CONET: COntrolled Data Packets Propagation in Vehicular Named Data NETworks

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***Abstract*—Named Data Networking (NDN) has been recently added to the future Internet family. NDN is basically an extension to the Content Centric Network (CCN) and is expected to support various applications. Those applications are to be supported by the future internet architectures. NDN believes in naming the content rather than using end-to-end device names. Recently, NDN has been adapted into Vehicular Ad hoc Networks (VANETs) and hence, we name it Vehicular NDN (VNDN). At it's early stage, VNDN faces several challenges such as consumer/provider mobility, Interest/Data forwarding, content caching and so on. Mostly, VNDN relies on the fact that Data is sent back to the consumer via same path the Interest packet was received from. However, we analyzed that it's not true in a VANET and there is lack of discussion about managing the Data flow back to the consumers in the current literature of VNDN. In this paper, we therefore, pursue to control the data flooding/broadcast storm of the conventional VNDN by proposing our scheme "CONET". The main idea of CONET is to allow the consumer vehicle to start hop counter in the Interest message and upon receiving that interest by any potential provider, to include Time To Live (TTL) value with data messages. The TTL value includes the number of hops, Data packets should travel on its way back to the consumer. Simulation results show that CONET forwards less Copies of Data Messages Processed (CDMP) while achieving similar Interest Satisfaction Rate (ISR) as the basic VNDN. In addition, CONET also minimizes the overall Interest Satisfaction Delay (ISD), respectively.**

***Keywords*—Named Data Networks (NDN), Vehicular NDN, Data Forwarding.**

I. Introduction

Vehicular Ad hoc Networks (VANETs) have been proven reliable and supportive for several classes of applications. The main reason of expanding Mobile Ad hoc Networks (MANETs) into VANETs was to minimize the risk while driving a car on the road [1]. Hence, we argue that enabling vehicles to communicate with each other is not a new concept. The VANET applications are mostly categorized into two basic classes, i.e. safety and non-safety applications. For the former class of applications, a Dedicated Short Range Communications (DSRC) protocol for VANETs along with the Wireless Access in Vehicular Environments (WAVE) has been proposed [2]. DSRC basically supports *Data* exchange without the TCP/IP overhead caused by the conventional IEEE 802.11 family. On the other hand, in case of infotainment systems (i.e. non-safety applications), numerous TCP/IP protocols have been proposed to run on top of the DSRC / WAVE in VANETs. However, running IP over IEEE 802.11p brings several technical issues. To solve this, there is a rich literature and research in the context of ad hoc networking over IP and a number of routing protocols have been proposed, however, a fundamental limitation in their deployment is the infrastructure support requirement for the purpose of global IP address allocations. Due to the dependency on the IP addresses, today's Internet communications faces several challenges including extensive packet lost, especially in the case of highly mobile devices such as vehicles [3]. Moreover, the dynamic vehicular environment also demands that routes to be recalculated and sessions to be re-established at a higher frequency due to the intermittent connectivity, which are also deemed infeasible.

Named Data Networking (NDN) has been introduced as a promising architecture for the future Internet to communicate *Data*/contents in the future Internet [4]. The beauty of NDN is to address the content rather than a device. More precisely, NDN enables nodes to name the required *Data* (i.e. Content) instead of naming the end-to-end host/destinations. For making communication information centric, in basic NDN, each node maintains three data structures named as Content Store (CS), Pending Interest Table (PIT), and Forwarding Interface Base (FIB) [5]. The functionalities of these structures/tables are as follows: (i) CS stores the contents generated by a node itself or cached during the *Data* retrieval process for some other node, (ii) PIT records the outgoing *Interest* packet(s) information for the required content such as ***"name"***, and (iii) FIB stores name prefixes and the interface(s) information that is/are used to forward ***"Interest"*** packet(s) to upstream.

Recently, the NDN has been adapted in VANETs (VNDN) by several researchers [6], thus driving the communication paradigm from host-based into the information centric for vehicular communications [7][8]. In traditional VANETs, it is mandatory that a node (i.e. Vehicle) in the network must be assigned its unique ID (e.g. IP address). The source vehicle uses this/these unique IDs to locate destination vehicle(s) to communicate information. Similarly, both the source and destination vehicles must establish and secure the communication channel before routing any sensitive information between each other. One of the most challenging tasks that traditional VANETs have been facing is the mobility management of hosts. In presence of mobility (e.g. Change in a source or destination host's topological and/physical location), it is difficult to retain the same host IDs as well as to maintain the ongoing communication path(s). However, the reality is that more than 90% of the communication is made for the sake of any "content" retrieval without taking the host identity and information into account, therefore, enriching VANETs with NDN approach can be a candidate solution to simplify and increase the network performance [9]. In any named-data network, each content unit is self-identifying and self-authenticating and can be retrieved by its name regardless of its location (i.e. Host Address).

In VNDN, content retrieval is achieved in a *pull*-based fashion where a consumer node[1] broadcasts an *Interest* message and all the intermediate nodes match the name within that *Interest* message in their CS and if found, *Data* is sent back to the consumer. Otherwise, the intermediate node performs search in its PIT and if same *Interest* has been recently forwarded, then it discards the packet and update the FIB value relevant to the desired content. Later on, when the *Data* is received by this intermediate node, it sends back a copy of the *Data* to the consumer node[2]. The *Data* message consists of a content name that was requested in *Interest* message, the content itself that best matches with the content name, meta-data, and other security related information [10] [11].

This simple working principle of VNDN brings several challenges such as the *Interest*/*Data* flooding issue, the consumers' and providers' mobility, and so on [12]. There are some recent works on mitigating the *Interest* flooding [13] and also the issue of consumer mobility has been resolved by rebroadcasting the *Interest* packet(s). However, due to the broadcast nature of the wireless medium, *Interest* packets are received by multiple nodes in the neighborhood of the potential provider [14]. As a result, broadcasting the *Data* back to the consumer causes *Data* broadcast storm/flooding in VNDN and it is still an open issue. Since Data packets carry the actual content, they are generally much larger than Interests and more likely to cause congestion. Similarly, the immediate neighbor(s) of a provider, after receiving the *Data* packet, attempt(s) to send the *Data* back to the consumer and thus waste the bandwidth, cause congestion, and additional *Data* copies are traversed. Therefore, in this paper, we proposed a controlled *Data* packets propagation algorithm named as *CONET* for VNDN to cope the given issue.

In CONET, each node while broadcasting an *Interest* packet, includes hop counter (h). After receiving the *Interest* packet, if the intermediate node is not a provider, it increments h, creates PIT entry along with h and then forwards the *Interest* packet. Once, the *Interest* packet reaches to its provider, the provider increments h one last time and includes the latest value into the ***"Time To Live"*** (TTL) field in *Data* packets. The purpose of including TTL in *Data* packet(s) is to ensure that the packet does not go further than the actual consumer and also using TTL, we limit the additional copies of the *Data*/content.

The rest of the paper is structured as follows: A basic working principle of VNDN is described in Section II. Section III provides the details of our proposed CONET algorithm. The performance evaluation and results are summarized in Section IV. Finally, we conclude our paper in Section V.

[1]The terms *node(s)* and *vehicle(s)* are interchangeably used.

[2]Generally, the hop distance between consumer and producer tends to remains the same while the intermediate nodes (ie, the paths) change.

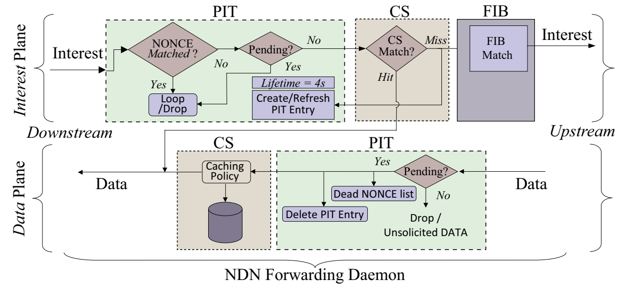


Fig. 1: *Interest*/Data Processing in Vehicular NDN

II. Named Data Networking in VANETs

In this section, we define the NDN enabled VANETs and basic working principle of VNDN. NDN is one of the Information Centric Networking (ICN) architectures for the Future Internet that is funded by the National Science Foundation (NSF). The other ICN architectures include: Network of Information (NetInf) EU funded project named 4WARD/SAIL, Publish Subscribe Internet Routing Paradigm (PSIRP) / PURSUIT project, Data Oriented Network Architecture (DONA) by UC Berkeley, Content Centric Networking by PARC, Content Mediation Networks (COMET), etc [15].

Recently, NDN has been emerged into vehicular communications, however, the basic operations of NDN are quite identical in VNDN. The detailed *Interest-Data* packets forwarding process of VNDN is illustrated in Fig. 1 and briefly discussed below.

When an NDN enabled vehicle requires any content, it sends *Interest* message with content name, *selector(s)*, $4-bytes$ *NONCE* value, and *InterestLifetime*, that is not used and set as $4s$. Any neighboring node(s) that receive(s) an *Interest*, perform(s) the following operations:

- The receiving node(s)/vehicle(s) follow(s) several PIT operations first. However, in pure ICN as well as in most of the literature, the CS look-up is the very first operation after arrival of an *Interest* message. The logic behind this in [16] is to minimize the CS look-up delay, because PIT is considered to be significantly smaller than the CS. It is also stated by few researchers that the *"*`ContentStore` *look-up can be skipped in certain cases"* to improve the overall network performance.
- Now, the node matches the *Interest* message in the already satisfied or discarded Interest list, called *NONCE list* due to expiration of `InterestLifeTime` timer, (e.g., `DeadNonceList`). This mechanism is applied to avoid the *Interest* looping due to the variable *Interest* delay(s) resulted by congestion or multi-path propagation. In case of no entry in the *NONCE* list, the *Interest* is considered to be legitimate and forwarded to the next step.
- Afterwards, the *Interest* is checked in the Pending list in the PIT. If the *Interest* is in the Pending list, the *Interest* is discarded. Otherwise, the content is searched in the CS using name and selectors.

- In case of no content found in the CS (*CS Miss*), the PIT entry is created for the received *Interest* along with the incoming interface `InFace`. Here it is declared that the receiving node is not a potential provider for the requested content. Therefore, the *Interest* is forwarded towards upstream based on the longest prefix match in the FIB[3]. Subject to availability of the matched content in CS, the content is forwarded towards downstream over the `InFace`. For simplicity, we provide the stepwise details in Algorithm 1.

Algorithm 1 Received `Interest` in Basic VNDN

```
Received [Name, Selector(s), NONCE]
if Content Not in CS then
  if Name Not in PIT then
    Add [Name, NONCE, Face] in PIT.
    Initialize Timer(s).
    Forward Interest using FIB.
  else
    Drop Interest.
  end if
else
  DATA[Name, MetaInfo, Content,...]
  Send DATA.
end if
```

- Similarly, when any node receives a *Data* message, it is expected that an NDN enabled node first searches entries in it's Pending list. Depending upon one or more entries found in the PIT, the *Data* message is forwarded to the `InFace(s)` available in the PIT. However, before forwarding the *Data* message, the content may be stored in the CS based on the caching policy. Along with that, the name and `NONCE` value is stored in the `DeadNonceList` and entr(y/ies) is/are deleted from the PIT. Algorithm 2 shows the operations performed on receiving *Data* message by any node in the basic VNDN model.

Algorithm 2 Received `DATA` in Basic VNDN

```
Received [Name, MetaInfo, Content,...]
if Name in PIT then
  if Face is Application then
    Node Received DATA.
  else
    Forward DATA to Face.
    Remove [Name, NONCE, Face] from PIT.
  end if
else
  Drop DATA.
end if
```

III. CONET: Controlled Data Propagation in VNDN

In previous section, we discussed in detail the working principle of the basic VNDN. In this section, we discuss the proposed *Data* and *Interest* forwarding mechanism in CONET. Due to the wireless medium, *Interest* and *Data* broadcast storm occurs during the communications. In order to mitigate *Interest* broadcast storm, recently we proposed "RUFS" [17], where only single node is selected as potential *Interest* forwarder among immediate neighbors of a requesting vehicle. However, from recent literature [18], we found that there is no mechanism to control the *Data* flooding issue in VNDN. Therefore, we proposed CONET as a new forwarding algorithm for efficient *Data* retrieval in VNDN.

[3] FIB stores the name prefixes and the corresponding face(s) to forward the *Interests* to upstream.

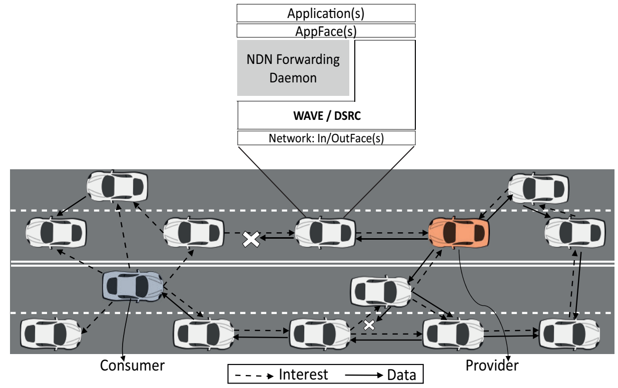


Fig. 2: Vehicular Named Data Networks

A. CONET: Description

In basic VNDN, the *Interest* packet is sent having various information fields such as Name, Selector(s), interface information, and `NONCE` value. Our CONET enables, every VNDN node to include additional hop-count field h, in order to keep the record of hop(s) traversed by an *Interest* packet. The value in h shows the number of hops (distance) the *Interest* packet has reached. For example, a requesting vehicle C broadcasts an *Interest* packet with 0 value in h. Furthermore, every receiving vehicle will increment the h and performs the operations as described in Section II. In addition to that, if the requested content/*Data* is not found in the CS, the intermediate node increments the h and forwards the *Interest* (refer the scenario in Fig. 2). Algorithm 3 shows the CONET operations for the *Interest* receiving vehicles.

Contrary to the basic VNDN, in CONET if a potential provider receives the *Interest* packet, it sends *Data* back to the consumer after moving the h value into the TTL field of `DATA` message. TTL plays a vital role in limiting the additional and wrong way *Data* dissemination within the network. Moreover, when an intermediate node receives the *Data* packets, it performs the steps depicted in the Algorithm 4. When *Data* packet arrives to a node that has the corresponding PIT entry, a node first checks that either h in PIT or it is less than or equal to TTL. If it is true, then the node forwards the *Data* packets after decrementing the TTL. Otherwise, if h is greater than the TTL, the node discards the *Data* message. Here it is worth mentioning that we might have the case where the consumer has moved a hop further or so. Therefore, we define TTL as follows:

$$TTL = h + x, \quad with\ (x \geq 1). \tag{1}$$

Algorithm 3 Received `Interest` in Proposed CONET

```
Received [Name, Selector(s), NONCE, h ]
if Content Not in CS then
    if Name Not in PIT then
        h = h+1 {Increment h}
        Add [Name, NONCE, h, Face] in PIT.
        Initialize Timer(s).
        Replace h in Interest.
        Forward Interest using FIB.
    else
        Drop Interest.
    end if
else
    TTL = h+1. {Initialize TTL}
    DATA[Name, MetaInfo, TTL, Content,...]
    Send Data.
end if
```

where x is a marginal value to let Data traverse to additional x-hops to cope with the consumer mobility. Overall, the proposed CONET reduces the additional *Data* message propagation on the longer and multiple paths in the VNDN.

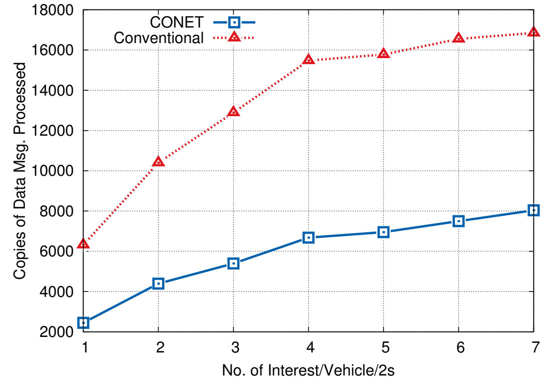
Algorithm 4 Received `DATA` in Proposed CONET

```
Received [Name, MetaInfo, TTL, Content,...]
if Name in PIT then
    if Face is Application then
        Node Received DATA.
    else
        if h in PIT ≤ TTL then
            TTL = TTL−1 {Decrement TTL}
            Replace TTL in DATA.
            Forward DATA to Face.
            Remove [Name, NONCE, h, Face] from PIT.
        end if
    end if
else
    Drop DATA.
end if
```

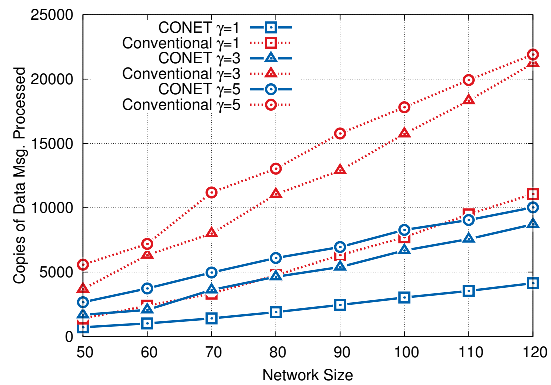
IV. Performance Evaluation

For the purpose of performance evaluation of our CONET, the overall VNDN architecture was implemented on the top of IEEE 802.11p. For simulations, Network Simulator (NS2.35) was used and additional attributes were added such as *Interest*/*Data* packets' structure, CS, PIT, and FIB in the upper layers. The performance of our CONET was compared with the basic/conventional VNDN model following the basic NDN implementation. For more realistic *Data*, we considered a mobility model consisting a four lane and two way highway scenario of $10Km$ long. In addition, we also varied the network size ranging from 50 to 120 nodes (i.e. NDN equipped Vehicles). The rest of the simulation parameters are summarized in Table I. Moreover, the results are obtained from the average of 30 simulation runs with 21% confidence interval. For comparisons, we introduced the following quality metrics:

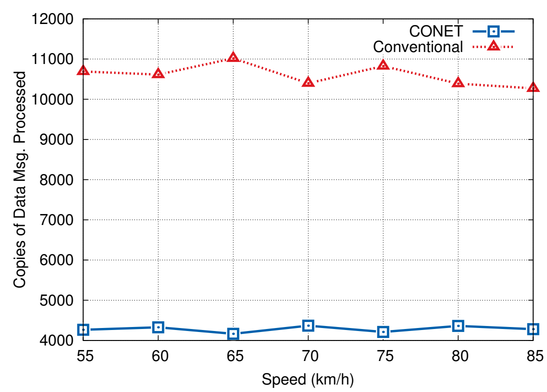
- CDMP: the total Copies of *Data* Messages Processed in the network.
- ISR: the *Interest* Satisfaction Rate in the network.
- ISD: the average *Interest* satisfaction delay.



(a) CDMP vs Number of *Interests* per Vehicle



(b) CDMP vs Number of Nodes



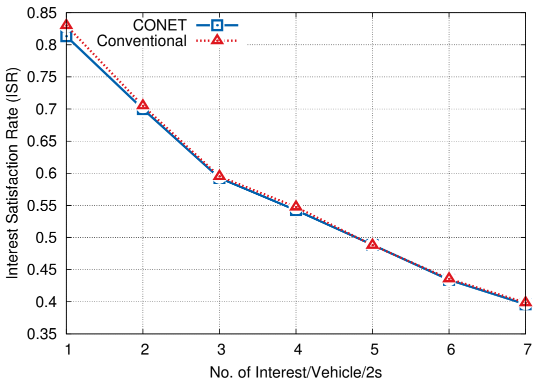
(c) CDMP vs Varying Speed of Vehicles

Fig. 3: *Data* Packets Forwarded in CONET vs Basic VNDN

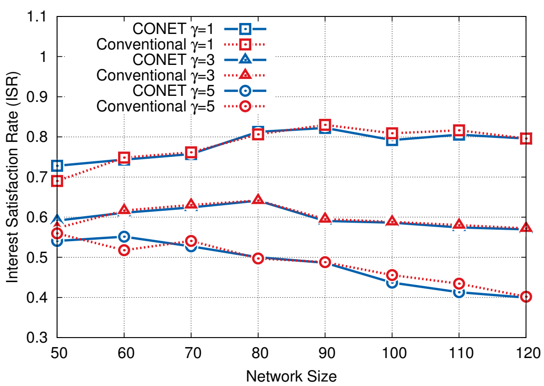
During simulations, each of the quality metrics is evaluated against the number of interests generated per vehicle, network size, and varying speed of vehicles. The main objective of CONET is to alleviate the number of *Data* messages within the whole network while keeping the same *Interest* satisfaction rate. It is evident from the Fig. 3 that CONET drastically

TABLE I: Simulation Parameters

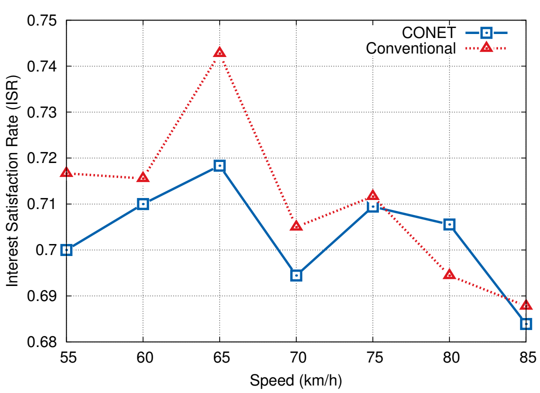
Parameter	value
Network Size	50, 60, 70,..., 120
No. of *Interests* (γ)	1-7
Vehicle Speed	55, 65,..., 85
T_x Power	6.198mW
Frequency Band	5.9GHz



(a) ISR vs Number of *Interests* per Vehicle

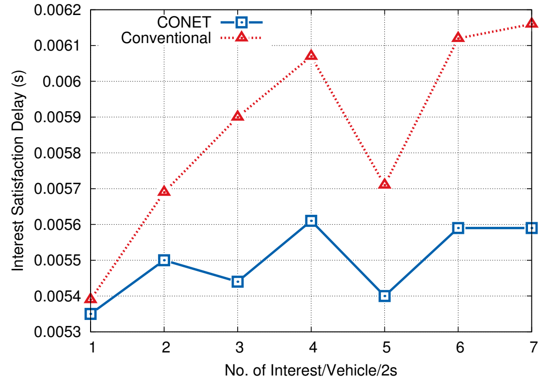


(b) ISR vs Number of Nodes

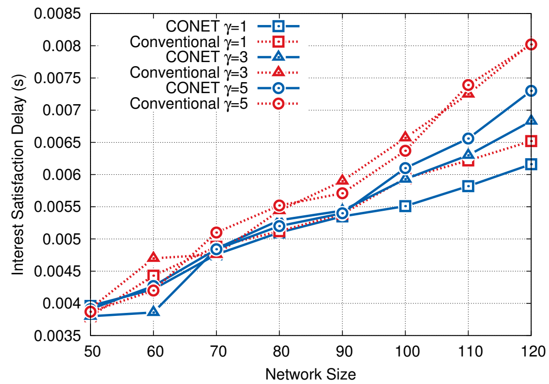


(c) ISR vs Varying Speed of Vehicles

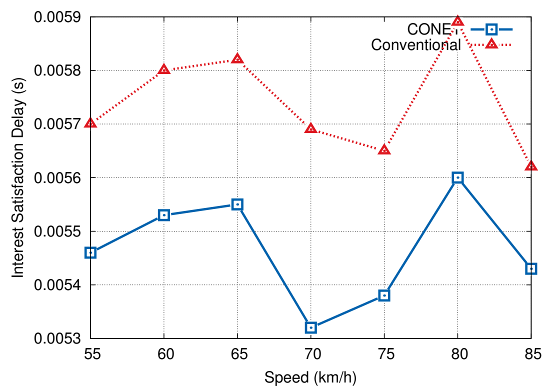
Fig. 4: *Interest* Satisfaction Rate in CONET vs Basic VNDN



(a) ISD vs Number of *Interests* per Vehicle



(b) ISD vs Number of Nodes



(c) ISD vs Varying Speed of Vehicles

Fig. 5: Interest Satisfaction Delay in CONET vs Basic VNDN

decreased the CDMP count and this is achieved due to the TTL limitations enforced by CONET while sending the *Data* packets back to the requesting vehicle. To be specific, CONET reduces by three times the *Data* packets forwarded as compared to the basic VNDN.

Similarly, Fig. 4 depicts the performance comparison in terms of number of satisfied *Interest* packets that CONET achieved against the basic VNDN mechanism defined in Section II. We found that ISR for CONET and basic VNDN is quite identical while forwarding less number of *Data* packets. Thus, we claim that CONET uses less bandwidth and thus reduces congestion and packet drop by sending less number of Data packets.

Finally, we evaluated the delay faced by *Interests* generated during the simulations and defined as the round trip time between *Interest* and *Data* retrieval. We agree with the fact that the dynamic environment of VNDN does not allow long lasting connections. Thus, *Interest* packets should be forwarded with minimum delay. Hence, *Interest* satisfaction delay must also be analyzed for CONET. Figure 5 shows that CONET faces less delay during the content retrieval process as compared to the basic VNDN and this is also achieved due to the less number of *Data* packets within network that may cause an increase in congestion and packet drop ratio. Another reason for the smaller *Interest* satisfaction delay is that the *Data* packet is not forwarded towards the longer paths with larger hop-counts due to the TTL in the *Data* packet.

V. Conclusion

In this paper, we proposed a COntrolled data propagation algorithm for vehicular named data NETwork (CONET). Like, traditional ad hoc networks, vehicular NDN also faces several challenges such as *Interest*/*Data* broadcast storm, consumer/provider mobility, and so on. There are some recent works to mitigate the *Interest* broadcast storm, however, literature lacks in dealing with DATA flooding issue. Our CONET mitigates *Data* flooding issue by utilizing the hop count h in *Interest* packet and *Time To Live* mechanism into *Data* message. CONET limits the additional copies of *Data* packets. Simulation results show that CONET achieves identical Interest Satisfaction Rate (ISR) as of basic VNDN with decreased satisfaction delay caused by congestion and packet drop ratio in basic VNDN. Our future work includes implementing CONET in a test bed environment. Also, we welcome suggestions for improvements from the research community.

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