# HOP COUNT BASED INTEREST SELECTION AND CONTENT FORWARDING SCHEME FOR VEHICULAR NAMED DATA NETWORKS

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***ABSTRACT***

*Vehicular Named Data Networks (VNDN) face challenges in efficiently disseminating content due to high mobility and intermittent connectivity. To address these challenges, a Hop Count based Interest Selection and Content Forwarding (HISCF) scheme for VNDNs is proposed. The scheme focuses on mitigating interest flooding, reducing data packet duplication, and alleviating network congestion. HISCF consists of two components: interest selection and content forwarding. The selection process chooses a vehicle based on hop count and Interest Satisfaction Ratio (ISR) to forward the interest packet. Content forwarding is performed considering a hop count limit and pending interests, ensuring efficient content delivery. The HISCF scheme is evaluated using extensive simulations in ns-3 with ndnSIM. Performance metrics such as Data Packet Replication Count (DPRC), total number of interest packets forwarded, Interest Response Time (IRT) and routing overhead are analysed. Results show that HISCF outperforms naïve VNDN, reducing DPRC, minimizing interest packets forwarded, and decreasing average IRT. The findings demonstrate that HISCF effectively mitigates interest broadcast storms, reduces data packet duplication, and improves content delivery efficiency in VNDNs. This study contributes to VNDN research advancement and provides insights for designing effective content forwarding mechanisms in vehicular networks.*

***KEYWORDS***

*Vehicular Named Data Networks, Content Dissemination, Interest Selection, Content Forwarding, Network Performance.*

## 1. INTRODUCTION

Over the past decade, Vehicular Ad-hoc Networks (VANETs) have gained significant attention but have faced challenges in meeting vehicle network expectations, primarily due to the lack of infrastructure support for global IP allocation [1]. VANET applications can be divided into critical and non-critical data, and to address the needs of critical applications and safety, Wireless Access in Vehicular Environment (WAVE) and Dedicated Short Range Communication (DSRC) protocols are used. [2]. The use of standard IEEE 80.211-based protocols in VANETs introduces TCP/IP overhead, which can be mitigated by leveraging DSRC for extended data exchange services. However, the TCP/IP protocol encounters issues in the dynamic automotive environment, including packet losses, session re-establishment, route recalculations, and inconsistent connectivity [3].

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Named Data Networking (NDN) is an emerging architecture for the future of the internet, shifting from host-centric to information-centric communication [4]. Vehicular Named Data Networks (VNDNs) have been proposed as an exploration of NDN in VANETs [5]. In a typical VANET, each node or vehicle has an IP address or node ID used for communication. However, in the vehicular context, where nodes are mobile and communication lines and node IDs frequently change, the NDN approach is considered more suitable as it focuses on retrieving data rather than relying on host IDs and positions [6].

Despite being a relatively new field, VNDN faces fundamental challenges. For instance, the broadcast nature of interest packets can lead to interest and data packet flooding, resulting in reduced network performance [7]. To address this, efficient forwarding methods are necessary. Additionally, while it is generally assumed that data packets follow the same path as interest packets, recent studies have shown otherwise [8].

This paper aims to tackle both interest and content packet storms by proposing an interest selection forwarder scheme based on multiple criteria, including hop count, Interest Satisfaction Ratio (ISR), and matching content names, thereby mitigating interest broadcast storms. Furthermore, a content forwarding scheme is proposed, considering hop count and Neighbour Data List (NDL), to minimize data packet duplication and alleviate network congestion. The research contributions of this paper are twofold: Proposal of an interest selection forwarder scheme and proposition of a content forwarding scheme to reduce packet duplication and mitigate network congestion.

## 2. RELATED WORK

This section highlights the related work in the field of forwarding schemes of VNDN.

The broadcast nature of NDN benefits the vehicular network environment, ensuring a fast mechanism to disseminate data packets. However, in dense networks, uncontrolled broadcasting leads to broadcast storms, resulting in redundant copies of interest and data packets flooding the network. To address these issues, researchers have explored modification of the forwarding plane's naive broadcasting nature, focusing on selection-based forwarding schemes. While extensive research has been conducted on VNDN in recent years, literature on forwarding techniques of VNDN is still in its early stages.

Several authors have classified various forwarding solutions based on criteria such as transmission mode and working principle [9], [10], [11]. In [12], a location-based solution was proposed to mitigate the broadcast problem. It involves maintaining a content location table by all nodes, storing the location of content producers/providers. Other nodes in the network forward interest packets to locations closer to potential providers/producers. However, this architecture does not consider vehicle mobility, leading to interests being forwarded to the previously known location of the producer instead of the current location.

A novel forwarding mechanism named COMPASS was proposed in [13]. Each node divides the area into directional interfaces and selects a relay node based on performance metrics to transmit the packets. If the driving direction changes, the Performance Information Table (PIT) and Forwarding Information Base (FIB) values are updated, and interface re-mapping is performed. However, the results show that the packets take a larger number of hops to reach the content provider compared to conventional techniques.

In [14], a neighbour awareness-based forwarding scheme is proposed, divided into two stages. In the first stage, vehicles share information with their neighbours, including hop count, metadata, and vehicle speed, which are maintained in a neighbour table. In the second stage, the node selects only one neighbour as the forwarder based on entries in the neighbour table, reducing the interest broadcast storm. However, the exchanged information metrics may not be sufficient for efficient forwarder selection, and the mechanism is tested in a low-density vehicle scenario.

Similarly, [15] proposes a mechanism where each node maintains a neighbour list, including velocity, distance, and neighbour IDs obtained through beacon exchanges. The forwarder is selected based on the relative distances from the relay node to the consumer and provider nodes. However, this mechanism experiences higher transmission delays, and the results are not validated by comparing them with the naive VNDN architecture.

In [16], a counter-based forwarding approach is proposed, setting a limit on the maximum number of hops an interest packet can take. The counter decreases by 1 for each hop, and when it reaches zero, the node drops the packet, thereby reducing the interest broadcast storm. The lifetime of entries in the PIT is calculated through an adaptive procedure to minimize packet loss, triggering retransmission if the lifetime lapses. However, the hop count value may be affected due to the lack of consideration for content mobility.

Authors in [17] propose a forwarder scheme based on link stability, where vehicles consider information such as the provider/forwarder's velocity, direction, and location to calculate connectivity time. The scheme selects the path with the highest stability, transmitting data packets in the same path but in the opposite direction. The authors in [18] also propose the transmission of interest packets based on priority. However, the efficiency of these schemes is not validated in low-density scenarios.

In [19], a link stability-based scheme is proposed, improving upon previous methods by incorporating a local threshold value. Vehicles calculate the link lifetime value based on motion metrics and forward the interest packet only if the value exceeds the local threshold. If the value falls below the threshold, the packet is dropped. Notably, this mechanism does not consider the non-linear path during link lifetime calculation.

While existing research on content or interest forwarding mechanisms has focused on mitigating interest broadcast storms or reducing packet duplication, this paper proposes a novel scheme that addresses both issues. The proposed approach involves selecting a single node as the interest forwarder, mitigating interest broadcast problems and reducing the duplication of data packets by hop count value.

## 3. RESEARCH CONTRIBUTION

The research contribution of the proposed work can be summarized as follows:

A novel Hop Count based Interest Selection and Content Forwarding (HISCF) scheme for VNDN is developed. The HISCF scheme aims to mitigate interest broadcast storm and reduce data packet duplication by introducing improvements in interest selection procedure and content dissemination process. Key metrics such as hop count and ISR are used in selection of interest forwarder. Hop count limit and neighbour information are used in data forwarding decisions.

The HISCF scheme is evaluated by considering parameters such as Data Packet Replication Count, total number of interest packets forwarded, Interest Retrieval Time (IRT) and routing overhead. In addition, the HISCF scheme is compared against naïve VNDN to determine the effectiveness of the proposed approach. The proposed scheme opens up numerous possibilities in the field of data dissemination and content retrieval for VNDN.

## 4. HOP COUNT BASED INTEREST SELECTION AND CONTENT FORWARDING SCHEME

This section presents the proposed Hop Count based Interest Selection and Content Forwarding (HISCF) mechanism for VNDN. In naïve VNDN approach, due to broadcast nature of interest packets, redundant copies are generated. The neighbouring nodes which receive these interest packets, reply with data packets if they are intended producer or have the data stored in cache. This process further aggravates congestion in the network since packet size of content is larger compared to requesting interest. To mitigate both these issues which are interdependent, HISCF scheme aims to reduce interest flooding and avoid processing of redundant copies of data packets, thereby reducing network congestion.

Interest forwarder selection and data forwarding constitute the elementary parts of the HISCF mechanism. Hop count and ISR are the two criteria based on which a vehicle is assigned to forward an interest packet. Beacon messages containing information related to CIT are exchanged among neighbouring vehicles periodically. Vehicles which have satisfied contents in the past 3 seconds update the name of the content along with vehicle IDs and their hop count. In addition, ISR is an important metric which gives the ratio of number of satisfied interests to the number of received interests. A vehicle is designated to forward the interest based on lower hop count and higher ISR values obtained from CIT instead of broadcasting it to all the neighbouring vehicles which leads to interest broadcast storms.

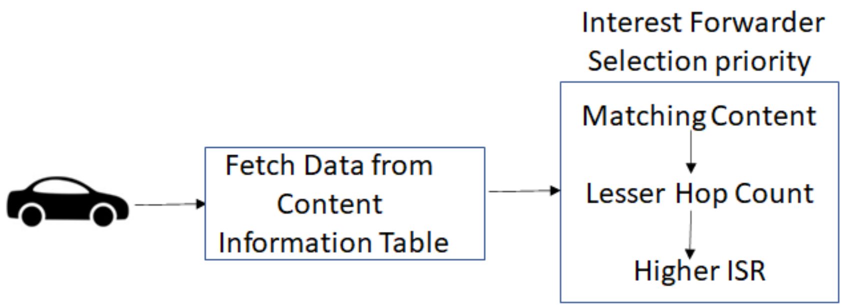


Figure 1. Interest Forwarder Selection in HISCF Scheme

The series of events that take place when a node receives an interest packet is listed in Algorithm 1. The node scans its Content Store (CS) data structure for matching content after receiving an interest. The node responds with the data packet if the matching content is identified. The Pending Interest Table (PIT) is examined next, if the requested content is not found in CS. The FACE ID of the incoming interest request is appended to the PIT list and the interest is dropped indicating a previous entry for the same content. If there is an absence of the PIT entry, the hop count value in the interest packet is incremented by 1 and corresponding entry is made. The naïve VNDN works in a similar way till this step and broadcasts the interest packet to all neighbouring nodes after PIT entry. However, HISCF uses information in CIT to select the interest forwarder instead of broadcasting. A sample CIT is shown in Table 1. The node checks if any one of the neighbours have satisfied the requested interest and selects the node if there is an entry present. The node selection criteria are used if there are multiple nodes in CIT which have satisfied the interest. A node with least hop count value and higher ISR is selected to forward the interest packet, and thereby increasing the likelihood of fetching the required content and reducing broadcast storms.

Table 1. A Sample Content Information Table

| Content Name | Vehicle ID | Hop Count | Interest Satisfaction Ratio (ISR) |
|---|---|---|---|
| C1 | V1 | 1 | 50 |
| C2 | V1, V2, V3, | 1,3,6 | 50,70,80 |
| C3 | V3, V4 | 6,1 | 80,70 |
| .<br>. | | | |
| Cn | V3, Vn | 6,0 | 80 |

The series of events that take place when a node receives a data packet is listed in Algorithm 2. Every node in the network maintains a Neighbour Data List (NDL) by periodically exchanging control packets to facilitate the content forwarding in HISCF. Table 2 illustrates a sample NDL. The node scans the PIT for an entry, whenever it receives a data packet. If an entry is not identified, the data packet is discarded from the network since it has not reached the intended receiver or forwarder. In addition, Hop Count Limit (HCL) value is examined by the node, if the value is exhausted, the packet is discarded and prevented from further participation in the network. In case the content entry is present in PIT and node ID matches the FACE ID, the data packet has successfully reached the destination. Alternatively, if the FACE ID does not match, the node examines the NDL and forwards the data packet to the node that has a corresponding entry in PIT.

Table 2. A Sample Neighbour Data List

| Vehicle ID | Hop Count | Pending Interests |
|---|---|---|
| V1 | 3 | I1, I2 |
| V2 | 1 | I1, I3 |
| V3 | 5 | I2,I4 |
| .<br>.<br>. | | |
| Vn | 3 | I3,I1,I4 |

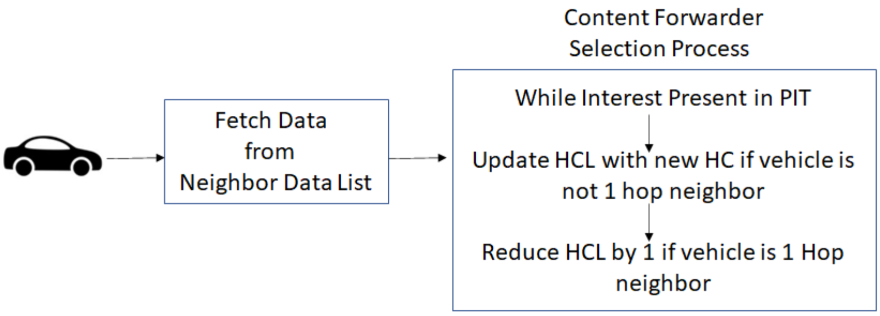


Figure 2. Content Forwarder Selection in HISCF mechanism

ALGORITHM 1: WHEN INTEREST PACKET IS RECEIVED AT THE NODE

```
If content present in CS, then:
    Prepare Data Packet using Name, Content, Meta Info etc…
    Send Data Packet
Else:
    If name present in PIT, then:
        Include Face ID in PIT
        Drop Interest
    Else:
        HC = HC +1
        Update HC in PIT
        Fetch CIT
            If CN matches any content in CIT, then:
                Fetch the V_id of matching CN
                    If HC of content matching V_id >1:
                        Select V_id with least HC
                            If HC of V_ids are equal then:
                                Select V_id with highest ISR
                                Forward interest to selected V_id
                            Else:
                                Forward interest to selected V_id
                    Else:
                        Forward interest to selected V_id
            Else:
                Include Face ID in PIT
                Drop Interest
```

HC: Hop Count
CIT: Content Information Table
$V_{id}$: Vehicle Identity
CN: Content Name

ALGORITHM 2: WHEN DATA PACKET IS RECEIVED AT THE NODE

```
If CN in PIT, then:
    If Face matched with node then:
        Cache the data; Data successfully delivered to requested node
    Else:
        If HCL ≥ 0 Then:
            Fetch HCs of all V_ni having Interest in PIT via NDL
            While Interest is present in PIT fetched via NDL:
                If HC of V_ni >1 then:
                    Update HCL = HCL + HC
                    Send Data to V_ni
                    Remove V_ni entry from PIT
                Else:
                    Update HCL = HCL -1
                    Send data to V_ni
                    Remove V_ni entry from PIT
        Else:
            Drop data packet
Else:
    Drop data packet
```

HCL: Hop Count Limit

HC: Hop Count
NDL: Neighbour Data List
$V_{ni}$: ID of neighbouring vehicle from NDL

## 5. SIMULATION ENVIRONMENT

The simulation platform set up for analysing the proposed HISCF mechanism is outlined in this section. Network Simulator (ns-3.30) is used as a simulation tool. The ndnSIM module is integrated to facilitate modelling of data structures such as FIB, PIT and CS, which are essential for NDN [20]. Traffic and mobility patterns are generated by SUMO (Simulation of Urban Mobility) package. [21]

Each vehicle is set a transmission range of up to 500 meters. The average size of beacon messages exchanged to maintain the CIT and NDL tables are 2 KB and preliminary analysis of results indicate 8 beacons can be exchanged among vehicles per second. Since the sizes of CIT and NDL are lesser than beacon size, these tables are eventually updated at rate of 8 times per second. The critical simulation parameters used to analyse the performance of HISCF in varying scenarios are summarized in Table 3.

Table 3. Simulation Parameters

| Parameter | Values |
|---|---|
| Network Simulator | Ns-3.29 |
| Simulation Area | 2 Lane, two-way traffic street of 4.8 Km |
| Simulation time | 300s |
| Mobility Model | Random Walk |
| Traffic Generator | SUMO |
| Transmission Power | 6.198mW |
| Frequency Band | 5.9GHz |
| Number of vehicle nodes | 60-120 |
| Vehicle speed | 60 km/hr -120 km/hr |
| Producer nodes | 10% of the total nodes |
| Number of RSU | 3 |
| Packet Size | 10 kb to 90 kb |
| Average beacon size | 2 kb |

## 6. PERFORMANCE EVALUATION

The performance evaluation aims to assess the effectiveness of the HISCF scheme in mitigating the issues associated with naïve VNDN, such as data packet duplication and interest broadcast storms. By comparing the performance metrics of HISCF with the traditional VNDN approach, the improvements achieved by the proposed scheme can be determined.

The parameter DPRC provides insights into the reduction in data packet duplication achieved by the HISCF scheme. A lower DPRC value indicates a more efficient forwarding mechanism, as fewer redundant data packets are processed by the network. Additionally, the total number of interest packets forwarded reflects the efficiency of the interest forwarding process. By analysing this metric, the effectiveness of the HISCF scheme in reducing unnecessary interest packet dissemination can be assessed.

Another crucial performance metric is the average Interest Response Time (IRT), which measures the time taken for an interest packet to be satisfied from the instance it is generated. A lower IRT signifies faster content retrieval, indicating improved network efficiency and reduced content delivery latency.

To gain a comprehensive understanding of the proposed HISCF scheme's performance, the evaluation considers varying vehicle speeds and network densities. Vehicle speed plays a significant role in the network's dynamics, influencing packet forwarding decisions and overall content dissemination. Likewise, network density influences the intensity of packet interactions and the potential for congestion. Analysing the performance under different scenarios allows for the evaluation of the scheme's robustness and its ability to adapt to diverse vehicular network conditions.

## 6.1. Data Packet Replication Count (DPRC)

The total number of data packet copies processed in the network for every satisfied interest is determined by DPRC. An ideal network should have low DPRC, since high DPRC can contribute for congestion. The proposed HISCF significantly reduces the DPRC as compared to the naïve VNDN strategy in terms varying network size. The speed of vehicles is maintained a constant 70 km/hr and the number of vehicles is varied from 60 to 110 in step size of 10. It can be observed from Fig. 1, that DPRC is directly proportional to network size. This can be attributed to the increase in duplication of data packet copies with vehicle density. In the next scenario shown in Fig. 2, the number of vehicles is maintained constant at 70, and the speed of vehicles is varied from 60 to 110 km/hr. It can be observed that, although DPRC increases with speed, it is not very significant and there is no clear corelation between them.

HISCF outperforms naïve VNDN in both the scenarios of varying vehicle speeds and network size. This is mainly due to the modification of content forwarding scheme in HISCF, which does not broadcast or reply to every incoming request. The scheme sends data packet to only a potential forwarder by analysing the data from NDL table and also the respective HCL value. These results validate the efficiency of the HISCF scheme in reducing the processing redundant data packets, thereby reducing the chances of network congestion and improving the overall efficiency.

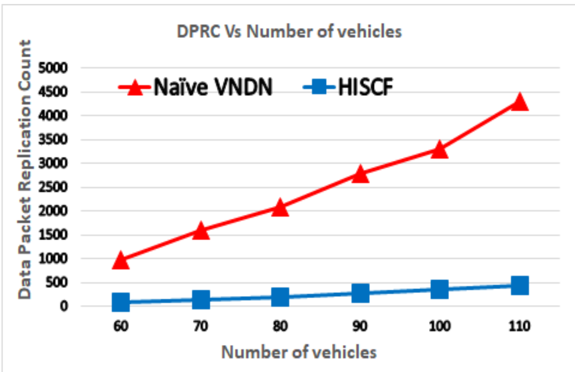


Figure 3. DPRC vs Number of vehicles

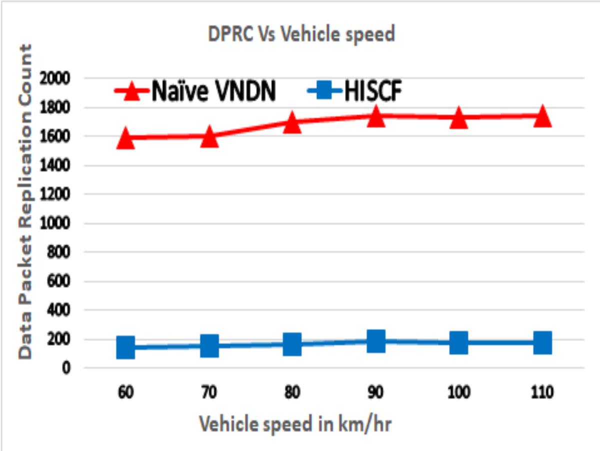


Figure 4. DPRC vs Vehicle speed

### 6.2. Total Number of Interest Packets Forwarded

A key measure of the effectiveness and performance of the forwarding schemes is the total number of interests forwarded in the network. The Fig. 3 and Fig. 4, display the performance comparison of naïve VNDN and HISCF against varying network size and vehicle speeds respectively.

In the first scenario, the network density is increased and the other parameters such as vehicle speed, packet sizes and number of chunks are kept constant. It can be observed from Fig. 3, that the number of interest packet forwarded increases with network density for both naïve VNDN and HISCF. However, from Fig. 4, it is evident that vehicle speeds do not have significant impact on this metric.

The HISCF scheme reduces unnecessary forwarding of interest packets unlike naïve VNDN that broadcasts interest packets to all the neighbouring nodes. The interest selection algorithm in HISCF designates only a single vehicle to forward the interest in the network based on the analysis of data from CIT such as matching content name, hop count and ISR. This substantially lowers the interests forwarded in the network, furthermore mitigating the interest broadcast storms and improving the overall network performance.

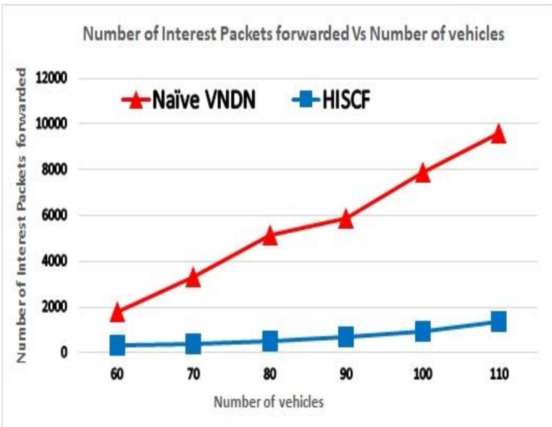


Figure 5. Number of Interest Packets forwarded Vs Number of vehicles

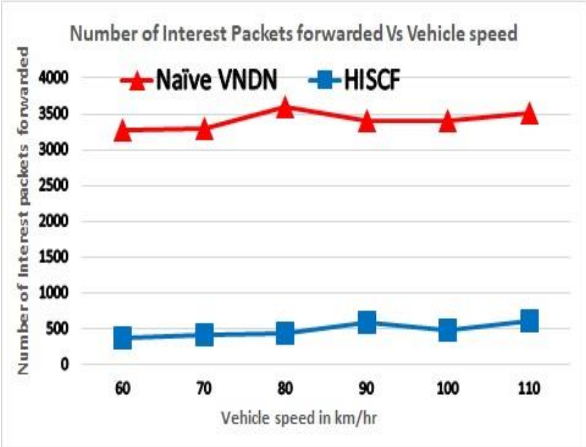


Figure 6. Number of Interest Packets forwarded Vs Vehicle speed

## 6.3. Interest Response Time

The IRT is a critical metric that measures the amount of time the network takes to satisfy an interest packet. Similar to DPRC and total number of interest packets forwarded in the network, IRT is also analysed by varying the vehicle speeds and network density, to get a better insight of the performance.

The results from Fig. 5 indicate that the delay in satisfying the interest also increases with network density. The packets travel larger distance and processing time at each node contributes to this additional delay. Similarly, from Fig. 6, it can be observed that, there is notable increase in the delay with vehicle speeds. At high speeds, due to intermittent connectivity, the complete packet transmission is not achievable. The packets have to be retransmitted in such scenarios and thus there is delay in satisfying the interest packet.

However, the HISCF scheme performs better in both the scenarios as compared to the naïve VNDN. Efficient content forwarding mechanism is one of the primary aspects that contributes to this superior performance and thereby improving the overall performance of the network. In addition, there is less chances of congestion due to mitigation of interest broadcast storms and reduction of redundant data packets. These factors overall aid the interest packet in reaching the producer soon and fetch the data packet.

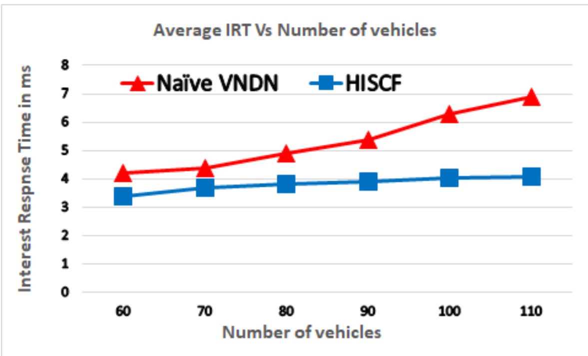


Figure 7. IRT Vs Number of vehicles

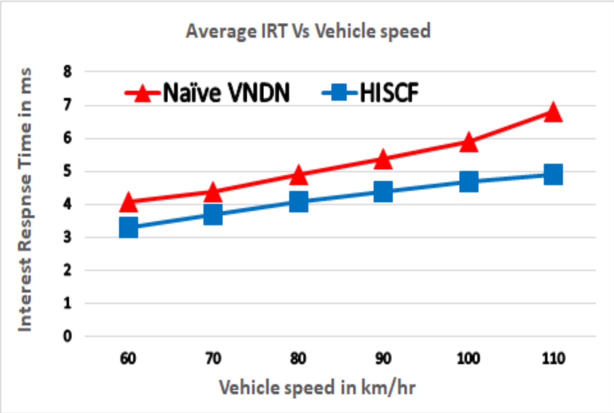


Figure 8. IRT Vs Vehicle speed

## 6.4. Routing overhead

The number of control packets required to successfully deliver one data packet is referred as routing overhead. It is an important metric that quantifies the overhead introduced in the network for routing the data packet efficiently. To analyse this parameter better, the network density and vehicle mobility is varied.

A comparison of naïve VNDN approach and HISCF by varying the network density is shown in Fig. 7. It is evident that, routing overhead increases with number of vehicles, since additional control packets are required to maintain the routes. Similar behaviour can be observed form Fig. 8, where vehicle speed also has a direct corelation with routing overhead. At higher speeds, due to intermittent connectivity, network may experience packet loss and transmission errors. In addition, fading of signal, link failures occur at high speeds, resulting in packet loss. The number of control packets required to recover from these situations and maintain routes is high, thus contributing to increasing routing overhead.

Naïve VNDN outperforms the proposed HISCF mechanism in terms of routing overhead for both the scenarios. Naïve VNDN approach is simple and straight forward. It does not generate additional control packets to forward interest or data packets. Very minimal data structures such as PIT, CS and FIB are used to facilitate the operations. However, HISCF approach maintains two additional data structures NDL and CIT. Many control packets are required to maintain and update these tables periodically. All these factors contribute to increased overhead of the HISCF mechanism.

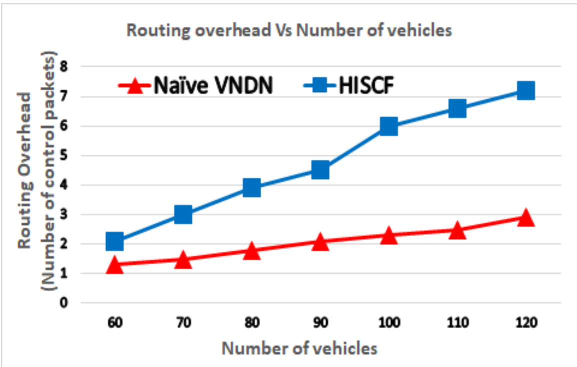


Figure 9. Routing overhead Vs Number of vehicles

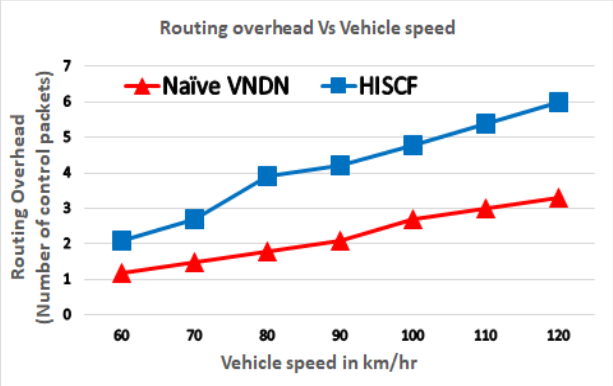


Figure 10. Routing overhead Vs Vehicle speed

The findings from the evaluation of all these metrics are summarized in Table 4.

Table 4. Summary of Simulation Results

| Performance Metrics | Results and Observations |
|---|---|
| Data Packet Replication Count (DPRC) | Due to selective forwarding of interest and data packets in proposed HISCF, redundant copies of data are reduced significantly by an average of 90% in both scenarios of varying network size and vehicle speeds. |
| Total number of interest packets forwarded | HISCF forwards only selective interest based on ISR and CIT, instead of broadcasting interests by naïve VNDN. This has significant impact and reduces the interest packets forwarded by an average of 84%. |
| Interest Response Time (IRT) | The efficient forwarding technique of HISCF ensures less delay in satisfying the interests. The response time is reduced by an average of 18% in both the cases of varying network size and vehicle speed. |
| Routing overhead | HISCF scheme uses data from additional data structures such as CIT, NDL and involves decision making parameters such as ISR, hop count, hop count limit, thus increasing the number of control packets involved in data transmission process. The routing overhead as a result increases by an average of 42% across both the scenarios of varying network size and vehicle speed. |

## 7. CONCLUSION

The proposed HISCF mechanism counters the challenges posed by naïve VNDN approach such as interest flooding and processing of redundant data packets. HISCF approach consistently outperformed the naïve VNDN across various scenarios and critical parameters such as DPRC, average IRT and total number of interests forwarded.

The HISCF mechanism's ability to reduce data packet duplication against varying network size and vehicle speeds is evident through DPRC metric. The effectiveness of the interest forwarding scheme was demonstrated by the significant reduction in the total number of interest packets forwarded in the network as compared to naïve VNDN. Combined efficiency of both interest and data forwarding schemes was noticeable through the reduction in the average response time for an interest packet in comparison with the naïve approach. However, the process of selecting the interest forwarder, maintaining CIT, NDL and analysis of HCL generates additional control packets, thus increasing the routing overhead. Other network parameters such as scalability, bandwidth utilization and energy consumption might be impacted by increased overhead.

Overall, the analysis of results obtained from this work indicate the effectiveness of the forwarding techniques of the proposed HISCF approach. These results support the realization of intelligent transport systems and contributes to the scientific advancement of VNDN.

Future research directions include optimization of the developed HISCF scheme by considering other network parameters such as content source mobility, network dynamics and scalability. In addition, incorporating security and privacy related techniques to the HISCF mechanism can be investigated.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest

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