RAPEL: Robust and Adaptive method for PIT Entry Lifetime in Wireless Content-Centric Networks

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***Abstract*—Content-Centric Networking (CCN) is an emerging Internet paradigm where the content is treated as the first-class citizen and content names are used for network layer communication instead of IP addresses. Use of CCN in wireless environment can cause various issues such as re-transmissions, collisions, delay and link failure. One of the key issues that affects the performance of CCN is the management of Pending Interest Table (PIT). PIT stores each broadcasted Interest packet forwarded upstream towards the content provider and is purged either when the requested content is returned or the PIT Entry Lifetime (PEL) expires. The conventional method in CCN for PEL does not considering the network impairments such as channel error, and congestion. As a result, timeout occurs, and Interest packets are re-transmitted for the chunks that have been dropped or delayed. Due to limited size of storage in wireless CCN, all new incoming Interest packets (including retransmissions) affect the performance of network by bloating PIT. In this paper, therefore, we propose a scheme that purges the PIT entries quickly by prefetching the un-obtained content in advance. Simulation results show that proposed protocol performs better as comparing with the conventional CCN and another recent proposed protocol.**

***Index Terms*—PIT entry lifetime, chunks, re-transmissions, channel errors, delay, congestion, wireless content-centric networking, future networks.**

I. INTRODUCTION

Initially the Internet was designed to provide communication between end to end hosts. Due to advancement in technology, the notion of Internet has been changed such as broadband and mobile devices. Everyday a lot of content is searched and uploaded on the Internet such as YouTube, Facebook, Flicker and Google etc. Due to such various types of data, the existing Transmission Control Protocol/Internet Protocol (TCP/IP) network has been met with limitations and problems; therefore, new Internet architectures are being actively researched. One of the most promising of these architectures is Content Centric Networking (CCN), which was proposed by Van Jacobson in 2009 [1]. It focuses on efficient requests for and distribution of Content. CCN does not focus on where the content is but rather its type. In other words, when specific content is required, the content is not requested or transferred from a specific server address; it can be transferred from any location.

Initially, CCN was designed for wired situations. However, new research has allowed its application in wireless circumstances [2]- [3]. Recently, the CCN has been adapted in Mobile networks such as Vehicular Adhoc Networks (VANETs) as Vehicular Content Centric Networks (VCCN)] by several researchers, [4]- [5]- [6]. The main aim is to overcome the most challenging tasks of mobility management and message storming in VANETs. The Nodes under wired circumstances are physically connected, the status of Node links is extremely stable. Furthermore, Nodes are immovable and the link can not be broken by movement. On the other hand, wireless communication uses radio airwaves, therefore, the status of Nodes is extremely unstable due to the attenuation of the signal, channel error, and channel fading. If CCN is applied to wireless circumstances, chunks of content will be distributed to and stored in several Nodes. In order to access the chunks of the content from distributed nodes, the content requester has to wait for long time due to frequent packet losses in wireless environment which directly affect the PEL. For that an efficient and robust scheme is required that could fetch the un-obtained chunks of the content in wireless environment in order to reduce the un-necessary delay. In this paper, therefore, we propose a robust scheme to reduce the Interest Satisfaction Delay (ISD) and increase the Interest Satisfaction Rate (ISR) by requesting the chunks in an efficient way from the intermediate nodes or the provider nodes in advance. The purpose of this paper is threefold. First, we model the content chunks problem in wireless CCN. In wireless CCN, content might be only partially saved in several chunks on different Nodes if the link is broken. The goal is to minimize the ISD by pre-requesting the unavailable chunks in parallel. Second, the number of hops is minimized between the content requester and provider by bringing content closer to the consumer. If the ISD is lower and the hops are minimum to the provider, then the forwarder Node(s) will purge entries very quickly. Third, we provide an extensive evaluation of our scheme using ndnSIM as comparing with the conventional method used for PEL in CCN and another recently proposed scheme.

The rest of the paper is organized as follows: Background and relevant studies on CCN are introduced in Section 2. The proposed method is explained in Section 3. Section 4 discusses the performance evaluation , and finally, Section 5 concludes the paper.

II. BACKGROUND STUDIES

A. CCN in a nutshell

The Node structure in CCN comprises of a Content Store (CS), PIT and Forward Information Base (FIB). The CS stores the data temporarily in the cache, a PIT keeps the records for unsatisfied upstream Interest packets and FIB directs the Interest packets toward the data providers [7]. When a consumer wants a specific content, it sends an interest packet containing the name of the content and the data packet follows the "breadcrumb". Any node on the path can reply with content if the content is already cached. The relay Node(s) when receive an Interest packet first check its own CS for data availability. If Data is found in CS then it is sent back to the consumer via the interface from the where the Interest was received. If not available, then PIT is checked for existing entry and if entry is found then the PIT is updated with a new incoming interface entry and the Interest is then discarded. In case the entry is not found then a new PIT entry is created, and the Interest Packet is sent further via interface(s) stored in the FIB.

The Data packet is sent on the reverse path of the Interest packet. When a Node receives a Data Packet, the Node checks whether it has received a Data Packet with identical content. If there is identical content, the Data Packet is destroyed. If there is no identical content, the PIT is checked to find a record of the request for the received Data packet. If there is a record of the request, the Data packet is forwarded and stored in its own CS. Subsequently, the record on the PIT is deleted. If there is no record of the request on the PIT, the Data packet is destroyed and considered as unsolicited Data.

B. PIT

The PIT is a data structure which keeps track of the interfaces of unserved requests. An entry in PIT comprises of *content name* , *list of interfaces*, *list of nonces* and *expiration*. The *content name* shows the name of the pending chunk; *list of interfaces* indicates all the interfaces from which the requests for chunks have been received; *list of nonces* refers to the nonces for avoiding loops and *expiration* refers to the expiry time of the PIT entry [16]. The PIT entries are purged either when an entry in the PIT expires or when a Data is received [20].

A Node in CCN performs search for each entry; a Node may recieve millions of entries and then the Node(s) will perform PIT search for each Interest packet. As a result, the large size of PIT will make worse the search delay [20]. Therefore, the selection of PEL plays a vital role in the management of PIT.

C. Wireless CCN

Besides the potential use of CCN in wired domains, CCN is also considered for pure wireless environments such as, ad hoc networks [8]. In CCN-based Mobile Ad hoc Networks (MANETs), the nodes are mobile and does not need any centralized infrastructure for communications.

One of the pure wireless CCN is E-CHANET [9]. E-CHANET deals with Routing, Forwarding, and Reliable Transport Function. In [10], "*listen first, broadcast later*" (LFBL) was proposed for named based data forwarding in which the node defers its tranmission and wait for a short time to access the channnel for potentional forwarder. In [11], the broadcast process is detailed along with the data message in CCN environment. In [12], authors have used the neighbor information details in order to defer the transmission for possible packet losses.The have used the Time to Live (TTL) for broadcasting messages. In [13], a scheme named "*neighborhood aware Interest forwarding*" (NAIF), has been proposed for flooding control in CCN via distance to provider and content retrieval rate. The authors in [14] evaluated two forwarding strategies: the blind-forwarding strategy and the provider-aware forwarding strategy. Authors have used overhearing and data defer mechanisms to limit collision probability.

Since scope of this paper is the efficient management of PIT entry lifetime, we showcase the recent work on management and size of PIT. In [15], bloom filter has been used to reduce the memory space of PIT. In [16], a solution was proposed to minimize the size of PIT. However, none of them focused on the lifetime management of PIT. In order to avoid long delays in the network due to congestion, authors in [17] have proposed a method where NACK packet has been used to inform the downstream Nodes if an Interest is not satisfied. When the downstream Nodes recieves the NACK, they will re-transmit an Interest on another interface if available, if not available then PIT entry is purged. However, in this scheme all the entries in the upstream Nodes will be kept for longer time. It is also an issue that the NACK packet could be dropped due to congestion on the way. In [18], authors have used a scheme to estimate PEL at routers. They have used queue size, processing and propagation delay for the PEL estimation. This mechanisms is not realistic for CCN networks. The reason is that the data is transfered all the way from provider to consumer for every Interest packet. In [19], authors have used data response interval (RI) for the PEL estimation. Initially constant PEL of 1 s is used. After receiving all chunks with RI1 and RTn, the maximum RI is calculated for all chunks within the time window of 60 s. The main goal is to estimate the time for next Interest re-retransmission. However, the entry for the first Interest will be kept for 1s. In [20], authors have proposed the per-fetching algorithm for fetching the popular content. The authors analyzed the importance of nodes and then cache the content on such nodes. However, they didn't mention the wireless scenario where re-transmissions, collisions and link failures occurs frequently. Authors in [21] proposed a scheme that dynamically estimate the PEL based on ISR of each Node. However, no method is provided for the ISR. There is no discussion on how these values are computed on consumer Node and how the ISR is enhnaced. Authors just used the ISR of the Nodes. It is true that higher ISR will result in purging more PIT entries. However, how to increase ISR for purging more PIT entries has not been provided. Moreover, this scheme brings challenges to the conventional CCN architecture. The reason is that no caching policy has been used which implies the transfer of content all the way from content provider towards consumer. Therefore, key benefit of CCN caching is avoided. Therefore, in this kind of scenario, it is very difficult to estimate PEL dynamically.

The conventional CCN uses caching policy on every Node which directly affects the ISR and PEL as well and this can not be a realistic assumption for CCN. Therefore, to address this issue, we propose a method for the PEL management based on chunks pre-fetching. Our work is based on our previous work [22], in which we reduced the content download time to retrieve any required content in terms of Content Download Time, Total Interest Satisfaction Rate and Average Hop Count and in that work our main objective was to reduce the content download time in wireless CCN. We believe that the same scheme can be easily applied to mitigate the PEL expiry problem and to purge the PIT entries quickly. Therefore, we apply our scheme with the objective to decrease the ISD by prefetching content closer to consumer and reduced the number of hops to provider. If the ISD is lower and the hops are minimum to the provider, then the forwarder Node(s) will purge entries more quickly. As a result more Interests will be satisfied that improves the network performance by reducing PEL. Our propose scheme utilizes least recently used (LRU) caching policy at each Node and purging entries in PIT quickly by prefetching the content in advance for the consumer. As a result the content goes in the vicinty of consumer, the ISD goes lower and ISR goes higher.

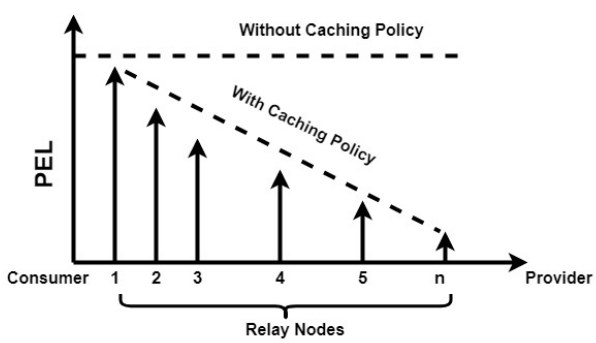

Fig. 1. PEL as a function of the number of nodes between consumer and provider

III. Proposed RAPEL

In order to clarify the features of the proposed method, first we have provided a motivation of this study. After that a robust method is proposed.

A. Motivation

Fig. 1 illustrates a motivation of this paper using an example. The figure shows an example of an NDN implementation ndnSIM that uses PEL= 4 s. It is evident from Fig. 1 that Node closer to the provider Node has very less PEL and vise versa. All the Nodes closer to the provider Node will keep their entries in PIT for a very short time. The reason is the data is retrieved very quickly and each PIT entry is purged upon successful data retrieval. On the other hand, all the unsatisfied Interest packets will be kept in the PIT for the PEL time that is 4 s by default in ndnSIM. Since the Node(s) near to the provider Node does not need to keep PIT entry for a longer time compared to a Node that is near to the consumer Node. Therefore for the unsatisfied Interest(s), the constant value of PEL may result in bloating PIT; as well as not efficient for keeping millions of entries in PIT for the fixed value of PEL [21]. It is very important to mention that the Fig. 1 shows the scenario used in [21], where authors did not used any caching mechanism. Therefore, if chunks are not cached, the major advantage of caching in the CCN architecture are lost. If no caching is implied then every request for the chunk(s) must be forwarded to the provider node and content will be delivered only from provider Node to the consumer. Therefore, utilizing key benefits of caching, it is useless to use fixed value for PEL for all Nodes. For example, if the content is cached near to the consumer Node, then the content will be retrieved earlier and no need to keep entry in PIT for the fixed time. While caching increase the ISR, it reduces the PEL. The higher the ISR is, the lower the ISD will be and the less time PIT will keep entries in the table.

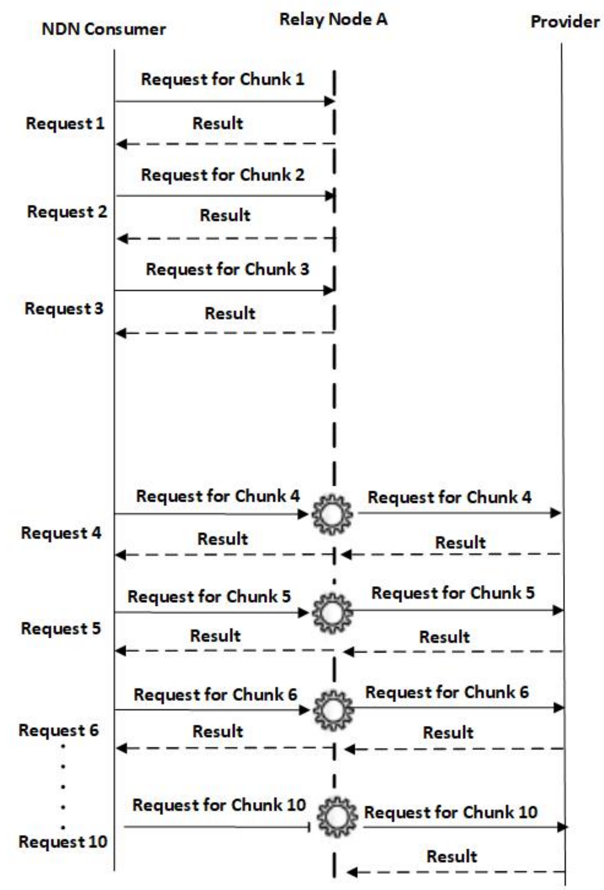

Fig. 2. Problem Scanario

Second, we tried to illustrate our motivation by another example shown in Fig. 2. In wireless CCN, the full content is divided into several number of chunks before transmission. Therefore, chunks of content will be distributed to and stored in several Nodes. Due to network impairment in wireless CCN, packet loss during the transmission of chunks can occur, or the content might be only partially saved in several chunks if the link is broken. Even though consumers usually request retransmission of the unobtained chunks, the intermediate Node can not satisfy this request, and only partial chunks are stored. We explain this issue with an example scenario as shown in Fig. 2. The consumer requests content chunks 1-10. It is evident from Fig. 3, that relay Node A has chunks from 1-5 only. Since relay Node A does not have the chunks from 5-10, the consumer receives the remainder of the requested chunks from other relay Node(s), which might be located farther or it will forward request to the provider Node, causing a delay in the content retrieval. This delay directly affects the ISR. The reason is that if the content is closer to the consumer, the ISD will be lower, and ISR will be higher. The farther the content is, the higher the delay will be and as a result the ISR will be very low. Due to such undesirable delay, the PIT will keep entries for long time which may exhaust PIT. Once the PIT storage becomes full, all the incomimng Interests will be discarded which will affect the overall performance of the network. In this paper, therefore, i we solve this problem by proposing an efficient method to reduce the ISD and increase the ISR by requesting the unobtained chunk from the farther Node before it receives the consumer request. This method is bringing the content closer to consumer Nodes in advance by parallel requesting to the provider Node or the node which cache the data. Hence hop count reduces and Interest packets will be satisfied closer to the consumer. As the ISR goes higher and ISD goes down, the less time PIT will keep entries in PIT.

Following section, details the operation of the proposed method.

B. Proposed Scheme Description

In this method, the intermediate Node generates an Interest packet for the chunks that the intermediate Node does not have and requests them from other Nodes prior to the consumer request. The example scenario is shown in Fig. 3 and can be expressed as follows: the consumer, relay Node A, and the provider are arranged in sequence. Each content consists of ten chunks, and the sequence numbers that are included in the content Name distinguish each chunk. Relay Node A has a total of five chunks with sequence numbers from 1 to 5, and the provider has all chunks with sequence numbers from 1 to 10. When the consumer requests the transmission of the Interest packet from a chunk from sequence number 1, Relay Node A responds to the consumer with the Data packet for the chunks that it has and simultaneously generates a new Interest packet and requests for chunks from sequence number 6 and beyond, which Node A does not have. Then, Relay Node A downloads the unobtained chunks from the provider, and the Data packet for the chunk in sequence number 6 is not transmitted from a more distant Node, but directly from Relay Node A, to satisfy the consumer's request. This operation reduces the ISD for chunks from sequence numbers 6-10.

Three new fields *(Chunk Threshold, Hop Count, and TTL)* are added to the Interest acket and Data packet method and is the operations of these fields is explained as follows. The

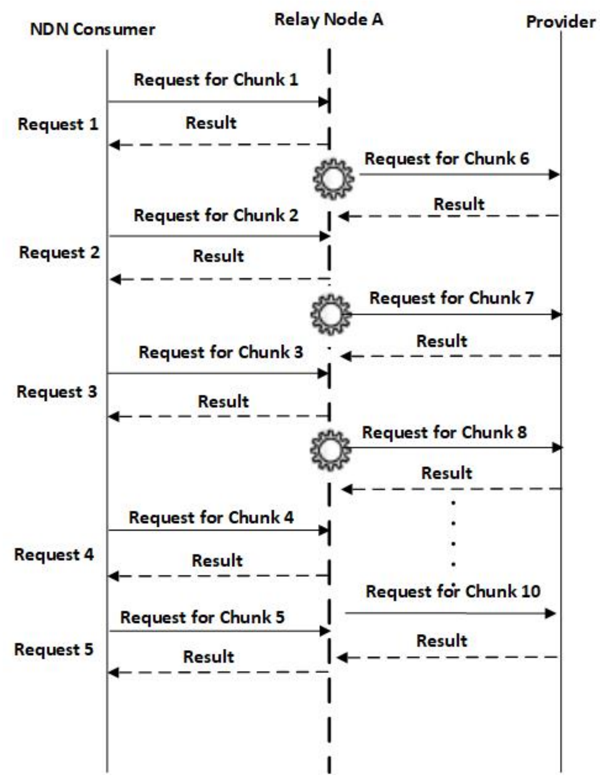

Fig. 3. Proposed Scheme

Chunk Threshold of the Interest packet *(ChunkTHi)* is the condition under which the Interest prefetch from the Node that received the Interest packet is conducted. If the Node has the same or a greater number of chunks of the requested content than the number stated on the *ChunkTHi*, the Node can initiate an Interest prefetch; otherwise, the Interest prefetching is not conducted. The Chunk Threshold of the Data packet *(ChunkTHd)* stores the number of chunks that it has for the content that is requested from the provider. The consumer uses *ChunkTHd* for conducting Interest prefetch by priority in case same provider or other Nodes have a similar number of chunks. The *Hop Count* of the Interest and Data packet increases by one as each Node is passed. The consumer and provider reflect the value of the hop count to the *TTL* of the Interest and Data packet, thereby utilizing it to restrict the transmission range of the packet. The *TTL* decreases by one for each passed Node and the packet is destroyed to restrict the range of transmission when it becomes zero. The packet size is increased because of the additional fields. The size of each additional field is four bytes.

IV. PERFORMANCE EVALUATIONS

A. Simulation Environment

We simulated a static simulation enviroment in which all the Nodes are static including consumer and Producer. The consumer, provider and intermediate Node(s) are placed on a 20×20 grid topology that is made up of 400 Nodes. The interval between Nodes is 75 m and the wireless transmission

TABLE I
SIMULATION PARAMETERS

Parameter	Value
Simulator	NS-3 (ndnSIM)
Benchmark Protocols	Conventional CCN and DPEL [21]
Propagation Delay Model	Constant Speed Propagation
Propagation Loss Model	Log Distance
Channel Error Model	Nist Error Rate
Path Loss Exponent	3
Technology	IEEE802.11a
Area (m × m)	20 × 20
Nodes	400
CWmin	15
CWmax	1023
Cache size of each CR	100 packets
Packet Size	1200 bytes
Data Rate	6 Mbps

radius is 1 hop. To evaluate the performance of the proposed method RAPEL, the conventional CCN, which cache chunks on every intermediate Node(s) between consumer and provider and DPEL [21] were selected as a benchmark work. The results in this paper are based on a modified simulation of a wireless condition using ndnSIM, which was implemented with the network simulator NS-3 for wired CCN [23]. In the simulations, a content is assumed to be split into 100 Data packets, and the payload size of the Data packet is 1200 bytes. The deferred time is set as the multiplied value of a randomly selected window with 9 μs. The contention window is set from 15 to 1023. For the simulation, IEEE 802.11a standard is adopted for physical and data link layers, and data rate is set to 6 Mbps. The Constant-SpeedPropagationDelayModel on the NS-3 simulator was used for the Propagation Delay Model. The LogDistance-PropagationLossModel of the NS-3 simulator was applied as the Propagation Loss Model with setting Path Loss Exponent to 3. As the channel error rate model, the NistErrorRateModel of the NS-3 simulator was applied [24]. Each experiment was conducted 10 times using the seed value, and the results were acquired from the average values of the measurements. The main simulation parameters are summarized in Table 1.

B. Simulation results and analysis

We have used ISD as an evaluation metric which is measured as the difference of simulated time when the Interest is sent and the chunk is recieved at the consumer Node.

Fig. 4 shows the ISD of intermediate Nodes with partial chunks in the conventional CCN, DPEL and and in the RAPEL. In this experiment, the number of chunks on the intermediate Node was set as 50. It is evident form Fig. 5 that in the conventional CCN, the ISD increases as the distance of the intermediate Node becomes farther from the consumer. This is because of the distance of the Data packet from the intermediate Node, which is farther from the consumer. In the proposed method RAPEL, the ISD was greatest when the distance between the consumer and intermediate Node was the farthest. In this case, the distance between the consumer and intermediate Node caused the delay. The ISD for the

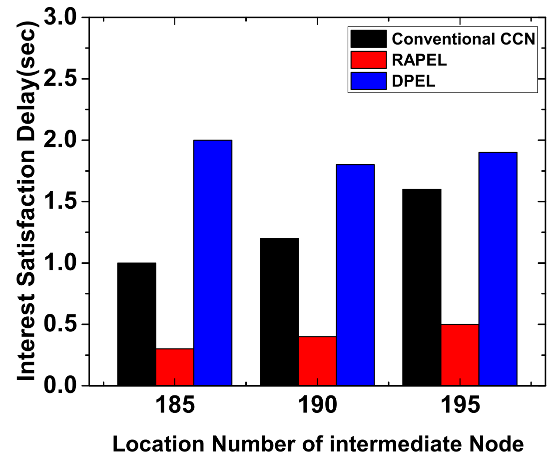

Fig. 4. Interest Satisfaction Delay as a function of intermediate Node positions

conventional CCN, DPEL and the proposed method RAPEL differ according to the position of the intermediate Node. However, the Interest pre-fetch method reduces the ISD of the chunks that were far away from the consumer and the proposed method RAPEL outperforms than the conventional CCN and DPEL in all positions.

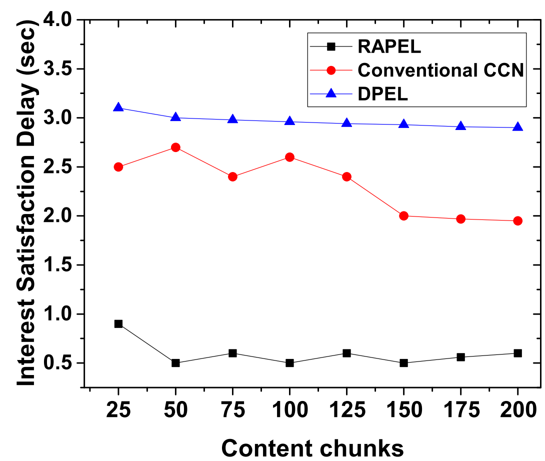

Fig. 5. Interest Satisfaction Delay as a function of Content chunks

Fig. 5 shows the average ISD of intermediate Nodes in the network as a function of content chunks. The initial delay incurred is due to the Interest forwarding from consumer to provider Node for the first time. It is evident from Fig. 6 that the proposed RAPEL shows lower ISD than conventional CCN and DPEL. The reason is that every Node downloads the chunks in advance. As a result Interest is not forwarded further and satisfied by closer Node(s) which results in lower ISD. On the other hand, Conventional CCN caches the content on Node(s). However, prefecthing operation is not triggered. As a result, it performs lower than the proposed RAPEL. DPEL shows the worst scanario in Fig. 6. The reason is no cache mechansim implied and all the time request is forwarded to provider for the content retrieval that increase the overall ISD in the network.

In summary, it is observed that using prefetching operation on intermediate Node(s) resulting in the best performance. We believe that the lower ISD is, the higher ISR will be and more Interests will be satisfied in the network. Moreover, the closer the content is, the lower the delay will be. Since PIT is purged either due to timeout or successful content retrieval. Therefore, PIT will accommodate more entries by fast content retrival with higher ISR and lower ISD.

V. Conclusion

In this study, we have proposed an efficient method named RAPEL for the efficient management of PIT. Proposed RAPEL reduces the ISD by pre-fetching the content in advance. In wireless CCN, content might be only partially saved in several chunks on different Node(s) if the link is broken. Therefore, RAPEL is proposed to minimize the ISD. The number of hops are minimized between the content requester and provider by bringing content closer to the consumer. If the ISD is lower and the hops are minimum to the provider, then the forwarder Node(s) will purge entries very quickly. As a result more Interests will be satisfied that improves the network performance by reducing PEL. Simulation results show that our proposed scheme RAPEL may contribute significantly in the PIT management of highly mobile wirelss networks. As a future work, our plan is to investigate the performance of our scheme in a highly mobile network such as Content Centric Vehicular Ad Hoc Networks with more simulation results and possible enhancements to the proposed scheme in terms of analytical modeling and algorithms.

Acknowledgment

This research was supported in part by the International Research & Development Program of the National Research Foundation of Korea (NRF) funded by the Ministry of Science and ICT. (No. NRF-2018K1A3A1A39086819), in part by the National Research Foundation of Korea(NRF) grant funded by the Korea government. (No. 2018R1A2B6002399), and in part by National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (No. 2017R1A2B4001801).

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