Adaptive Interest Packet Lifetime Due to Pending Interest Table Overflow

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Pending Interest Table (PIT) is a novel data structure for forwarding processes in Content-Centric Networking/Named Data Networking (CCN/NDN). It brings CCN/NDN significant features, such as multipath routing, communicating without the knowledge of consumers or publishers and packet loss detection. However, despite the numerous advantages of PIT, hardware challenges, including PIT are still existing in respect to CCN/NDN implementation in terms of memory efficiency. Thus, with the current trend of Internet activities through access speed required for data traversing, a tendency for the PIT to overflow with consequent service disruption and possible network collapse is always feasible. The PIT problem of overflow could be subjected due to the massive usage of long Interest Lifetimes, which would further increase the number of simultaneous entries in the PIT. The objective of this paper is to propose a smart scheme named Adaptive LifeTime (ALT) in order to manage the Interest Lifetime at content routers that will adapt Lifetimes as a function of the network load. With such a scheme, we would break down the hypothesis that states that intermediate nodes do not manage Lifetimes values. The evaluation from the performance analysis show that ALT result is considerably better performance for the metrics average PIT Lifetime to compare with original PIT.

Keywords: Content Centric Networking, Named Data Networking, Pending Interest Table, Interest Lifetime.

1. INTRODUCTION

Van Jacobson et al.\textsuperscript{1} proposed the concept of Content-Centric Networking (CCN) which is also referred to as Named Data Networking (NDN)\textsuperscript{2}. In CCN/NDN, users which are normally referred to as subscriber need not to know the location of the requested data. When data is needed in a CCN/NDN, a request known as Interest is subscribed into the network. CCN/NDN nodes through its designated data structures cache and forward the needed Interest packets from the user point through mid-interconnected nodes (CCN/NDN nodes) to the publishers of the requested information\textsuperscript{3}. Every CCN/NDN node comprises of three specially designed datasets namely: a Content Store (CS) for caching and serving as primary memory, Forwarding Information Base (FIB) charged with routing, and the Pending Interest Table (PIT) for tracking keeping and timely caches\textsuperscript{1,2,4}.

PIT performs a function of an Interest check whenever a request is posed to the network. It is a special table that indexes all traversing and served request in the network\textsuperscript{2}. Implementing a PIT needs large and fast memory configuration to store the incoming Interests packets at a particular point in time\textsuperscript{5}. Moreover, the entry is lodged in the PIT for a time interval referred to as Lifetime (i.e. Interest Lifetime value is indicated as the approximate time remaining before the interest times out); this is specified as an inbuilt parameter of the Interest. As soon as the Interest Lifetime expires, while the response still remains pending, the holding memory is thus freed to accommodate an incoming Interest. Interestingly to note is the lifespan of the parameter is usually chosen by the subscribers. Furthermore, the PIT size could amount to a bottleneck problem for the CCN/NDN infrastructure when large sets of requests are flooding the network\textsuperscript{6}.

Additionally, it is predicted that the usage of longer Interest Lifetimes may results into having to save large number of entries that are simultaneously distributed in
the PIT. Despite the diversified nature of the CCN/NDN, sometimes, a large Lifetime is still of the essence since users subscribe for some given contents that will be asynchronously produced in future requests\(^7\). In this paper, the specific problem is driven by providing an Adaptive LifeTime (ALT) scheme, which defines the management of an Interest Lifetime at content intermediate nodes, which adapt Lifetimes filed as a feature of the network load when load increases and the PIT is full.

The paper is structured as thus: Section 2 presents the details and literatures of the previous works. Section 3 provides model assumptions and a description of the system. The processing of ALT scheme is presented in Section 4. Setting parameter and performance analysis are exemplified in Section 5; and the conclusion is presented in Section 6.

2. RELATED WORKS

Anastasiades, Rotz, and Institute\(^8\) described two newly developed algorithms (i.e. CCNTimer and WMA) to adaptively set the Interest lifetimes. CCNTimer performed better for low traffic scenarios, while in high traffic scenarios, CCNTimer performs similar to Timeout Estimator and TCP’s. Evaluations have shown that increasing the Interest Lifetime slightly (CCNTimer) is enough to receive subsequent segments without timeouts.

Zhang et al.,\(^9\) proposed CHoPCoP protocol that utilizes an explicit congestion control mechanism to cope with the multiple-source and path situation. The resulting evaluation concludes that CHoPCoP is feasible accessions that effectively curtail congestion in non-singular path environment. Moreover, it shows that CHoPCoP significantly improved the overall network throughput to about 103\% over the existing solutions that use a single RTT estimation.

The authors in\(^10\) implemented an AIMD strategy for controlling the pipeline of Interests, which is compatible with TCP’s behavior. The results of the experiments revealed a success, but at the cost of increasing the implementation complexity in order to compensate for the fact that in CCN content may originate from different points in the network.

Carofiglio, Gallo, and Muscariello\(^11\), proposed an Interest Control Protocol (ICP) for the CCN. The submitted design was done using a window-based structured AIMD controller of the Interest rate expressed at the receiver end. The ICP performance was evaluated by packet level simulation and corroborating analytical results on a hierarchical network topology.

3. SYSTEM DESCRIPTION AND ASSUMPTIONS

Initial design of the PIT memory size was to determine the number of entries and the Lifetime of each entry\(^12\). Thus, to adapt Lifetime may be helpful by using the PIT memory size in sufficient way. According to\(^8\) in the CCN/NDN nodes’ prototype implementation (i.e., CCNx\(^13\)), the default Lifetime for Interests is 4 seconds. However, this parameter is chosen by the subscribers not under a network controller itself. The problem can exacerbate via a massive use of long Interest Lifetimes. In order to deal with the aforementioned problems, we need to develop a special scheme to management Lifetime (i.e. Adaptive LifeTime (ALT)) at content routers levels by adapting Lifetime as a function under CCN/NDN network load: CCN/NDN node can be giving larger values of Interest Lifetime when the PIT have not overflowed and conversely, giving short values of Interest Lifetime in case the load increases and PIT suffers overflow.

In the above discussion, we noted that the goal of ALT’s scheme is to de-postulate the submission that intermediate network nodes does not fully coordinate the Lifetime values. Therefore, the main objectives of ALT are:

- To observe the Interest rate on incoming interfaces of an intermediate node in order to determine from which interface has a high receiving Interest rate (if and only if there is variety Interest rate over the node links).
- To manage at incoming Interest packet Lifetime into PIT when the PIT overflows, as a function of the network load.

As a research, the important thing is to define some of assumption before presenting any proposed model. In order to achieve that, the assumptions made to develop this model are as follows:

- Each CCN/NDN nodes is homogenous and have only one CS, FIB and PIT.
- Each Interest packet has constant size.
- The main cause of delay is PIT overflow as well as higher Interest Lifetime field. The packet loss probability of congestion and link failure due to the traffic is omitted.
- Overflow occurs only in PIT, when the Interest packet increases since using the current storage technology, which cannot indulge with the current trend of Internet activities through access speed required for data traversing, entries and the possibilities offered in this sense of current memory technologies.
- The Interest Lifetime parameter is equal or less than 4 second (400ms)\(^13\).

Consider a Named Data Network which consists of set \(N\) of nodes; where \(\mathcal{N} = \{1, 2, 3, \ldots, n, \ldots, N\}\), for \(n \in N\) with Interest transmission rate of \(m_{\nu}(t)\) at time \((t)\) per second. Moreover, consider this network contains another set \(L\) of links where \(\mathcal{L} = \{1, 2, 3, \ldots, l, \ldots, L\}\) for \(l \in L\). Let \(P\) represents Interest packet, and each \(P\) has Lifetime (LT) field that is set by a consumer which is denoted as \((P_{LT})\).

Let \(m_n = [m_1(t), m_2(t), \ldots, m_n(t)]^T\) be a vector of all node Interest rates. In this case, each \(n\) uses a set \(L_n \subseteq \mathcal{L}\).
of the links. Hence, set \( N \) which uses link \( l \) is represented as \( N_l = \{ n \in N | l \in L_n \} \). Also, consider \( \text{PIT}_{\text{size}} \) to be a reflection of maximum capacity of PIT, which is as follows: \( \text{PIT}_{\text{size}} = \{ 1, 2, 3, \ldots, P_{\text{LT}}, \ldots, \text{PIT}_{\text{size}} \} \).

In a case where the PIT does not overflow, let \( L_{\text{LT}_{\text{Threshold}}} \) be denoted as a higher Lifetime that represented an Interest Lifetime inside PIT which is given as:

\[
P_{\text{LT}} = \max (L_{\text{LT}_{\text{Threshold}}}, P_{\text{LT}})
\]

(1)

Where \( P_{\text{LT}} \) is the Lifetime of an incoming Interest packet. Since \( L_{\text{LT}_{\text{Threshold}}} \) is less than Lifetime, then \( L_{\text{LT}_{\text{Threshold}}} \) will be updated dynamically.

While in the case where PIT does overflow, calculate the average Lifetime for all Interest to face \( f \) (when the Interest rate of links are varying) or for all Interest of PIT (when the Interest rate of links are similar) and subtract from the old threshold based on following equations:

In case of there are different Interest rates over the links, to determine the faces \( f \) which have maximum Interest rate:

\[
f_{\text{max}} = \max (m_i(t), m_{i+1}(t))
\]

(2)

Let \( (L_{\text{LT}_{\text{Threshold}}}(f)) \) denote the average Lifetime that PIT received from the face \( f \):

\[
L_{\text{LT}_{\text{Threshold}}}(f) = \frac{\sum P_{\text{LT}}(t)}{W}
\]

(3)

Where \( W \) is the total number of Interest packet of face \( f \); and \( P = 1, 2, \ldots, W \).

While in case of the Interest rate been similar over all links, let \( (\text{Threshold}_{LT}(\text{PIT})) \) denote the average Lifetime that the PIT received.

\[
L_{\text{LT}_{\text{Threshold}}}(\text{PIT}) = \frac{\sum P_{\text{LT}}(t)}{W}
\]

(4)

Where \( W \) is the total number of Interest packet of PIT; and \( P = 1, 2, \ldots, W \).

Consequently, if and only if one of these equations is true (i.e. 3 and 4 are mutually exclusive). Accordingly, the average value of Lifetime is the expected value of the random variable of Lifetime as calculated as follows:

\[
L_{\text{LT}_{\text{Threshold}}} = \left[ \frac{\sum P_{\text{LT}}(t)}{W} \right]_{\text{PIT}}^\text{LT}
\]

(5)

Where \( W \) is the total number of Interest packet \( f | \text{PIT} \). \( \left[ x \right]_{\text{PIT}}^{\text{LT}} \) represents the update of the Lifetime of the incoming Interest packet for face \( f \) or PIT.

During overflow, the value of Lifetime of an incoming Interest packet is updated based on Equation (6):

\[
P_{\text{LT}} = \max (L_{\text{LT}_{\text{Threshold}}}(f|\text{PIT}), P_{\text{LT}})
\]

(6)

4. ALT SCHEME PROCESSING

In this section we present the proceeding algorithms of the ATL scheme at the reception of Interest packets and treat the Interest Lifetime as follows:

For each Incoming Interest, Interest arrives on a given face \( f \) which is firstly checked with a \( L_{\text{LT}_{\text{Threshold}}} \) parameter. Figure 1 presents a flowchart describing the main process of the ALT scheme according to this submission.

Fig. 1. ALT scheme flowchart

i. In a case where the PIT does not overflow, checking the Interest packet Lifetime done as to update the threshold if needed. In order to do that, two cases are tested:

ii. A positive result implies that the Interest Lifetime will need to update the \( L_{\text{LT}_{\text{Threshold}}} \) based on Equation (1) and allow the incoming Interest packet to be inserted to the PIT.

iii. A negative result means that the Interest Lifetime will not update the \( L_{\text{LT}_{\text{Threshold}}} \) and thus allow a new Interest packet to be insert to the PIT.

iv. In the case of the PIT overflow, then a recalculation of the average Lifetime is needed for all Interest face \( f \) (when the Interest rate of links are varying (see Equation 3) or for all Interest of PIT (when the Interest rate of links are similar (see Equation 4).

v. Now, the assigned \( L_{\text{LT}_{\text{Threshold}}} \) is taken into account as the new value. After that calculate the maximum Lifetime between the average threshold and the Lifetime of the Interest packet (Equation 6) for the newly incoming packet so as to allow the Interest packet that has new Lifetime to be replace by using LRU policy.
5. SETTING THE PARAMETERS AND PERFORMANCE ANALYSIS

A case scenario is used in the study and widely established research approached that has received extensive and a wide variety of use in various disciplines. This forms the basis of the paper in demonstrating the theoretical constructs of the roles of the PIT in the network. It can be considered as an instrumental case study. It can also be considered as an explanatory case study due to its wide attempts to answer the relational theories that play considerable roles in the real life context.

Consider a PIT which contains a set $S$ of $P_L$: where $S = \{P_L(t_1), P_L(t_2), ..., S\}$, at time $t$ per second. Moreover, consider this PIT consisting of another set $F$ of incoming faces where $F= \{f_1, f_2, ..., F\}$, since each $P_L$ has a corresponding finite face $f$, where $f \in F$. Thus, the set $S$ is represented as $S = \{P_L(t_1, f_1), P_L(t_2, f_2), ..., \}$. Also, consider the maximum number of $PIT_{size} = 10$, Interest a second, randomly setting $P_L \leq 400$ms and a replacement policy is LRU policy. Assume the number of incoming faces are 3 at which $F= \{1, 2, 3\}$ (i.e. router A: face 1, router B: face 2, and router C: face 3), and the CCN/NDN networking topology as presented in Figure 2.

As well as the Interest packets set are 20 which is as follows:

$S=\{packet \_Liftime, \ incoming \_face\}=\{[240, 3], [87, 3], [310, 2], [40, 3], [101, 1], [178, 3], [215, 3], [371, 1], [215, 3], [222, 2], [190, 3], [195, 3], [63, 2], [249, 3], [314, 1], [366, 3], [53, 2], [211, 3], [107, 2], [195, 3]\}.$

As earlier submitted in section 4, the ALT scheme involves two cases.

**Case 1:**

Assume the Interest rate for a list of incoming faces is similar ($m_A = m_B = m_C = 10$) Interest a second, which means we will ignore the face field from the data set and focus only on the Lifetime field. Table 2 illustrates the results that reflect our scheme in process.

By executing one operation in order to detail how the scheme works, PIT keep receiving the Interest packet and updates are computed for the $LT_{Threshold}$. Until the PIT becomes full, means PIT table include 10 Interest packet, and the value of $LT_{Threshold}$ has reached the highest Lifetime value (in our case $LT_{Threshold}$=371ms). The newly incoming Interest packet records $P_L = 190$ms. First, the scheme calculates the average PIT Lifetime, which results to 198ms (see Equation 4). Then, updating $LT_{Threshold}$ by applying Equation (6) in order to allow only the Interest packet that has Lifetime equal or less than the $LT_{Threshold}$ to replace an old one based on LRU policy. So, in this scenario example, no need to update the Lifetime field for it at the initial iteration. Moreover, in order to juxtapose that it fulfills its intended requirements in terms of adaptive Lifetime, we evaluate our scheme results with the original PIT (i.e. PIT without ALT scheme) (see Table 1). The Figure 3 is reflected in the result obtained in Table 1 and Table 2 consecutively, which is shown the average PIT Lifetime for PIT with ALT scheme is obtained a better result. The scenario here supposes all 10 process is controlled. Lifetime updated and replacement for each incoming Interest packet when the PIT overflow. Thus, decreasing the Lifetime parameter for all incoming Interest that is replacement for an existing one.

![Fig. 2. CCN/NDN General topology](image)

**Case 2:**

Assume the Interest rate for a list of incoming faces is a varied ($m_A = 3, m_B = 5, m_C = 12$) Interest a second, which implies that we will focus on both the Lifetime field and the face field as well.

Table 3 depicts the result that conflict our scheme process by applying the same concept as in case 1, until the PIT becomes full. Thus, the treatment of this case determines the face that has the highest Interest rate by monitoring the face’s Interest packet (see Equation 2). First, the scheme is to calculate the $LT_{Threshold}$ for every Interest packet inside PIT, which in this case was equal 163ms. Then, updating $LT_{Threshold}$ by applying Equation (6) in order to allow only the Interest packet that has Lifetime equal or less than the $LT_{Threshold}$ to be replaced with old ones based on LRU policy. Conclusively, in our example the $LT_{Threshold}$ = 163ms, which means it requires an update of the $P_L$ for all newly requested Interest packet and pass it to PIT.

Additionaly, as illustrated in Figure 4, performance of PIT with ALT scheme has a good average PIT Lifetime in the environment of the CCN/NDN of 10 processes. This is because of the incoming Interest packet Lifetime is

![Fig. 3. Avg. PIT Lifetime for PIT with and without ALT scheme](image)
upgrading based on the LT

threshold by calculating the average for all packet belongs to the same face that got maximum value. Thus, decreasing the Lifetime parameter for all incoming Interest that is replacement for an existing one.

### 6. CONCLUSION

A PIT is a special table in CCN/NDN and has no semantic equivalent as in IP or any other Information-Centric Networking (ICN) approaches. However, the PIT may present stringent restrictions in terms of management due to CCN/NDN initial design. In this paper, we have presented an Adaptive LifeTime (ALT) scheme that reworks and manage incoming Interest Lifetime fields in order to mitigate the load on the PIT. This scheme maintains the Interest Lifetime of the incoming Interests packet which is compatible with PIT behavior. In order to evaluate the ALT, we analyzed the performance of the scheme with varying parameters. Our analysis results show that in CCN/NDN node, when coupled with our ALT, the performance can successfully stabilize the PIT table and improve to manage the PIT in order to avoid the Interest to stay in PIT a long-time when it is full. Furthermore, we are observed in both cases the ALT scheme got a good results to compare with standard PIT. More so, we expect future plan to extend this work by combining ALT scheme with special replacement policy in order come up with a suitable decision system.

### REFERENCES


