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A TAXONOMY OF PENDING INTEREST TABLE IMPLEMENTATION APPROACHES IN NAMED DATA NETWORKING

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ABSTRACT

Content-Centric Networking/Named Data Networking (CCN/NDN) architecture introduces a novel paradigm for the future of the Internet by moving the current system to cutting edge network protocols. Generally, the main goals of CCN/NDN are to improve the traditional network operations by having devices that are aware of content's name, to route the decisions that are taken based on the content's name of the consumers' requests. Despite the numerous advantages out of this shift, hardware challenges, including Pending Interest Table (PIT) are still existing in respect to CCN/NDN implementation in terms of memory that is fast in time accessing and large packet storing. In addition, designing, implementing, and evaluating a fast and enough PIT with higher capacity is certainly another issue in respect to both packet processing and router storage. Furthermore, existing memory technology that is deployed in PIT, such as DRAM and SRAM, is presenting further limitation. Therefore, PIT should be able to serve a very large number of Interest (scalability). Significant works have been presented by several researchers concerning the scalability of PIT, in accommodating more interest; however, there are remaining possibilities for more improvement in such a context. This paper aims to classify an extensive and critical concerning PIT implementation in a concise manner. Then identifying their strength and weaknesses and underline the necessary requirements for better PIT improvement in terms of scalability.

Keywords: *Information Centric Networks, Named Data Networking, Scalability, Pending Interest Table.*

1. INTRODUCTION

Information-Centric Networking (ICN) is an alternative paradigm of computer architecture networks. The founding principle of this is which a communication network should allow consumers to focus on the contents that are required, instead of having a specific reference (physical location) to the contents [1]–[3]. This comes from the fact that the majority of present web usage that is nearly 90 percent of web traffic, include data dissemination from one source to many [4]. Therefore, the existing and diverse ICN activities essentially concentrate on outlining an Internet structural planning which will replace the host-driven model and will straightforwardly address the issues and constraints recognized in the present Internet (such as routing, scalability, security, delivering and mobility) [5]–[7]. In order that, many architectures proposed have emerged in the last few years, including Content-based Network [8]/ Combined Broadcast and Content-Based [9], Data-Oriented Network Architecture [10], Network of Information architecture [11], Content-Centric Network architecture [12]/ Named Data Networking [13], Publish/Subscribe Internet Routing Paradigm [7], MultiCache [14] and Content-Centric Inter-Network architectures [15]. In this paper, we are focusing and presenting the CCN/NDN architecture which is related to our study.

Van Jacobson *et al.,* [12] proposed the concept of CCN, which is also called NDN (NDN is an instance of the general concept of CCN). At CCN/NDN, consumers (endpoints) did not need to know where the required content or interest is located. As content in a particular CCN/NDN node is needed, an "Interest" packet has to be sent to that node. CCN/NDN nodes cache and forward the Interest packets from consumers and other CCN/NDN node, and transmit Data packet from other CCN/NDN nodes or publishers to the

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requested consumers and CCN/NDN nodes [16]. Every CCN/NDN node includes three databases: Content Store (CS), Forwarding Information Base (FIB), and Pending Interest Table (PIT).

PIT is a cache table for Interest packet. Every Interest that requests a content is forwarded to connect node. When a node receives an Interest packet, and the node does not have the content required by the Interest packet, then the node will store the interest (content and originated face) in the PIT [13], [16]. For implementing the PIT, it needs large and fast memory to store the incoming Interests packets [17]. Furthermore, PIT can never utilize collection of contents because Data and Interests must precisely match. Considering the case where the average Interests arriving rate is 125 million packets/second and each packet needs 80ms as average for its Round Trip Time (RTT) [18]. Hence, the current memory technologies are not capable to handle the PIT implementation. A PIT needs to store a number of Interests in the order of 10^7 [19].

Therefore, huge memories are needed with their known limitations, especially when dealing with their access time. Despite that, PIT designing and implementation have not got much interest until now because PIT is a new network component that is not presented in any other Information-Centric Networking proposed architecture. Nevertheless, PIT is as important as a CS and more demanding than FIB due to the many updates in the PIT [20]. In contrary, FIB does not need much updating intervals. This represents the main reason behind focusing on this component in this research because it is very important in the performance of the CCN/NDN nodes [19].

To achieve the goal of this paper, this study tries to answer the following questions: are the current PIT implemented approaches suit with this new technology (CCN/NDN); which one has the greatest effect on behavior of PIT; and which one has the best performance. Therefore, we study and analyze many of PIT implemented approaches in respect to CCN/NDN. Moreover, to be critical in reviewing them by highlighting the advantage and disadvantages of each one. This paper proceeds as follows: Section 2 clarifies the CCN/NDN approach. The problem in PIT is presented in the following section. In Section 4, we discuss the main approaches which are used to implement PIT. Comparative study between these approaches is presented in Section 5. Open issues are highlighted in the Section 6. Finally, the conclusion of this work is presented in Section 7.

2. CCN/NDN ARCHITECTURE

CCN is one of the new paradigms for Future Internet by shifting the current network to the modern network protocols, while NDN is another undertaking under Future Internet Architecture (FIA) program in light of CCN structural engineering [21]. The main activities for this undertaking are the advancement of CCN forwarding as well as routing. The objectives of NDN structural planning are to totally overhaul and build up the present Internet by replacing the IP with content chunks as a widespread part of transport [22]. CCN/NDN is an efficient and simple communication model driven by subscribers who broadcast Interest packets to ask for a content by name, regardless of the IP addresses of the nodes supplying the content. Interests' packets are forwarded by intermediate nodes upstream to providers that are any node storing or owing the requested content. Providers simply respond to ask for Data packet, which goes through the way back to the subscribers [23], [24].

CCN/NDN architecture introduces two types of packets as showed in Figure 1 (a). The first one is the "Interest" package, via sending these over the outgoing interfaces, a node announces the node's demand for content that is named by the packet. It is simply broadcasted on the available interfaces in hope to get the relevant data returned by the mechanisms of CCN/NDN architecture. Usually by default, the Interest packets contain the desired content name. Apart from this, it is accompanied with selective information such as scope inside the network where the data has to come from or specific filter information. While the second packet, namely "Data" packet that is used in response to an incoming Interest packet. Names in CCN/NDN are hierarchical with consequence. Hence, Data packet is considered to satisfy an Interest packet in that they keep a one-to-one relation, where Interest packet is consumed by data.

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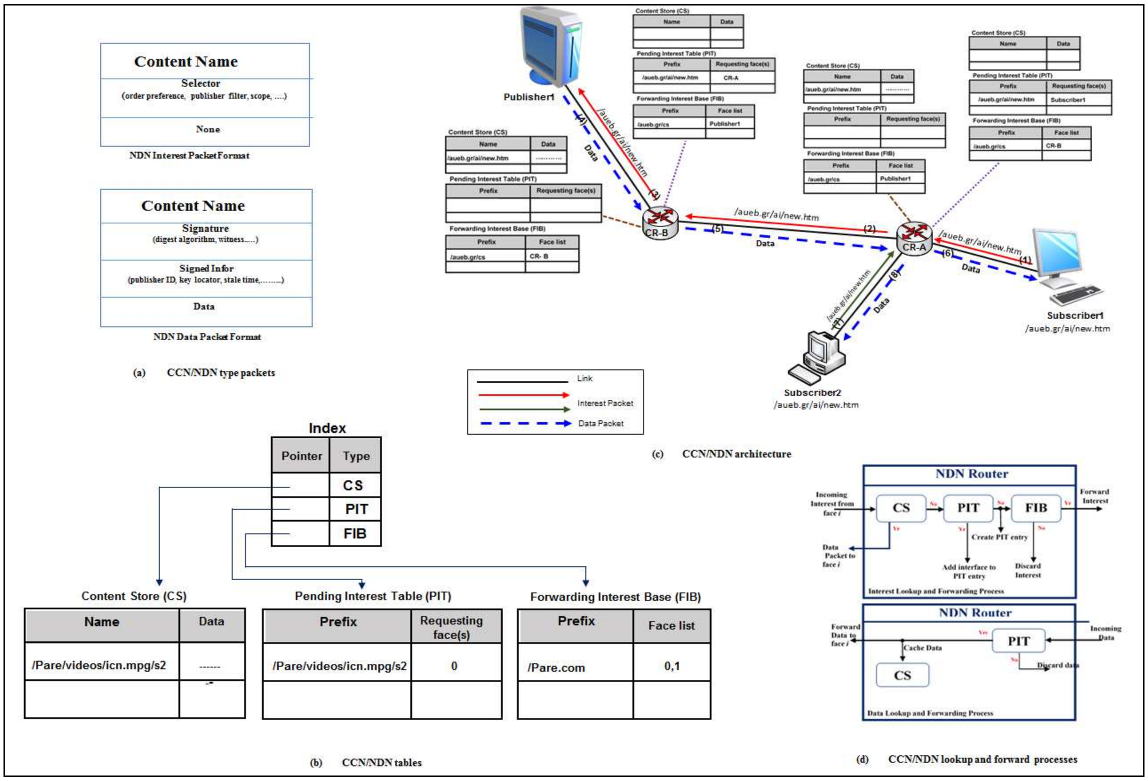

Figure 1. Ccn/Ndn Architecture [1], [12], [13]

This rule of thumb keeps a flow balance at every hop and blocks congestion in the middle of a connection path. This Data packet just serves one Interest packet, if its name prefix and the name of Interest packet are matching. Apart from arbitrary binary data and name, Data packet also has a digital signature that is of certain cryptographic digest of the packet and signed information. This last mentioned field provides extra information regarding the packet including the publisher's ID, where to locate the key for checking the time stamp or signature.

With these ways of verification, it was guaranteed that the packet is identified and authenticating itself and is in no need of legitimacy by the channel it got transferred. All routers use three varying structures in processing of packet forwarding. They are the CS, FIB and PIT [12], [13], [25]. These are illustrated in Figure 1 (b).

- ***Content Store (CS)***: it is a cache structure (buffer memory) in a CCN/NDN router. These store chunks for a very long time via applying for cache update policies. As content is self-authenticating as well as self-identifying, every one of the packets should be useful to certain potential participants in the network nearby. Ability for serving content directly rather than generating additional lookups reduces total bandwidth usage as well as latency.
- ***Forward Information Base (FIB)***: it is used for storing information on packet forward. It is like a routing table in common IP router. FIB stores information on which faces Interests got to be forwarded upstream towards the source of the content of the question. Hereby the design enables more than one entry that may be needed to be queried in parallel, as forwarding is not just limited to one spanning tree.
- ***Pending Interest Table (PIT)***: it consists of arrival interfaces of Interest packets, which have been forwarded. Nonetheless, are still waiting for a matching Data's packet. This information is needed in order to deliver data to their consumer. For increasing the PIT usage, the PIT entries have to be timed out pretty quickly, somewhere around the packet RTT. Nevertheless, Data will be dropped in case they are timed out prematurely, Data will

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be dropped, and it is the customer's duty to re-transmit their Interests.

PIT state in all routers has many critical functions: Firstly, the PIT consists of the number of faces through that Interest packet has arrived. Moreover, it provides natural support for multicasting. Secondly, the router can control the amount of incoming Data packets by controlling its PIT size as well as content storing. CCN/NDN system uproots the reliance on transport protocols keeping in mind the end goal to prevent congestion collapse. Thirdly, the condition of PIT might be utilized to moderate DDoS attacks: the number of PIT entries is an explicit indication of the router load. A most extreme bound on this number sets the upper bound on the impact of a DDoS attack [13].

At CCN/NDN, communications is driven by the data subscribers. For requesting objects, the subscriber sends out an Interest packet that carries a name, which identifies the desired content. For instance, subscriber requests /aueb.gr/ai/new.htm (see Figure 1 (c) and Figure 1 (d)). When Interest packet arrives and a content name that matches the requested name is found at a CS in intermediate nodes (CCN/NDN routers) or publishers' nodes, the Interest packet is discarded, and the content is returned in a Data packet through the incoming interface. If not, then check if the PIT already includes for any pending Interest packet in this content (meaning that this content already was requested) the router adds the incoming interface to the entry list of PIT, discards the Interest packet as well. Otherwise, a CCN/NDN router should remember the interface where the interest comes in, after that it forwards the Interest packet by searching for the name inside its FIB that is populated by a name dependent on the routing protocol.

In the event, Interest packet is reached with the publishers' nodes that have the required data. In this case, a Data packet is returned. This Data packet is returned depending on the state information setup by the Interests packet of every single router hop. On the other side, when Data packet returned, and it is arrived at the intermediate node, the node lookups for finding the matching PIT entry and forwards the Data packet to all or any interfaces listed in the PIT entry. Furthermore, routers remove PIT entry, and cache the data inside CS table, which is simply the router's memory caching be subject to a cache replacement policy. Data packet takes exactly the same route as the Interest packet request which solicited it, but in the reverse direction. One Data packet fulfills one Interest packet request over each and every hop, attaining hop-by-hop flow balance [12], [13], [26].

3. THE PROPBLEM IN PIT

ICN architectures must be able to serve a huge number of contents (scalability); It can easily recover if faults occur (reliability); and maintaining its usable operation rate (availability) [2]. Furthermore, the main challenge in ICN is to face the distribution of billions of objects to billions of interconnected devices. According to Bari et al. [22], the largest Border Gateway Protocol (BGP) table, as of now 4×10^5 routes that cover 3.8×10^9 and 6×10^8 . On the other side, approximately 10^{12} URLs have been indexed by Google. As such, the name-based routing approach used by some ICN architectures such as CCN/NDN or CONET, got to deal with an expected name-space of various orders of magnitude greater than the present address space.

For achieving scalability, the existing Internet routing protocols usually employs hierarchical structure, which is based on some location-dependent identifiers. For instance, route aggregation and prefix-based routing are employed by BGP for reducing by a factor of 10^4 numbers of routes that are essential for covering all utilized IP addresses. Anyhow, it is tough to collect names in ICN architecture [27]. A problem associated with this is the synchronization among contents for avoiding naming conflict or the satisfaction that the name is internationally unique. ICN got to propose a solution, an efficient procedure for name allocation, which has to be distributed and is self-manageable for coping with numerous numbers of objects in the network and for favoring content generated dynamically.

Reliability of naming has anyhow a price regarding the scalability. Because of huge spatial distribution of objects along the network, scalability becomes a crucial challenge for storage of content and cache policy [28]. In CCN/NDN network, when a node receives an Interest packet, information about the Interest packet (i.e. the face from which the Interest packet has come from) is stored in PIT. Consequently, a number of PIT entries will grow as the number of content increases. If the network is large and the number of contents requested is also large, the PIT table size will grow rapidly till the content request is satisfied. Additionally, as an Interest packet is re-transmitted by its consumer until reception of matching Data, the number of entries in the PIT will be increased exponentially for overall network [2].

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In fact, this table may be overflowing, hence interrupt the normal network operation or even slow down the Internet packet with consequent service interruption and possible network collapse [29].

4. CLASSIFICATION OF THE MAIN APPROACHES USED TO IMPLEMENT THE PIT

Accordingly, the PIT may present stringent restrictions in terms of scalability. The challenging task is the design of a scalable PIT because it requires per packet updating and longer naming. This increase in the size of PIT leads to memory consumptions [30]. To address the problem, several PIT approaches have seen proposed. The PIT approaches are classified into three: Hash Table e. g., NPHT [12], [31] and Fingerprint-only PIT [30]; Trie Structure e. g., ENPT [32]; Bloom Filter e. g., DiPIT [33], Compress PIT [34] and MaPIT [35]. Figure 2 shows the classification of PIT approaches. The pros and cons of the said solutions are detailed as follows

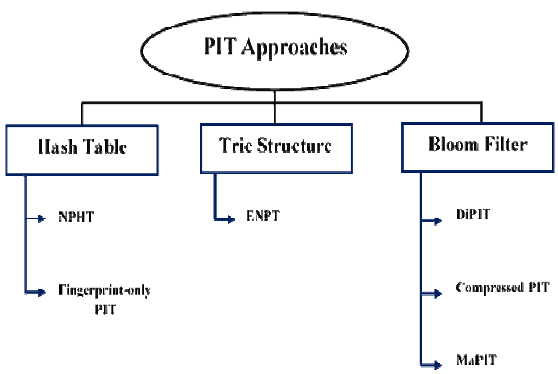

Figure 2. Pending Interest Table Approaches

4.1 Name Prefix Hash Table (NPHT)

NPHT [12] is the first and simple approach in which PIT and FIB share the hash table logical. Two kinds of structures are indexed; they are the Forwarding Information Entries (FIEs) and the Propagation Entries (PEs), where metadata about pending interest info and forwarding info are kept respectively. Each bucket in NPHT points to PEs and FIEs. In PIT, Interest packets are presented in form of PEs. Each packet has a unique nonce field. Propagating Hash Table (PHT) is established to store all the nonce fields. Because of the uniqueness propriety of nonce fields, they used as keys in PHT. The benefit of this design is to prevent loops in the network due to its impact on the operational flows in CCNx. Figure 3 illustrates NPHT.

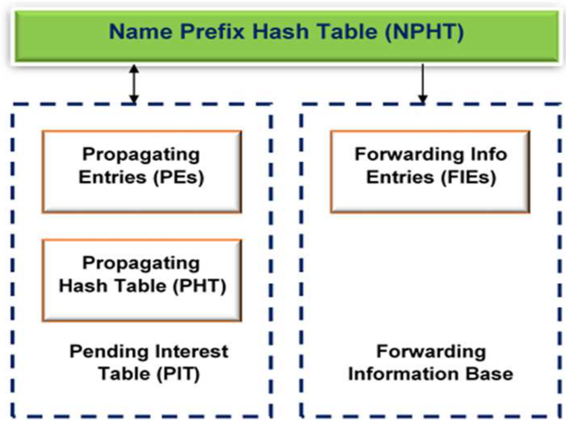

Figure 3. NPHT Approach [12]

4.2 Fingerprint-only PIT

Fingerprint-only PIT [30] proposed a novel PIT plan utilizes fixed-length fingerprints rather than name strings. It promises packet delivery with a minimized representation of the storage. This design approach depends on thoughts that putting away fingerprints save memory space, and that edge switch can total a large portion of the copy Interest packets. Subsequently, this system-wide solution for versatile PIT can unwind the Interest packet collection necessity for the core routers. Figure 4 demonstrates the framework plan.

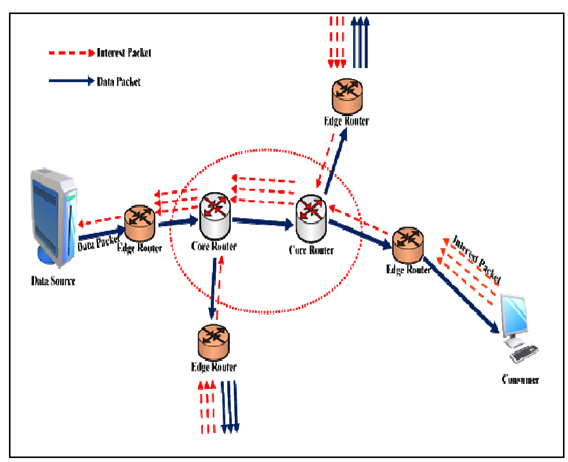

Figure 4. Fingerprint-only PIT System Approach

In this figure, Interest packets are accumulated at the edge switches and afterward arrive at the central network. The central router essentially forwards the

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overall arrived Interest packets. In the end, the main Interest packet bundles are gathered at the edge routers before coming to the publisher. The publisher gets merely one Interest packet request. At that point one Data packet is replayed and dispersed to the clients. The whole packet handling methodology is straight forward to the clients and publishers. Where name strings are put away, and Interest packet aggregation is sustained.

The PIT in the central router stores fixed length fingerprints rather than name strings. Two difficulties emerge with this methodology: duplicate Interest packet requests and fingerprint collisions. To ensure packet delivery, aggregation is not supported in the central routers if unique finger impression crashes happen. Impacting fingerprints are not erased from the PIT unless they achieve their time of expiration (T*exp*), sufficiently giving time to sit tight for potential numerous Data packets. To accomplish this, every PIT section in the core routers records if copies fingerprints have been gotten. PIT entry expiration time and face list data is overseen in the same manner on core and edge routers.

The next issue is the duplication of Interests packet. Even though duplicate Interest packets from a distinctive interface may create its PITs entry remain for a long time, while leverage the notion that majority of the Interest packets are collected at the edge router. If requests arrive at the main router, the CS will be checked to look if the content is already arrived. Otherwise, if it is not arrived and stored, the PIT is consulted to look whether it has been requested already or not.

The lookup keys are the fingerprints of the content names. If no match is found in the PIT, the fingerprints are inserted, its time of expiration is managed, and its arriving interface is recorded. If a match is found in the PIT for this fingerprint, the additional data for the collision is updated. The time of expiration is refreshed, and the incoming interface is recorded. Finally, the Interest packets are forwarded to the particular outgoing interface by doing an FIB lookup, regardless of the knowledge that there is a match for PIT or not. At the end, according to the authors, Fingerprint-only PIT approach can be reduced the memory size of PIT for central router, therefore, the fast memory chip, such as RL-DRAM or SRAM, may be deployed to support per packet update. The given result is such that 37 MB out of 245 MB of memory is required at 100 Gbit/s.

4.3 Encoded Name Prefix Trie (ENPT)

This approach denoted by ENPT [32] relies on encoding the Name Component Encoding (NCE) approach to shrink the size of PIT by speeding up the performance of looking up, insert and delete operations. NCE stores the elements as character strings to be searched within the table (see Figure 5). Following this approach is not the efficient way. A Name Prefix Trie (NPT) strategy is utilized to emerge the names with the same prefix. Because of the nature of NDN, the names will be organized in a hierarchical way. This contributes to more organized and manageable PIT. However, shrinking the PIT size in this way is not sufficient for faster

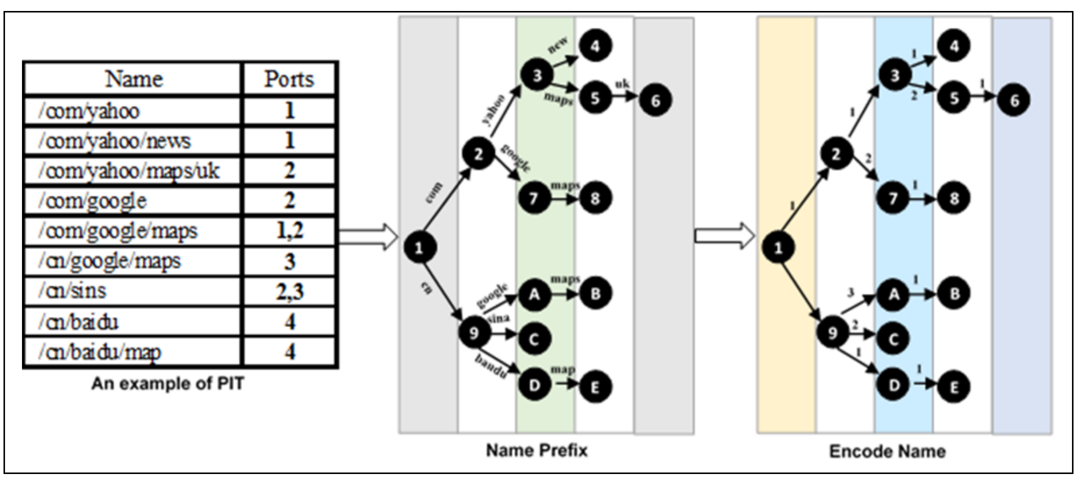

Figure 5. NPHT Approach [32]

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PIT access. Therefore, the names are associated with codes (integer values) so that the PIT operations such as lookup, delete, and insert will be faster.

The experiments confirmed that PIT showed suitable scalability with the application of NCE. During mapping of 20 Gbit/s gateway traces of IP application to NDN platform, of the size of PIT and its access frequency are quantified before and after using NCE. According to the authors, the achieved results demonstrate that resultant PIT consists of 1.5 M entries, and frequencies for insert, delete, and lookups are 0.9 M/s, 1.4 M/s, and 0.9 M/s, respectively. NCE can reduce memory utilization up to 87.44%, and the access performance are effectively improved, which satisfies the required PIT access speed.

4.4 Distributed Bloom Filter based PIT (DiPIT)

The novel in [33] implementation of PIT is denoted by DiPIT. This approach performs better on PIT tables in terms of speed, space, and cost of content retrieval. For DiPIT, Bloom Filters (BFs) are an important part because it is faster updated and lookup operations. Furthermore, these are also very effective for memory utilization, but the ratio of “false positive” can be increased in this regard. Figure 6 illustrates the DiPIT CCN node architectures.

In the original design of PIT, the CCN node applies a centralized PIT table, while in the DiPIT-based design, it builds one PIT*i* (a small PIT table) on each CCN face. In the DiPIT design, BFs are used to construct PIT*i* tables. Moreover, all faces share an additional BF. The idea behind this design is that each PIT*i* works independently and the footprints of the Interest packets are recorded in a Counting Bloom Filter (CBF) that are arriving from the perspective face. In this way, Data packets attained all PIT*i* tables are parallel, checked and then forwarded on the faces if there is any matching footprint in the PIT*i*.

Thus, the computational overhead and memory utilization are minimized by using BFs in DiPIT architecture. Normally, in CCN approach, the Interest packet associated with the Data packet is removed from the PIT table when the packet forwarded. Therefore, entries are frequently added and removed in a PIT. In DiPIT, removal of expired Interests packet are managed by a timer. DiPIT includes one timer that manages the removal of expired Interests packet. Each PIT*i* counter is minimized by one (while it does not become 0) at a periodic interval. This interval is configurable and called DiPIT-TTL (TTL means Time-To-Life).

For that, the value of the interval should be configurable and large enough. It should be at least double of the average response time so that to wait

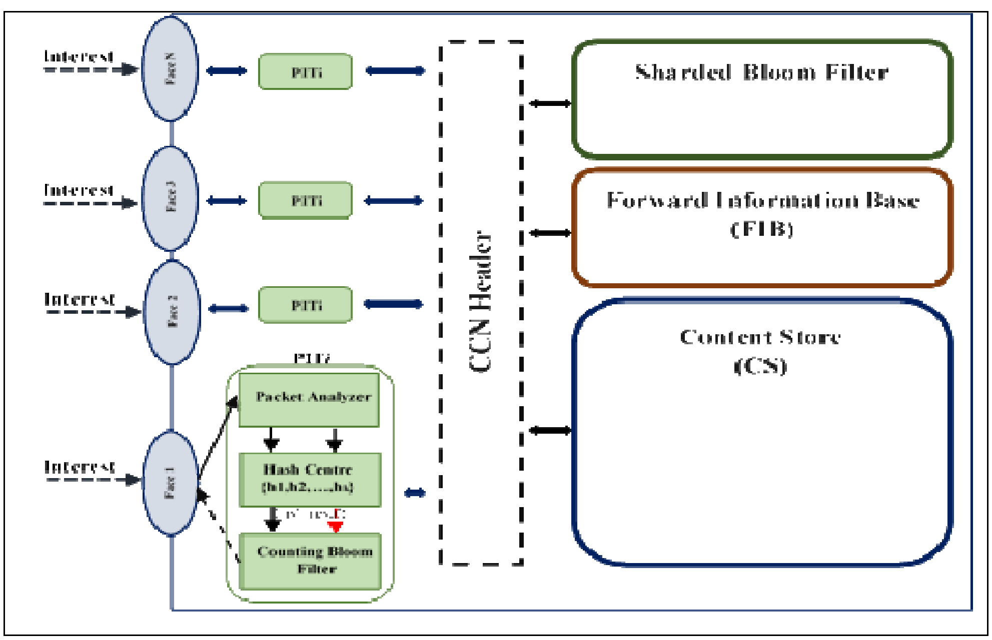

Figure 6. DiPIT CCN Node Approach

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until receives the requested data. The counter is minimized when the Data packet is received before DiPIT-TTL because the Interest packet has already received the corresponding data. In the end, the evaluations show that using the DiPIT-based approach with small DiPIT-TTL values, the memory space can be significantly reduced for the implementation of the CCN PIT table.

4.5 Compressed PIT

Compressed PIT approach [34] is a proposed a PIT compression with United Bloom Filter (UBF) to compress PIT effectively. For compressing PIT with Bloom Filters (BFs), the key is a face as well as the value is a name set. In the transposed PIT entries, it is associated to each face, there is one BF that exemplifies the name set. Hence, PIT comprises of all these BFs as can be seen in Figure 7.

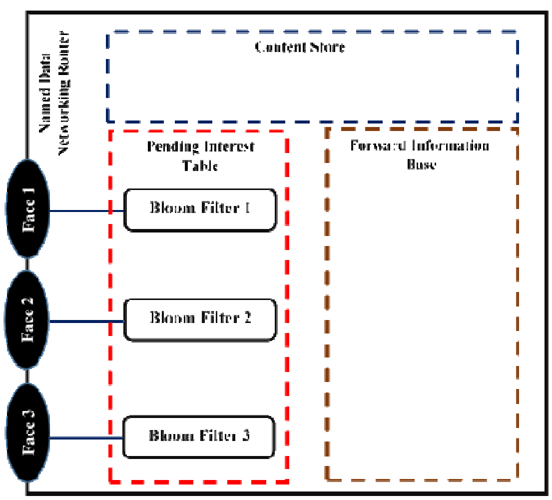

Figure 7. Compressed PIT Approach

The essential form of BF is not suitable for this compression because the deletion of elements is not supported. However, BF is utilized to represent every one of the possible extensions of BF. For every received Interest packet, CCN router checks the Interest name, in case it is matched in any of the BFs, the Interest packet will not be forwarded. On the other hand, for every Data packet, which is received from an interface, CCN router will check the Interest packet name in all available BFs. The packets will be forwarded to the faces with BFs that contain the name.

UBF is proposed to get rid of the need for deletion in order to avoid such unexpected anomalies. While names of Interest packet in PIT will exist just for a short time (i.e., setting by the consumer). UBF takes benefits of this characteristic. UBF consists of two BFs and the time is divided into different epochs as well. At the start of every epoch, the non-existing BF will be cleared ("all bits are placed at 0"). During this epoch, the insertion operates on both BFs even though the query operates only on the existing ones. Following the end of this epoch, two BFs swap their identities.

Existing BFs in UBF represent the set of names (for Interest packets) that were received during the last epoch as well as the existing epoch. Each name in a single BF will be completely cleared at the end of the next epoch after it is being inserted. Timeout acts such as implied deletion in UBF. As a result, the Compressed PIT approach can reduce the space for a storage requirement by about 40% as well as in most incurs only a 0.1% error probability. The communication may be easily recovered from the errors through retransmission.

4.6 MaPIT

To enhance the implementation of PIT to fulfill the existing network requirements and memory technology, Li *at el.,* [35] proposed a new data structure Mapping Bloom Filter (MBF) as well as an improved PIT called MaPIT to meet the PIT requirements and make its usage of the existing memory chip. MBF is a data structure improvement of Bloom Filter (BF), to support mapping and querying the set elements in the memory as well as lowering on-chip memory utilization. MBF comprised of two modules, the first one is the Index Table (IT) and the second one a Packet Store (PS). IT is deployed on the on-chip memory to get into the PS. Recorded contents will be designated for dispersed locations on the PS that is fixed cache in the off-chip memory.

Index Table consists of two structures, i.e., a regular BF and Mapping Array (MA). While using the BF, the elements are checked if they are in available in the MBF or not. To reach the PS, the MA value is utilized as being the offset address of the PS. For this reason, the BF is split into *m* equal parts, and each part resembles to a single bit of *m* bits MA. At the same time, the primary condition of

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each bit in the MA is set to zero for any arriving content. When contents are inserted in the MBF, some MA bits are set to be one based on the *k* hash values of this element in the BF. Thus, for the incoming contents, if any bit position hashes in the *i*th ($i = 1, 2, 3, 4 \ldots m$) part of BF, the value of the *i*th bit in the MA equals one. If not, this value will be zero. At the end, MA value is the offset address of this content in PS.

MaPIT consists of two storages, which are off-chip memory and an on-chip memory. Off-chip is the memory where CBF is working, while on-chip memory is the one where the IT of MBF is working as a summary. PS of MBF is deployed as shown in Figure 9. Data packets are stored in the PS, while the value of MA in IT is the offset address to access the PS. MaPIT can support deleting using periodically synchronization between the BF of IT and CBF based on the design BF concepts [36].

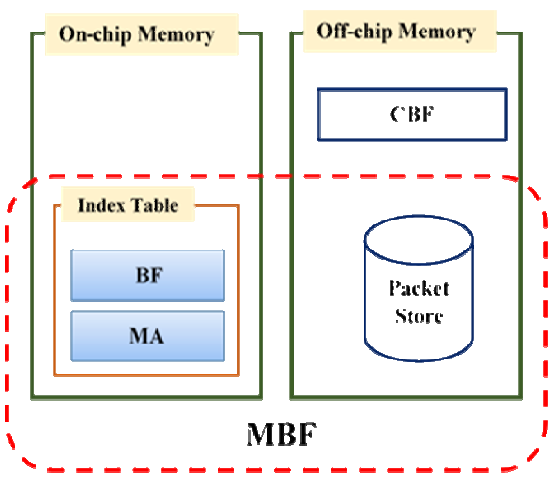

Figure 9. MaPIT Approach [35]

Normally, the keywords' element name is merely used if time out happens in the PIT cache. Similarly, by developing the proceeding algorithms, name of content is deleted from the entry which has the lists (i.e., list faces, list nonce, and expiration) in the PS of MaPIT. Therefore, the off-chip memory utilization can be largely minimized as compared to the classic PIT. According to the authors, MaPIT depending on MBF has largely minimized the on-chip memory utilization to 2.097 MB for two million names with the probability of false positive under 1%. It enables the MaPIT to use SRAM memory as the on-chip memory as well as overcome the current network requirements.

5. CRITICAL ANALYSIS ON PIT APPROACHES

Implementation The comparison in Table 2 presents a summary of characteristics of the PIT implementing approaches.

NPHT approach is effective during normal operation because the main idea is to implement PIT. The hash table is capable of doing a quick lookup operation, but it is suffering from the following drawbacks. Because of the architecture of NDN, the PIT is depending on rigorous matching where each record must be remembered. This requires more memory space. This situation is getting worse if the number of entries has increased because it results in increasing the delay time experienced by a consumer. In the case, the NPHT approach will be not efficient for scalability issue. Furthermore, there is no clear operation to avoid PIT overflow, hence this can effect on memory usage and increase the packet loss.

Table 2. Comparison between Approaches

	Approach Name	Evaluation Technique	Focus on	Drawback
1	NPHT	Testbed	Implementing the FIB and PIT by sharing the hash table logically. It is capable of doing a quick lookup operation.	Increasing the delay time, not efficient for scalability issue, operation to avoid PIT overflow not clear, the bits number per element for the storage is quite high
2	Fingerprint-only PIT	Analytical model	Implementing to reduce the PIT table for a core router with SRAM/RDRAM chips, and it is overcome duplication Interest request and fingerprint collisions.	Poorly explanation in the side of lookup when the link speeds increase, it is not include operation to avoid PIT overflow.
3	ENPT	Emulation	Improving PIT by arranging the PIT entries in order also ensures high insert, delete, and search speed, furthermore, to shrink PIT size.	Needing more complex architecture to achieve shrink PIT size, special encoding algorithm has been required an additional, consuming much more storage space, and not mention how to avoid PIT overflow when occur.
4	DiPIT	Real test impleme-tnation in last CCNx	PIT is splitting into several sub-PIT and deploying them on every face of NDN router, increasing throughput for an incoming packet, and to reduce the memory usage (up to 63%) in the NDN router.	It can't filter Interest duplications, Impacting CBF at PIT when the false negative is occurred, entry lookup should check on every PIT*i*.

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5	Compressed PIT with BF	Simulation	Proposing UBF, a new extension of BF, to compress PIT effectively, in UBF the compactness may be organized because there is no incorrect deletion, obtain about 40% compression ratio and 0.027% error probability.	Increasing routing overhead, it is not include operation to avoid PIT overflow. Interest packet with similar name cannot be forwarded twice or more.
6	MaPIT	Testbed	Enhancing the implementation of PIT, minimizing the on-chip memory consumption, more efficient in time and space.	Proceeding algorithm has been required an additional much more storage space, and not mention how to avoid PIT overflow when occur, false negative.

Fingerprint-only PIT approach is implemented to reduce the PIT table for a core router with SRAM/RDRAM chips, and it overcomes duplication Interest request and fingerprint collisions. Despite that, this approach has given a poor explanation in the side of lookup when the link speeds increase. Moreover, the approach does not include operation to avoid PIT overflow, hence this can effect on memory usage and increase the packet loss in both core and edge router.

ENPT reaps some benefits from both access frequencies considerably advanced fulfilling the access speed necessary for PIT, in this case the memory utilization can be decreased. Although this approach improves PIT by arranging the PIT entries in order to ensure high insert, delete, and search speed as well as to shrink PIT size. Anyhow, this approach needs more complex architecture to achieve these objectives [30]. Since special encoding algorithm has been required an additional, consuming much more storage space.

DiPIT approach is an efficient PIT approach based on Bloom Filter. It can increase throughput for an incoming packet, and to reduce the memory usage (up to 63%) in the NDN router [33]. However, this approach has a drawback since it does not filter Interest duplications for the reason that the same Interest packet arriving at different interfaces are recorded individually at different PITi. Moreover, the authors did not mention about the impact CBF at PIT when the false negative is occurring if any of counters decrease to zero, hence it can lead to packet loss and redundant traffic. In addition, this approach did not mention what should happen if PIT becomes an overflow that can affect the performance approach.

Compress PIT with Bloom Filter (BF) approach is using an extension of BF namely UBF to eradicate the demand of deletion to avoid such unexpected anomalies. Hence, the communication can easily be recovered from the errors through retransmission. The most important advantage of UBF, the density can be controlled whereas there is no incorrect deletion. This approach can reduce storage space required by about 40% with only 0.1% error probability [34]. However, the drawback of this approach is increasing the routing overhead because Interest packets which have the same name is forwarded twice or more times in one epoch couple and this approach does not include operation to avoid PIT overflow.

MaPIT approach presented to enhance the implementation of PIT. This approach can be minimized to the consumption of memory to 2.097 MB, lower the probability of false positive is to be under 1% for 2000000 names [35]. Furthermore, it is implemented on SRAM memory as on-chip memory to satisfy today's memory technology as well as network requirements. Hence, the proceeding algorithm has been required an additional much more storage space since many additional components included in this approach. Furthermore, it is not mentioned how to avoid PIT overflow when occur.

6. CURRENT ISSUES IN PIT

There are yet many challenges and solutions must be developed and deployment aspects that call for in-depth investigation in terms of PIT since it can become a main important research field. The section here, highlights some open issues in PIT, which are identifying a list of desirable properties for it.

- ***PIT overflow***: the PIT tables are very dynamic due to the high speed packet arrive rate to the PIT with current memory technologies. Thus, for all incoming request packet and matching data packet, hence a special process must be happening in these tables. These processes should have to be performed faster to avoid these tables may be overflowed, which cause the delay and packet loss for these packets because the PIT receive and remove the packets exponentially. It is not easy to predict the tables are full. If the table is overflowing, consumers' requests will be discarded from the routers, and based on this, consumers will experience an increasing retransmitting rate that will lead to a complete collapse of the whole network.

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- ***Lookup operates*:** since the PIT grows when subscribers sending their Interest packet and shrinking when Data packets arrive at the CCN/NDN routers. In case of the number of PIT entries increases, these required access speed to PIT structure and the possibilities available in this meaning by using current memory techniques, that make the PIT size representable as the main bottleneck that affects the whole CCN/NDN infrastructure. PIT table in the CCN/NDN router is very dynamic. Thus, for all incoming Interest packets and matching Data packets, a special process (lookup process) must be happening in the PIT table which should to be performed faster. This requires fast memory that is unfortunately merely offered for small storage sizes.

- ***Filtering***: One of these issues, malicious users can create artificial requests in order of filling the PIT on CCN/NDN routers. Hence, it is implementing a DDoS attack. This type of attack can possibly be implemented by distributing the generated request packets that include valid destination prefixes without existing resource names, in order that the routers correctly forward requests and keep new entries inside the table. Nonetheless, replies never come back. Another issue of security in CCN/NDN architectures is the vulnerability of CCN/NDN to the PIT pollution attacks. This type of attack includes sending random Interests packets for content as a way to modify large values for the LifeTime field. Thereby forcing CCN/NDN routers, for storing unpopular entries in their PIT.

- ***Entries situation***: PIT should provide low-routing overhead, metadata updates, avoids congestion, low-latency entry operations addition and deletion. The interesting question at this point, how to determine that the Interest packet deletion must be expiry-time based on some hybrid or explicit schemes.

- ***Interest LifeTime:*** According to the CCN/NDN nodes' prototype implementation (i, e., CCNx [37]), the asset value of Interest packet LifeTime is 4 seconds, which is reasonable values of Interest LifeTime to enable complete publish/subscribe services in a CCN/NDN network. However, since this parameter is chosen by subscribers not under a network controller itself. The problem can exacerbate via a massive use of long Interest Packet LifeTimes. Hence, continuously will be increased the number of simultaneous entries in the PIT. By developing of special mechanisms to management LifeTime at content routers, by adapting LifeTimes as a function under CCN/NDN network load: CCN/NDN router can be giving larger values of Interest Packet LifeTime when the low traffic congestion and, conversely, giving short values of Interest packet LifeTime in case of the load increases.

7. CONCLUSION

A deeper review of recent advances in the area of the PIT approaches was presented. The design and implementation of PIT is beneficial in CCN/NDN architecture because this component can impact on the performance of these kinds of networks, since the PIT is controlled on the incoming and forwarding Interest packets that arrived to the CCN/NDN nodes. In addition, this paper classified several approaches according to the data that are presented, which are NPHT, ENPT, DiPIT, Compressed PIT, Fingerprint-only PIT, and MaPIT. This paper explained their general aims and processes as well as how they design and implement each of these approaches inside CCN/NDN architecture, culminating with comparative reviews of the different design choices in each of these areas. Eventually, the final conclusion is highlighting the differentiated strength and weaknesses in every approach, and also this study can state that PIT is a promised and fertile research field for more investigation and underlined the requirement for improvements in terms of scalability.

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