CONET: COntrOlted 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 its 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 VDN 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, metadata, 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 (i.e, the paths) change.
• 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. 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

Receipt: [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 entriy/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

Receipt: [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 "RUF" [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.

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:

\[ \text{TTL} = h + x, \quad \text{with} \quad (x \geq 1). \]
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 \( \leq \) 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
- ISR: the Interest Satisfaction Rate in the network.
- ISD: the average Interest satisfaction delay.

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

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

- ISR: the Interest Satisfaction Rate in the network.
- ISD: the average Interest satisfaction delay.
TABLE I: Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network Size</td>
<td>50, 60, 70, ..., 120</td>
</tr>
<tr>
<td>No. of Interests ($\gamma$)</td>
<td>1-7</td>
</tr>
<tr>
<td>Vehicle Speed</td>
<td>55, 65, ..., 85</td>
</tr>
<tr>
<td>$P_c$ (Power)</td>
<td>6.19mW</td>
</tr>
<tr>
<td>Frequency Band</td>
<td>5.9GHz</td>
</tr>
</tbody>
</table>

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.

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

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


