# DPEL: Dynamic PIT Entry Lifetime in Vehicular Named Data Networks

Safdar Hussain Bouk, Syed Hassan Ahmed, Muhammad Azfar Yaqub, Dongkyun Kim, and Mario Gerla

***Abstract*—Vehicular named data network (VNDN) has emerged as a promising network technology, where the focus of communication is moved from host-centric to information-centric. Since, the VNDN is at its early stage in development, there are several open issues to be explored and pending interest table (PIT) management is one of them. In VNDN, PIT stores each broadcasted interest until the required content is retrieved or its timer (PEL: PIT entry lifetime) expires. When the PIT storage is full, the vehicles discard new incoming interests, thus decreasing the network performance. Therefore, in this letter, we propose a dynamic PEL (DPEL) scheme that enables each relaying vehicle to dynamically compute PEL timer for each incoming interest using its interest satisfaction rate (ISR) and the hop count. The higher the ISR and the longer the hop count, the shorter the time the relaying vehicle keeps the PIT entry. Simulation results show DPEL reduces by more than 75% the PEL and the number of entries in VNDN.**

***Index Terms*—VANETs, NDN, PIT entry lifetime.**

## I. INTRODUCTION

NAMED Data Network (NDN) has been recently proposed as a promising architecture for the future internet technologies and is an extension of the well known Content Centric Network (CCN) project. The main objective of the NDN is to redesign the current Internet architecture and enable a system to follow the *"named data"* instead of a set of *"named devices"*. It's a common prediction that in the near future, we will have billions of wireless devices. The mobility support provided to those devices with content distribution and retrieval capabilities have also accelerated the challenges for the current host-to-host communications [1].

Similarly, Vehicular Ad hoc Networks (VANETs) have been providing various applications including safety and non-safety ones. Currently, VANETs are operating under the Dedicated Short Range Communication (DSRC) protocol along with Wireless Access in Vehicular Environments (WAVE) such as IEEE 802.11p. Since, non-safety applications involve a lot of content distribution in VANETs with intermittent links, the traditional IP-based communications in VANETs are expected to face a similar set of technical issues like the remaining 802.11 family does [2]. Hence, the efforts have been driven in the research lane to emerge NDN communication architecture into VANETs [3] and we collectively call this a VNDN architecture. Similar to NDN, VNDN also alters the conventional host-based communication system into the named data oriented communication.

In VNDN, each vehicle maintains three data structures, namely a *Pending Interest Table* (PIT), *Forwarding Interface Base* (FIB), and *Content Store* (CS). Communication in VNDN involves two message types; *Interest* and *Data*. The senders of *Interest* and *Data* messages are called *consumer* and *provider* nodes/vehicles, respectively. Consumer sends *Interest* $I$ if it requires *Content* $C$ and wait for the *Data* message, which contains $C$ either as a whole or chunk ($C_i$) of $C$. Similarly, a PIT is a data structure that records *pending* as well as the *satisfied Interests*. It stores *Interest* `Name`, `NONCE`, and the `Interface/Face` from where the *Interest* was received. This information is used to forward `Data` packets downstream towards the consumer. Similarly, the FIB data structure maintains the `Name` prefixes and their respective outgoing `Face` information, which helps to forward *Interests* in the upstream direction to the potential providers.

For better understanding of the working principle of VNDN, we present an example of NDN enable vehicular ad hoc networks. Here, a vehicle $V_c$ sends *Interest*[1] $I$ when it requires any content. Since VNDN supports multiple *faces*, therefore, initially the $V_c$ forwards $I$ through all the faces. When any vehicle $V_i$ receives $I$, it first searches information from $I$ in the PIT. If the requested content `Name` is not pending, then it searches the content in CS[2]. The $C$ is sent in Data packet(s) in case the content is found in CS or available at Provider node, $V_p$, and $V_p$ does not forward the $I$ further. If both searches fail, a new PIT entry is created and $I$ is sent upstream based on the FIB search. After forwarding $I$ towards upstream, the PIT entry is kept for a specific time period to wait for the *Data* in response. This timer for a new PIT entry is initialized and set according to the `InterestLifeTime` field in $I$, called PIT Entry Lifetime (PEL), $\tau$. The default value of `InterestLifeTime` in basic NDN is $\tau = 4s$ [4], which is considered sufficient duration for a vehicle to hold an entry in its PIT to receive *Data*/*Content*, $C$. The PIT entry is purged when; the `InterestLifeTime` timer expires or the node receives the required content $C$ in response to the interest packet $I$. In a highly dynamic and ad hoc environments, i.e. VANETs, the prolonged $\tau$ and a large number of incoming interests can exhaust the PIT that may affect the overall Interest satisfaction rate (ISR).

In addition, the packet drop in broadcast nature wireless mode is very common and this may lead to a maximum number

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[1] *Interest* contains content *Name*, *Selector(s)*, and unique *NONCE* value.

[2] In previous implementation of NDN, called Content Centric Networking (CCN), CS search precedes the PIT search.

of entries in the PIT. Consequently, it may cause bottleneck by exhausting memory space as well as the $I$ search and propagation delay. The size of a PIT is directly proportional to PEL and to avoid the bottleneck resulted by PIT size, the PEL should be reduced. On the other hand, the Interest satisfaction delay is *unknown*, therefore, the PEL can not be fixed.

In literature, there is only one solution [5] that adjusts the PEL of the *Interest*(s) generated for $C$, $\tau_c$, based on the Interest-Data response interval, $RI$. If $C$ is sent to $V_c$ in chunks, then the PEL for $C$ is the maximum of $RI$ of all chunks of $C$, $RI(C_i)$, received within the time window of $60s$.

$$\tau_c = max[RI(C_i)] \quad i > 1 \tag{1}$$

The $\tau_c$ is hold for $\rho = 60s$ and after that a new $\tau_c$ is computed as:

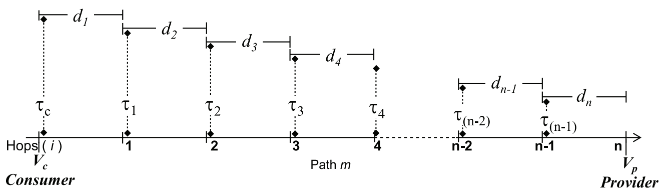
$$\tau_c = \left(\frac{RI_{max} - RI_{min}}{2}\right) + RI_{max} \tag{2}$$

However, PEL of an initial *Interest* is set to $\tau_c = 1s$ and if the *Interest* is not satisfied at any node, the entry will be stored in the PIT till $\tau_c$ expires. Hence, the proposed scheme in [4] brings following challenges with the NDN implementation for vehicular networks:

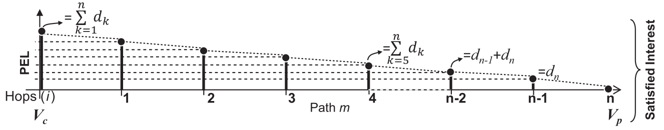
- The $\tau_c$ of the satisfied content $C$ is held for a duration of $\rho = 60s$ and used to compute PEL if $C$ is requested again by another $V_c$. It may be computationally as well as memory space inefficient, to store millions or may be billions of entries just only to set PEL of a content that has been requested before.
- Along with that, the response delay can not be similar within $\rho$ due to several reasons such as consumer and provider mobility, unstable multi-hop path, etc. Therefore, it is impractical to make $\tau_c$ dependent on $RI$ along with longer $\rho$, which is the most variable parameter in a highly dynamic environments, i.e. VNDN.
- In case of unavailable content, e.g. provider is out of coverage in case of ad hoc environment, $\tau_c$ of $I$ in the whole network is set to constant, $\tau_c = 1s$. The constant PEL for unsatisfied time is a constraint, because a node near the provider does not need to keep PIT entry for a longer time compared to a node that is near to the consumer node.

To mitigate the above-listed shortcomings, we therefore, propose a Dynamic PIT Entry Lifetime (DPEL) scheme in this letter, that:

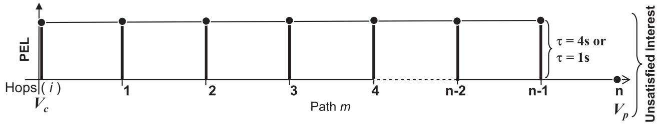
1) dynamically adjusts the PEL of $I$ as it is forwarded upstream towards the $V_p$ using hop count as a one of the PEL decay factors, because the *RI* of Data is smaller and larger at the $I$ forwarding nodes that are near the $V_p$ and the $V_c$, respectively. Therefore, PEL is not constant for any Interest in the PIT at any node in the network.
2) It is also common that the nodes with large *ISR* have very short PEL. Hence, we consider *ISR* as one of the PEL decay factors. In result, the larger the *ISR*, the shorter the PEL at the node.
3) No extra information other than the *ISR* is stored at every Interest forwarding node to compute PEL.
4) Can be applied in any name forwarding daemon (NFD) without making any major modifications in it.



(a) PIT Entry Lifetime.



(b) PEL of Satisfied Interest.



(c) PEL of Unsatisfied Interest.

Fig. 1. PEL of a satisfied and unsatisfied Interest.

The rest of the letter is organized as follows: Section II and III briefly discuss the proposed DPEL and simulation results, respectively. The letter is concluded in Section IV.

## II. DPEL: DYNAMIC PIT ENTRY LIFETIME IN VNDN

In distributed and ad hoc wireless networks, e.g. VANETs, the $RI$ of *Interest–data* is dynamic due to node mobility, intermittent links, unpredictable link load, etc. Assume that the propagation delay, $d_i$, of each link $i$ is equal. Then for the dropped Data message, the PEL at each hop on an active path of $I$ is kept for a constant period i.e., NDN implementation ndnSIM uses ($\tau_c = 4s$), and authors in [5] use $\tau_c = 1s$, refer Fig. 1. On the other hand, the PEL of a satisfied $I$ at every hop $i$ in an active path is the *RI* of *Interest–data* message. The precise PEL of a satisfied $I$ at $V_c$ ($\tau_c$) with the $V_p$ at $n$ hops away, is presented as:

$$\tau_c = \sum_{k=1}^{n} d_k \tag{3}$$

Similarly, on a single path, the PEL of $I$ forwarded by the intermediate node at hop $i$ between $V_c$ and $V_p$ at $j$-hops away from $V_p$, is computed as:

$$\tau_{c_i} = \sum_{k=j+1}^{n} d_k \tag{4}$$

It is obvious that on a single path $\tau_{c_i} > \tau_{c_{(i+1)}}$. On the other hand, the PEL of unsatisfied $I$ in previous implementations constant, $\tau_c = 4s$ in ndnSIM and $\tau_c = 1s$ in [5], as mentioned before. The main objective of the constant $\tau_c$ is that the position of the $V_p$ is unknown to the $V_c$. Therefore, each Interest forwarding node $V_i$ including $V_c$ have no precise time duration information to hold a PIT entry of that Interest. Along with that, the packet drop in the dynamic topology network i.e., VANETs, is quite common. Therefore, for the fixed PEL of the $I$ in the PIT results in large PIT size.

In our proposed DPEL, the PEL of an $I$ is dynamically adjusted in the PIT of each intermediate node that forwards $I$. The Interest's PEL at successive forwarder is computed using Interest's hop-count, $i$, $(\tau_0)$, and forwarder node's own $ISR$ information.

It is evident from the results that any forwarding node with higher $ISR$ has a very small average PEL because it frequently purges PIT entries after receiving the requested data messages. In result, a forwarding node with high ISR does not need to store PIT entry for a longer time. Similarly, the PEL of an $I$ at each forwarder node in the upstream direction is reduced to avoid Interest aggregation in its PIT. To support this claim, we propose the following PEL mechanism:

The decay rate of PEL of an $I$ generated for $C$, $\tau_c$, at hop $i$ is computed as:

$$\frac{d\tau_c}{di} = -\tau_c \cdot \lambda \cdot (1 + ISR), \tag{5}$$

where $\lambda$ is the decay constant, $\tau_c$ is the PEL at $V_c$ and $ISR$ is the interest satisfaction rate of the Interest forwarding node at hop $i$. The hop number, $i$, is incremented and updated by every upstream Interest forwarding node.

By solving the eq. (5), we get:

$$\tau_c(i) = \tau_{c_i} = \tau_0 \cdot e^{-\lambda \cdot i \cdot (1+ISR)}, \tag{6}$$

where $\tau_0$ is the initial decay value assigned by the $V_c$. At the network setup time, the $ISR$ of all the vehicles is set to 0. In this case, the proposed model also ensures the exponential decay in PEL $\lambda$ at hop $i$, as:

$$\tau_{c_i} = \tau_0 \cdot e^{-\lambda \cdot i}. \tag{7}$$

The $\tau_0$ and $\lambda$ are initialized by the $V_c$ and PEL depends on these values along with the Interest forwarding node's $ISR$ and hop-count $i$ of the Interest message. Hence, DPEL quickly discards the pending interests received from the consumer at a significant distance to alleviate the PIT size without compromising ISR. Through extensive simulations, we analyze our DPEL scheme in VNDN scenario.

## III. SIMULATION RESULTS AND DISCUSSION

In this section, we briefly discuss the simulation results of DPEL and it's comparative analysis with the recently proposed scheme in [5]. We considered it as a baseline for our evaluation and named it as a "Conventional Scheme". The simulations are performed in Network Simulator NS2.35. The NDN comprising PIT, FIB, and CS structures along with the Interest and Data packets are implemented over the IEEE 802.11p. The simulated vehicular network consists of 50 to 120 vehicles, $N$, that are equipped with the NDN elements. Likewise, real-time traffic, each vehicle randomly selects the speed between the range of 55 and 85 km/h using the highway mobility model [6]. Initially, $1 \times 10^8$ contents $(n)$ with equal probability distribution $P_i = 1/n$, are uniquely distributed in the CS of each vehicle in such a way that no two vehicles have a copy of the same content. The number of Interests $I$ generated per vehicle per second range from 1 to 7. Varying initial PEL $\tau_0$ between 0.1 to 0.5 and decay rate $\lambda$ from 0.01 to 0.05 are considered in the simulations. The Interests were generated with no acknowledgment or negative acknowledgment and no retries mechanism.

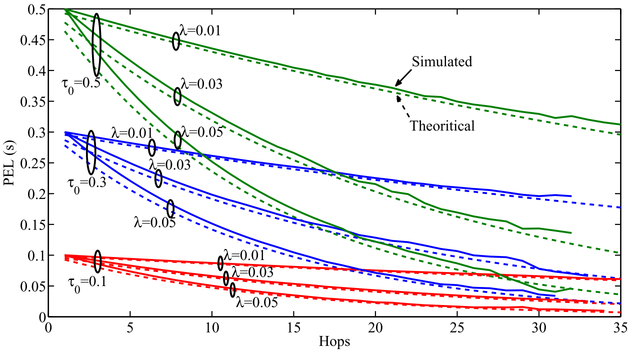


Fig. 2. Theoretical and Simulated PEL for different Initial PEL $\tau_0$ and decay constants $\lambda$.

The $C$ in response to $I$ propagates from $V_p$ to $V_c$ through different intermediate nodes $V_i$ and based on the caching policy the $C$ may be stored by $V_i$ [4]. However, in this letter we use *no caching* policy, where the requested $C$ is only stored at $V_c$, if it successfully receives $C$. The simulations are run for 500$s$ and the results are averaged from 20 independent simulations. Performance of the proposed DPEL is compared with the very recently proposed PEL management scheme in [5] using the following metrics.

- PIT Entry Lifetime (PEL): Time period (in seconds) an unsatisfied Interest's entry remains in the PIT.
- Average No. of PIT Entries/Vehicle: Average of maximum number of PIT entries found in the PIT of a vehicle within a period of 0.2$s$.
- Interest Satisfaction Rate (ISR): The percentage of satisfied Interests per vehicle in the network.

Figure 2 shows the theoretical and simulated PEL of an $I$, when its PIT entry was created while relayed upstream towards $V_p$. The $ISR$ of 50% is used for theoretical PEL computation. The PEL has been simulated for different $\tau_0$ and $\lambda$. The PEL in the conventional scheme is constant for the unsatisfied initial Interest propagated in the network for any content $C$, that is 1$s$. On the other hand, the PEL in our proposed scheme depends on the $\tau_0$ and $\lambda$. It is evident from the graph that the larger the $\tau_0$ and $\lambda$, the larger the PEL near $V_c$ and the shorter the PEL to upstream, respectively. Consequently, the short PEL results in a smaller number of entries in the PIT. The average PEL of our scheme is 76%, 55%, and 40% less than the conventional scheme for $\tau_c = 0.1$, 0.3, and 0.5, respectively. Thus, it will put a marginal impact of the same magnitude on the average number of PIT entries that is discussed next.

Secondly, we analyze the average number of maximum PIT entries per vehicle in the network. It is obvious that if $M$ Interests are broadcasted in the network and the content of interest $C$ is not available in the network, then at most $M$ entries could be in the PIT of each vehicle before $\tau_c$ expires. Therefore, the average number of Interests and $\tau_c$ have huge impact on the average number of PIT entries in a vehicle. Figure 3 and 4 show

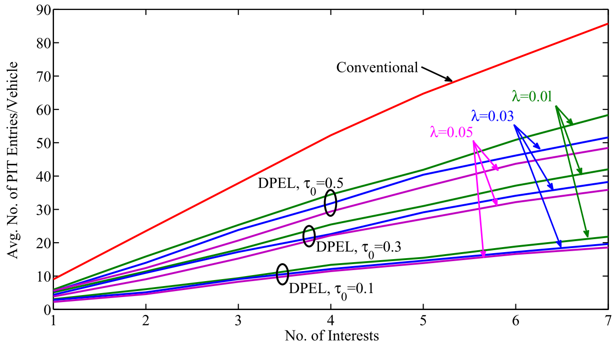


Fig. 3. Average No. of Max. PIT Entries in a network of 90 vehicles for varying Interests/vehicle · second.

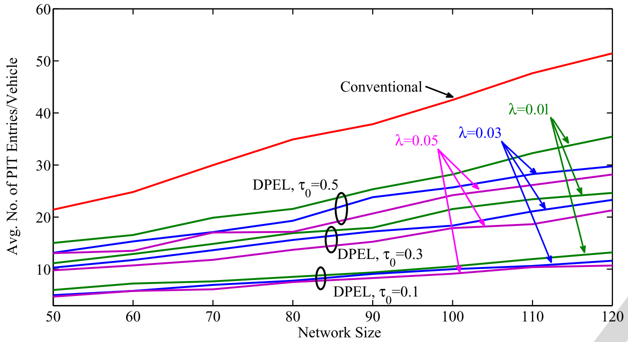


Fig. 4. Average No. of Max. PIT Entries for the varying network size with 3 Interests/vehicle · second.

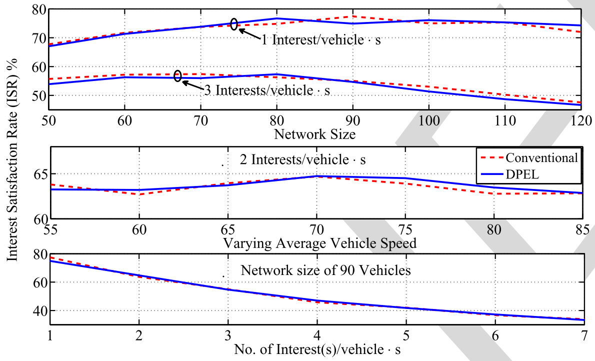


Fig. 5. Interest Satisfaction Rate.

the average number of PIT entries per vehicle for varying number of Interests per vehicle per second and for network size, respectively. It is obvious from the graphs that there are fewer PIT entries at every vehicle for smaller $\tau_0$ and larger $\delta$ because DPEL quickly purges the entries owing to short $\tau_c$. However, in the conventional scheme, the entries are kept for a constant time, thus, showing the lower performance. Furthermore, we also analyzed that the vehicle speed has no significant effect on the PIT size. On the whole, DPEL reduces 76.51%, 54.97%, and 39.26% PIT entries for $\tau_c = 0.1$, 0.3, and 0.5, respectively, that is analogous to the PEL alleviation achieved in Fig. 2.

The ISR of DPEL and the conventional scheme for different network sizes, vehicle speeds and a number of interests is shown in Fig. 5. In DPEL, we focused on the PIT entry lifetime only in the NFD of NDN, therefore, the ISR of both conventional and the proposed DPEL is identical as shown in the figure.

## IV. CONCLUSION

In this letter, we proposed DPEL scheme for vehicular NDN that dynamically computes the PIT Entry Lifetime (PEL) of an Interest received by a vehicle from downstream nodes based on the number of hops it traveled and the ISR of the vehicle itself. Hence, the lifetime of PIT entries in the network gradually decreases as Interest is forwarded upstream. This resembles the natural phenomenon of the *Interest–Data* response interval (RI) in the network. Additionally, we introduced initial PEL and decay constants that are set by the consumer vehicle to compute PEL. Simulation results show that our DPEL mitigates approximately 40%, 55%, and 77% of PEL and number of PIT entries for $\tau_c = 0.5$, 0.3, and 0.1, respectively. Thus, DPEL ensures the minimum number of PIT entries and will contribute significantly in the development of new searching algorithms for PIT entries in VNDN.

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