC Scenario

d) Miscellaneous:

Routing entries used in NDN are content names; hence NDN routing scalability must be the primary goal. If each node in the network makes the routing decision, there may be chances of duplication of contents in neighboring nodes. To resolve this problem, Choi et al. [14] proposed the method that alleviates routing scalability and improves the efficiency of the in-network storage. CoRC arranges caching and routing mechanisms to control the similar content namespace for a better-enhanced efficiency. The benefit of this arrangement are, first there is no ad announcement overhead to declare cache contents in in-network storages and second is there is no replication of similar data routers from a wider perspective in network. But this may take a longer delivery path and causes latency.

Dehghan et al. [17] proposed Time to Live based cache with a PIT and determines its cache hit probability, size of the PIT and average response time required by the consumer. A random variable is defined by the server that deals with the time needed for a cache for downloading a file from server. To verify the accuracy, caching policies like RANDOM, LRU and FIFO are used.

Barakat et al. [16] elaborates ICN that proposed to appease Internet usage. The on-path caching reduces the caching of overall volume of data, due to its inefficient performance where data gets replicated on the routers; however a great global performance has. To overcome this problem, off-path caching is introduced where contents are provided to properly established off-path cache and distract the traffic to the minimal path towards these caches that are distributed across the network, which enhances the hit ratio globally using Off-path caching.

Zeng et al. [15] introduces mobile ad hoc network in NDN for improvement of performance. Content diversity is simulated and examined on this network performance. Table 1 shows comparison between different cache placement strategies.

TABLE I: Comparison of different Cache Placement strategy

Schemes	Description	Decision basis
Li et al.[12]	Cache placing along the forwarding path	Content Popularity
Wu et al. [13]	EMC is developed for multipath routing	Content Popularity
Li et al.[14]	Caches replicas on the path in a coordination fashion	Content Popularity
Yeh et al.[16]	Uses actual and Virtual plane	Content Popularity
Cho et al.[17]	WAVE, caches as per popularity of content	Content Popularity
Laoutaris et al.[18]	Stable object placement	Selfish node
Hu et al.[19]	NSCC for content storage	Selfish node
Rezazad et al.[20]	NDN traffic is divided into multiple classes	Partitioning cache
Choi et al.[21]	CoRC deals with caching and routing mechanisms	No
Zeng et al.[24]	Improved performance in mobile ad hoc network	Data Interval
Barakat et al.[23]	Off-path caching scheme	Chunk number
Dehghan et al.[22]	TTL cache with a PIT	TTL

2) Cache Replacement

In-network caching in NDN facilitates the efficient movement of data in core network, also improves response time of query and reduces the unwanted data traversal to main server. However, in distributed environment in-network caching does not perform really well, also less cache space will limit the hit ratio and future overhead is caused by cache management, these are the challenges that exist in in-network caching.

a) Content Popularity:

Information enhancement in net-work the caching policies in an ad hoc network is described by Dron et al.[18] that shows advantages of naming data. Development of caching strategy for ad hoc network is represented in different ways which separately provides, (i) a better standard of data (in terms of overall coverage of data), (ii) improved turnout(in terms of response to a query) and (iii)lesser delay. To make a complete utilization of content popularity, Ran et al. [19] proposed cache replacement schemes, data structure is designed as well as replacement algorithms are discussed. Replacement policies should follow these points: 1) able to adapt fast changes in dynamic network, 2) should not get affected by data of short-term change.

To continuously monitor the popularity with appropriate usage of memory, Dai et al. [20] proposed a method based on bloom filter. Here, many bloom filters are engaged and each one of them is responsible for popularity in particular range. The objects which will be inserted in the bloom filter are the content packets whose popularity felt in the range of respective bloom filter. Sliding window monitoring scheme is put forward so as to implement chronic and real-time popularity update.

b) Content Priority:

The content priority is also important factor while accessing different caches in network, there is a need to give priority to each content in cache for its accessibility. Dron et al.[18] not only proposed a content popularity scheme but also dealt with content priority. Co-ordination and sharing of cached data in multiple nodes are allowed in the scheme which is proposed by Gao et al. [21]. The scheme is also called as supportive cooperative caching scheme in Disruption Tolerant Networks, decreases the data access time. The strategy deals with sending and caching the data at Network Central Locations (NCL), which can be easily accessible by the nodes in the network. Table 2 shows the comparison of different cache replacement strategy.

3) Cache Management

The NDN router has feature of content caching. The distributed caching [23] is scalable and cooperative caching is effective in increasing the cache hit ratio. Mori et al. [24] has proposed a method for cache management, i.e., Traffic-Aware distributed Cache management which is push-based technique also known as P-TAC. For balancing the entire network the router takes care of content caching and pushing the contents in the network. This P-TAC uses the connections so as to improve cache hit ratio by utilizing the connections having certain limits in transmission bandwidth.

TABLE II: Comparison of different Cache Replacement strategy

Schemes	Description	Decision basis
Yan et al.[22]	Hierarchical Cluster-based Caching	Clustering
Dron et al.[18]	Caching schemes for ad hoc networks	Content Popularity
Dai et al.[20]	Uses bloom filter	Content Popularity

Smooth performance of NDN during mobility is a main challenge. Farahat et al. [25] suggested a scheme that uses location predictors as well as pattern of content request so as to cache the contents before the handover actually takes place, which is generally used for optimal caching for producer during mobility as called as OpCacheMob. It anticipates future needs for Interest, which is sent to producers initially and cache the contents prior to request.

Pre-caching mechanism is suggested by Faran et al. [26] which are popularity-based for huge chunks of data like video streaming whenever they are requested by user. Considering the capacity of cache of content routers (CRs), collaboration is provided in a mesh network during caching in between neighboring CR. Pre-caching is distinguished as an additional problem in which the objective is to collectively reduce the number of replicas of object and decrease the number of hops from caching node while moving towards consumer, while dealing with cache capacity of every CR. Four algorithms are suggested, first is for producer-driven caching scheme, second is distributed scheme for CRs, third is deterministic caching in distributed scheme, fourth is probabilistic caching in distributed system.

Rao et al. [27] proposed a scheme so as to increase smooth user-side mobility by using Proactive Caching approach for NDN (PCNDN). It is based on the idea that to request and cache the data that has not received to consumer which was requested before handover process. Hence, when consumer reconnects to network he can fetch the data which was not received by consumer earlier. NDN should also secure network from different types of attacks during data caching [28] [29].

TABLE III: Comparison of different Cache Management strategy

Schemes	Description	Decision basis
Mori et al.[24]	Push-based Traffic-Aware distributed Cache	Chunk ID
Farahat et al.[25]	Optimal caching in producer's mobility	No
Faran et al. [26]	Pre-caching mechanism	Content Popularity
Rao et al.[27]	PCNDN for consumer mobility	No

III. CONCLUSION AND FUTURE SCOPE

This paper describes various caching features in NDN architecture along with the named data network itself. NDN architecture's cache placing strategy and on what basis they are cached, for example, popularity of data, its selfishness, partitioning of cache and various other features of cache placing technique is also discussed in paper. Replacement of contents in the cache in NDN is also important factor that is mentioned in paper. Also details of cache replacement policies like popularity and priority of content carried out by variety of algorithm is also discussed. Not only placing and replacing the cache is important but also managing cache in the network is main factor, algorithm dealing with cache management is explored. Caching strategies with all its aspects is studied thoroughly with its problems and implementation designs. NDN could also be used in near future as reliable future internet architecture and should also provide more secure network.

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