NO-DSA: A Novel and Optimal Forwarding Protocol for Data Packet Storm Avoidance in Named Data Network-Based Internet of Vehicles (NDN-IoVs)

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Abstract

In recent times, techniques aimed at addressing specific challenges within Named Data Network-based Internet of Vehicles (NDN-IoVs) have been researched. A novel approach is imperative to tackle the issue of broadcast storm of Data Packet, mitigate network congestion, and ensure the reliable transmission of Data Packets from data providers and data producers to consumers. According to several studies, Interest Packet flooding management might be utilized to resolve the difficulties caused by Data Packet storms. However, these approaches often overlook factors such as the number of distinct pathways and network congestion ratios. Consequently, these methods may inadvertently lead to excessive Data Packet transmissions and heightened network congestion. To effectively address the Data Packet storm problem in NDN-IoVs, this paper introduces a novel and optimal forwarding protocol. Within this proposed forwarding protocol, intermediate nodes possess the capability to delay or discard the transmission of content packets to alleviate congestion, particularly in cases of geographical network overload and the emergence of new pathways.

Keywords: Future Internet Architecture, Named Data Network, Internet of Vehicle, Internet Packet, Data Packet, Data Packet Storm

Introduction

Internet of Vehicles (IoVs) is considered a new field in wireless networks, which underpins the development of Intelligent Transportation Systems (ITS) for smart cities. IoV establishes connections between moving vehicles and those parked on the roadside, serving as essential infrastructure. While several methods for content delivery have been developed using current TCP/IP implementations (Naseer & Mahmood, 2015), they prove inadequate in highly dynamic environments and areas with low traffic due to intermittent or poor connectivity. This deficiency largely stems from irregular connectivity. Moreover, IP addressing systems constitute the focal point of all TCP/IP-based content delivery strategies. Furnishing each vehicle with a distinct IP address in a bustling Vehicular Ad Hoc Network (VANET) poses considerable challenges (Ahmad, Manzoor, et al., 2022).

A recent futuristic Internet paradigm known as Named Data Networking (NDN) has been introduced (Sandhu, Haider, Naseer, & Ateeb, 2011). In this context, instead of requesting a server using the server's IP address, the requester in the network generates an Interest Packet and broadcasts it into the network. Any intermediary node that has the required content can respond to the Interest Packet upon receiving it. Thus, when the Interest Packet reaches the provider or producer, then a new packet called a Data Packet is generated. This Data Packet is traveled back to the requester by using the same path as the Interest Packet (Abrar et al., 2021). When a Data Packet reaches a node, the Pending Interest Table (PIT) is checked to determine if there is an Interest Packet entry matching the Data Packet. If yes, then Content Store (CS) is used to store the data and then the Data Packet is forwarded to the next node using a Forwarding Information Base (FIB). If there is no match in PIT, the Data Packet is discarded by the node and halts its transmission (Ahmad, Manzoor, Naseer, Ghaffar, & Hussein, 2021).

However, an issue known as a Data Packet storm arises, resulting in the rapid transportation of massive Data Packets within constrained spaces, thereby troubling NDN techniques. To be more precise, when a node requires certain content, it transmits an Interest Packet, which is received by intermediate nodes that then examine their Content Store (CS) (Arsalan, Burhan, Naseer, & Rehman, 2022). The requested data may be distributed across multiple nodes holding Data Packets. Consequently, the Data Packet transfer volume escalates with the density of nodes possessing the required data (Ahmad, Manzoor, et al., 2022). This scenario increases the likelihood of consumers receiving duplicate Data Packets, leading to an unnecessary depletion of network resources. This superfluous transmission needs to be minimized given the limited availability of network resources (Benkirane et al., 2023).

Thus, we present a novel solution in this paper to address the issue of Data Packet Storm called Novel and Optimal Data Packet Storm Avoidance (NO-DSA) (Malik, Ghafoor, & Naseer, 2011). This forwarding protocol involves broadcasting an Interest Packet throughout the entire network, similar to the native NDN approach (Ali, Khan, & Naseer, 2022). When the Interest Packet is received, all nodes attempt to communicate the relevant data if it is present in their CS (Satti et al.). To achieve this, the provider and intermediate nodes utilize their PIT, FIB, and a newly introduced table (Kaur et al., 2022). This coordinated operation aims to curtail the transmission of duplicate Data Packets. When the geographical congestion ratio of a vehicle is low and the transmission path is not overwhelmed by other packets, the associated data may be successfully transmitted. Conversely, vehicles will refrain from participating in the transmission of Data Packets under conditions of high geographical congestion or an overwhelmed transmission path (Naseer, Ghafoor, bin Khalid Alvi, & ul Islam, 2022).

Contribution

- This research primarily focuses on a straightforward and effective data forwarding protocol for Named Data Network-based Internet of Vehicles.
- The proposed forwarding protocol solves the Data Packet broadcast storm issue by calculating the geographical congestion window for each vehicle, ensuring that only specific vehicles transmit Data Packets.
- Furthermore, the proposed forwarding protocol is flexible and suitable for environments with high densities and significant levels of dynamic change.

This paper is structured as follows: Section II discusses the related work. Section III addresses the problem statement. Section IV is used to discuss the proposed framework. We present the simulation parameters, performance metrics, and results analysis of our proposed framework in Section V. Finally, in Section VI, we conclude our work.

Related Work

Over the past few years, researchers have dedicated significant effort to mitigating the flooding issue in NDN, particularly concerning Interest Packets and Data Packets, through various applications. This section, however, is intended to discuss a selection of the approaches being pursued (Adil, Ghafoor, Shafqat, Munir, & Murtaza, 2023).

Muhammad Burhan and Asif Rehman introduced a forwarding method known as the Broadcast Storm Mitigation Strategy (BSMS) (Naseer, Saleem, et al., 2023). The primary objective of this method is to mitigate the adverse impacts of redundant transmission of Interest Packets within the network. To achieve this, a timer is employed, which selects a single vehicle for propagating the Interest Packet if deemed necessary. This timer operates based on various parameters, including the speed of the content-requesting vehicle, the speed of the receiving vehicle, the transmission range of the vehicles, and the distance between the consumer and the data provider (Naseer, Ghafoor, bin Khalid Alvi, Zafar, & Murtaza, 2023).

Ahmad Arsalan and Asif Rehman presented a forwarding strategy to address the flooding problem of Interest Packets, named the Broadcast Storm Avoidance Mechanism (BSAM). In this approach, rather than having all nodes rebroadcast the received Interest Packet, only one node is chosen for this purpose. The selection process is guided by a defer timer, which operates based on distance.

Syed Hassan Ahmed et al. introduced a forwarding strategy called Robust Forwarder Selection (RUFS). This strategy is designed to mitigate the redundant transmission of Interest Packets, utilizing the vehicular communication environment. To accomplish this, each vehicle node maintains two types of lists; the first list, kept by all vehicles, records satisfied Interest Packets, while the second list maintains records of neighboring vehicles. Additionally, RUFS relies on beacon messages to facilitate the exchange of these lists, although this approach might introduce extra overhead to the network (Arshad et al., 2023).

Grassi et al. introduced a forwarding strategy called Navigo. This strategy employs graphical location to regulate the flooding mechanism of Interest Packets. Additionally, the Dijkstra algorithm is utilized to determine the path for transmitting the packet from the consumer node to the data provider node (Naseer, 2021).

Syed Hassan Ahmed et al. introduced a forwarding strategy to regulate the flooding of both Interest Packets and Data Packets. To achieve this, two fields are included in the Interest Packet and Data Packet, respectively. The first field (hop count) signifies the number of hops covered by the Interest Packet. The other field (data dissemination limit) prevents incorrect broadcasting of the Data Packet in the network (Naseer et al., 2021).

Another forwarding strategy named Push Vehicular Named Data Networking (P-VNDN), was proposed by Majeed et al. This strategy operates on a proactive approach and is intended to enhance user experience during coincidental events. Moreover, roadside units actively participate in fulfilling content requests from requester nodes (Bokhari et al., 2022).

Maryam et al. introduced a forwarding strategy known as Intersection-Based Forwarding Selection (IBFS). This strategy governs the flooding mechanism of Interest Packets and offers a solution for disconnected links among vehicle nodes (H. Ali et al., 2022). Additionally, the strategy’s objective is to identify the most suitable forwarder for broadcasting the Interest Packet within the network. The selection process involves utilizing various intersection or trajectory information (Ahmad, Cherif, et al., 2022).

Problem Statement

The data storm problem arises when multiple producer vehicles generate and transmit Data Packets. These packets are subsequently rebroadcast by intermediary vehicles, leading to a Data Packet storm issue, as illustrated in Figure 1. In the given scenario, a producer vehicle (P) receives Interest Packets from neighboring nodes (4, 5), prompting it to generate and forward a Data Packet. Similar to the paths taken by the Interest Packets, the generated Data Packet traverses the network. Consequently, vehicles 4 and 5 also receive Data Packets from producer P, since they fall within its transmission range. Subsequently, vehicles 4 and 5 rebroadcast the Data Packet within their range, perpetuating the cycle until the consumer vehicle C receives multiple copies of the Data Packets. This replication of Data Packets triggers a data storm, leading to congestion within the network. Consequently, the network's throughput is compromised.

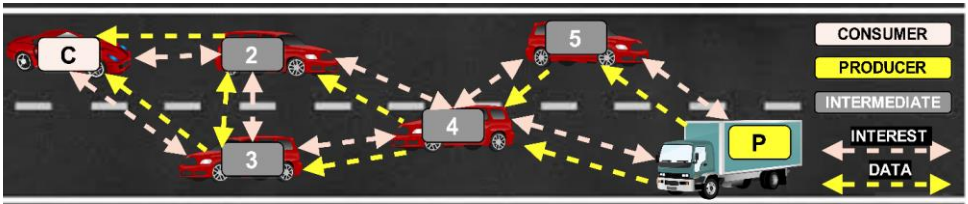

Figure 1. The problem statement concerning the Data Packets storm in NDN-based IOVs.

The Proposed Framework

To address the challenge of the data storm problem, we have introduced a lightweight forwarding protocol called Novel and Optimal Data Packet Storm Avoidance (NO-DSA). The proposed forwarding protocol involves calculating a Geographical Congestion Window (GCW) for the vehicles, in conjunction with a counter value. The calculation of GCW is achieved using Equation 1.

$$GCW_v = \left(\left(\left(\frac{ATC_v}{TTC_v} \right) * \left(\frac{BF_v}{TF_v} \right) + GCW_{v-1} \right) (1 - \theta) \right) \quad (1)$$

In the equation, ATC denotes the available transmission capacity, and TTC represents the total available transmission capacity of the vehicular node. BF stands for the number of busy faces, and TF represents the total number of faces of a vehicular node. The symbol θ denotes a weight factor.

The aforementioned equation facilitates Data Packet transmission only if a specific vehicular node possesses a lower GCW value, indicating a reduced likelihood of transmitting and storing the packet at neighboring vehicles. The proposed counter value, denoted as data hop count (DHC), comes with a default setting of 1. The DHC value increments by one each time a node broadcasts an Interest Packet. In scenarios where intermediate vehicles lack the necessary content, they store the Interest in their Pending Interest Table (PIT) along with updated DHC value information. This information is organized in a new data structure referred to as the Neighboring Node List (NNL), where DHC values correspond to PIT entries. Subsequently, these vehicles broadcast the Interest Packets to their adjacent nodes. Additionally, they monitor neighboring nodes that transmit similar Interest Packets, along with their corresponding DHC values, and compare this data with the entries in the NNL. Algorithm 1 illustrates the operation of our NO-DSA scheme.

Performance Evaluation

This section encompasses a comprehensive analysis of the proposed scheme's performance, accompanied by an exploration of the metrics and simulation settings employed to evaluate its effectiveness in comparison to native VNDN.

A. Simulation Parameters

The performance of the proposed NO-DSA is evaluated in this section. Furthermore, the comparison is performed with the traditional native VNDN implementation. Network Simulator NS-3 along with ndnSIM is used to simulate NO-DSA as well as a comparative scheme using a vehicular network scenario. The simulation involves the movement of 100 vehicles within the network. It is noteworthy that the speed of all vehicles remains uniform. Among these, a consumer node and six provider nodes are selected randomly. Additional simulation parameters of our scheme are presented in Table 1.

Algorithm 1: onReceivedDataPacket()

```
Terminologies
DP: Data Packet
DHC: Data Hop Count
NNL: Neighboring Node List
IP: Interest Packet
GCW: Geograhphical Congestion Window

ctimer == FALSE;
GCW ⟵ calculateCongestionWindow();
if (DP == PIT.entry()) then
    L1:
    if (NNL(IP.DHC) >= Node.DHC ) then
        if (GCW < 0.2) && ctimer == FALSE
         then
            cacheData(DP);
            Forward(DP);
        else
            if ctimer == TRUE then
                increaseTimeExponentially(timer);
            else
                timer = calculateTimer(Node.DHC);
                wait(timer);
                ctimer = TRUE;
                goto L1;
            end
        end
    else
        DiscardPacket();
    end
else
    DiscardPacket();
end
```

B. Performances Metrics

The simulation was executed 20 times, each lasting 300 seconds. During this process, two metrics were utilized to evaluate the performance of the proposed forwarding protocol.

- **Total number of Data Packets:** It is calculated as the aggregate count of Data Packets required to satisfy all Interest Packet entries within the network.
- **Interest Satisfaction Delay (ISD):** It is calculated as the duration required to obtain the requested Data Packet corresponding to the Interest Packet, which can be utilized to determine the ISD.

Table 1: Simulation Parameters Used in NO-DSA

Parameters	Values
Number of Vehicles	100
Transmission Range	150 m
Velocity of Vehicle	35 km/h
MAC Protocol	802.11a
Number of Producer Vehicles	1 – 6
Mobility Model	Random Mobility
Type of Vehicles	Mobile
Transmission Power	0.0091 mW

C. Result Analysis

Figure 2 illustrates a performance comparison between NO-DSA and native VNDN in terms of the quantity of Data Packets dispatched to satisfy forwarded Interest Packets. Unlike NO-DSA, there is no inherent mechanism in native VNDN to mitigate a Data Packet storm. Consequently, native VNDN disseminates numerous Data Packets across the network, thereby compromising network efficiency.

Conversely, our proposed scheme (NO-DSA) manages to curtail the impact of the Data Packet storm, especially as the number of vehicles in the network increases. Our findings reveal that NO-DSA outperforms native VNDN by 85%.

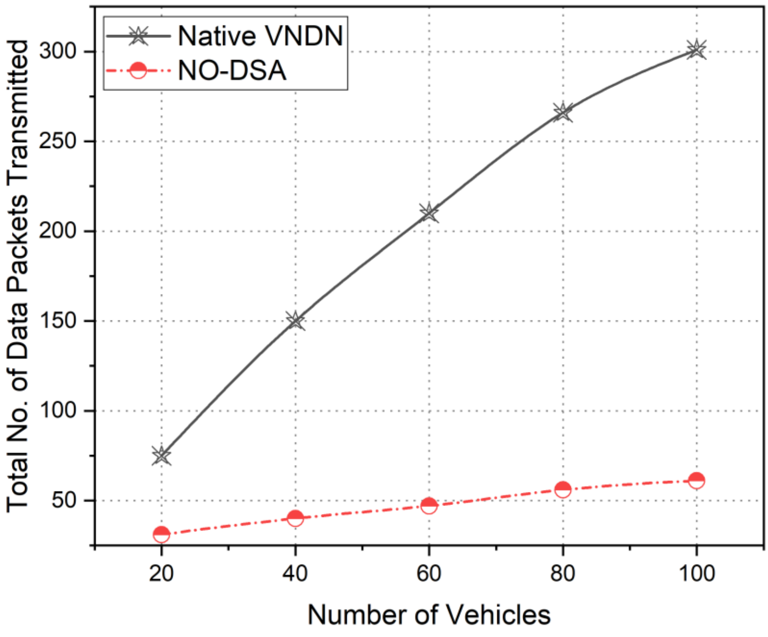

Figure 2. The comparison of the total number of Data Packets transmitted in the network concerning the number of vehicles.

Figure 3 illustrates the Interest Satisfaction Delay (ISD) as a function of the number of vehicles. With an increasing number of vehicles, the count of Interest Packets also rises, consequently leading to an escalation in the network congestion ratio. This phenomenon results in a consistent rise in ISD for both native VNDN and NO-DSA. Notably, in the NO-DSA forwarding protocol, intermediate vehicles intentionally delay the transmission of Data Packets forwarded by other vehicles. This characteristic contributes to our scheme demonstrating a lower ISD compared to native VNDN.

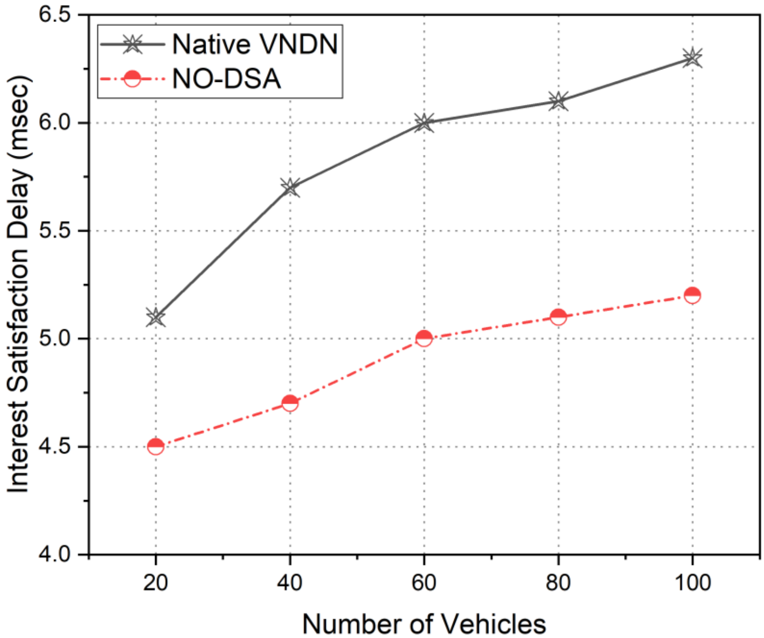

Figure 3. The comparison of the interest satisfaction delay concerning the number of vehicles.

Conclusion

In this paper, we introduce a novel and optimal forwarding protocol named NO-DSA, designed to regulate Data Packet transmission based on the Geographical Congestion Window (GCW) ratio within the context of Named Data Network-based Internet of Vehicles (NDN-IoVs). Within the NO-DSA forwarding protocol, intermediate vehicles that encounter new interests perform a tally of the number of neighbors anticipated to engage in the Data Packet transmission process. Additionally, these intermediate vehicles calculate the GCW ratio. Following this, upon the arrival of a Data Packet, the vehicle conducts a dual analysis of both the GCW ratio and the count of neighboring vehicles utilizing the Neighboring Node List (NNL). It opts to participate in the data response process similar to native VNDN when the number of neighboring vehicles and GCW values are minimal. Conversely, the vehicle opts to either delay or discard the Data Packet under conditions of substantial GCW values and a high count of neighboring vehicles, particularly when additional copies of the Data Packet can be forwarded via other vehicles.

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