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Towards Improved Vehicular Information-Centric Networks by Efficient Caching Discovery

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Abstract: The number of connected cars and the massive consumption of digital content on the Internet have increased daily. However, the high mobility of the vehicles, coming from patterns' variation over time, makes efficient large-scale content distribution quite challenging. In light of this, the emerging Vehicular Named Data Network (VNDN) architecture provides support for content-centric network communications and caching capabilities, which allows reliable and larger-scale content delivery over Vehicular Ad-Hoc Networks (VANETs). This notwithstanding, the high number of interest packets in VNDN tends to introduce broadcast storm occurrences during the cache discovery process. Thus, network performance degradation comes up for the influence of both increased packet loss rates and delays on content recovery during communication between vehicles. This work proposes a new cache discOVEry pRoTocol (OVERT VNDN), which combines the computational geometry and degree centrality concepts to tackle the VNDN performance degradation challenges and issues. The main idea behind OVERT VNDN is to choose the most appropriate relay vehicles to engage interest packets' delivery within the VNDN, seeking to achieve higher network performance by optimizing broadcast storm incidence. The obtained results suggest that OVERT VNDN outperforms its competitor in the following key performance indicators: (i) improving the cache discovery process by 120.47%; (ii) enhancing the content delivery rate by 43%; and (iii) reducing the number of interest packets by 80.99%.

Keywords: cache discovery; computational geometry; degree centrality; broadcast storm; VNDN

1. Introduction

The Vehicular Named Data Networking (VNDN) technology advent promisingly paves the way to tackle challenges of high performing large-scale content distribution provisioning in Internet Protocol (IP)-centric Ad-Hoc Vehicular Networks (VANETs) [1]. By definition, the IP paradigm cannot both offer users massive content delivery, as well as ensure the requirements of distributed VANET application concerning Quality of Service (QoS) and Quality of Experience (QoE) [2–4]. The reason behind the aforementioned IP issues in VANETS arises from the intense vehicle mobility patterns, which result in constant topological dynamics. As a consequence, this ends up generating overload on the network to maintain the particular requirements of the Transmission Control

Protocol (TCP)/IP protocol stack, such as neighbor discovery and maintenance, address reallocation, and connection-oriented sessions [5–7].

Named Data Networking (NDN), which implements the Information-Centric Networking (ICN) [8] communication paradigm, affords VNDN inter-vehicle communication. In NDN, communication happens through exchanging interest and data packets. In contrast to IP-based architectures, interest and data packets harness the content name as the exclusive network identification. Thus, the NDN networking planning steps in the inter-node communication task are two-fold. In the first step, a particular consumer node sends an interest packet carrying the name of the intended content. In the second step, a producer node transmitting a respective data packet returns the requested content to the consumer node. In other words, the producer node who has the searched content in the cache (Content Store (CS)) sends it through a data packet to the consumer node. Because of that, the cache discovery process refers to the search for content on the network. The content delivery rate regards the percentage of vehicles that have successfully received the requested content [9]. Aside from that, it is worth noting that intermediary nodes operate as both content consumers and producers [10]. Hence, nodes can function as data mules in the lack of connectivity, so that future requests in content are attended more closely to the consumer nodes.

Therefore, VNDN comes up with the prospecting potential to maximize large-scale content delivery, taking into account both the QoS and QoE requirements of applications distributed in Intelligent Transport Systems (ITS) [11–13]. Incidentally, ITS are contemplated as a key technology to enable more efficient and secure traffic management that ranges from cooperative and distributed route planning [14–17], traffic and road alerts [18–20], and enhanced video distribution [21–23], to advisory systems for driving strategy [24–26], and autonomous driving capabilities [27–29]. Furthermore, the VNDN concept exploits the ICN communication paradigm by changing the ways of requesting and retrieving content from the network, since the content name is the main element of the network and must be globally unique, persistent, secure, and location-independent [30]. It is noteworthy that cache content is another fundamental element in VNDN, which increases the availability of content on the network with multiple providers. In this way, the original producer can retrieve the content or the intermediate nodes that have a replica of the local cache's content.

However, the integration of the NDN architecture into VANETs (i.e., VNDN) is not trivial and raises many challenges, especially concerning vehicle mobility, access security, naming, and content storage [10]. Regarding large-scale content delivery across traditional VNDN, the occurrence of a broadcast storm during a cache discovering process raises the main critical issue that this paper addresses. Such an issue refers to the multiple uncoordinated transmissions of interest packets, which severely jeopardize the underlying communication channel as a consequence of network flooding events [10,31].

This paper proposes OVERT VNDN, a cache discOVEry pRoTocol that harnesses both computational geometry and degree centrality concepts to tackle the broadcast storm problem that arises during inter-vehicle communications efficiently. The OVERT VNDN proposal was designed with the ability to choose the most appropriate relay vehicles to reduce interest packets' transmission within the VNDN by employing both the convex hull and the degree centrality of the neighbors. It is important to mention that the prime motivation for leveraging VNDN architecture comes from the network cache element that the NDN architecture offers, along with the content-centric inter-vehicle communication approach. Simulation outcomes suggest that OVERT VNDN outperforms the VanillaVNDN-related benchmarking solution in the following Key Performance Indicators (KPIs): (i)successfully mitigates the broadcast storm incidence during inter-vehicle communication, diminishing packet collision rate occurrence beyond 50%, on average; (ii) enhances the content delivery ratio by 58.02% while achieving a high cache hit rate maintenance of more than 43% during the cache discovery process; and (iii) decreasing the interest packets' transmission by 80.99%.

The remainder of this article is organized as follows. Section 2 surveys the most relevant related works that motivate our solution design. Section 3 introduces the OVERT VNDN proposal in detail, including the functional architecture and embedding mechanisms and functionalities. Section 4 presents a discussion of the simulation results and related insights. Finally, Section 5 wraps up the article with concluding remarks along with the prospects for future works.

2. Related Work

This section examines how recent VNDN approaches tackle the interest broadcast storm problem during a cache discovery process in information-centric VANETs and discusses the impacts on inter-vehicle communications.

Kuai et al. [32] proposed a neighborhood-prioritization approach called Density-Aware Delay-Tolerant (DADT). DADT uses timers to prioritize nodes in the cache discovery process. To improve the packet delivery ratio, DADT considers the neighboring vehicles (receivers) farthest from the sender vehicle and closest to the producer vehicles. Thus, DADT relies on two factors: (i) periodic beaconing for neighborhood discovery and (ii) the knowledge of data producers' location. Due to the latter factor, consumers and producers are not fully decoupled, which is one of the drawbacks of current IP-based solutions.

Yu et al. [33] came up with an Opportunistic Interest Forwarding Protocol (OIFP) to tackle the interest broadcast storm problem in VNDN. To manage redundant interest transmissions, OIFP considers the distance between a current forwarder and its neighboring vehicles. In contrast to DADT [32], the OIFP protocol does not use the location information of the content provider. The prioritization is accomplished by the use of defer timers, which are related to their distance to the current forwarder vehicle. Thus, the vehicles that are farther from a sender node have a lower interest transmission defer time.

Boukerche et al. [34] and Sousa et al. [35] introduced a link stability-based interest-forwarding protocol to deal with the broadcast storm problem. These approaches aim to reduce the number of interest packets and data packets on the network. For this, the strategies control interest packets by prioritizing neighboring nodes with more stable links with the current forwarder (i.e., sender). Its connectivity duration determines the link stability between the vehicles with the existing interest forwarder. Thus, the vehicles with a higher priority transmit first, while the vehicles with a lower priority suppress their transmission of the given interest.

Rondon et al. [9] designed a cache discovery protocol to mitigate the interest broadcast storm problem, called CDP (Content Discovery Protocol). CDP uses the best geographically positioned vehicles to forward the interest, which avoids redundant transmissions. To choose the best vehicles, CDP first considers the distance of the current transmitter relative to its neighborhood. The best-positioned concept (i.e., sweet spot) is applied to prioritize the highest priority vehicles to continue the cache discovery process. In contrast, the lowest priority vehicles suppress their scheduled interest transmissions. Although CDP is efficient in a topological matrix scenario, such a protocol tends to lose performance in the cache discovery process in radial scenarios. This is due to the angle of the sweet spot that was modeled for matrix scenarios, such as a highway. Furthermore, the strategy for choosing retransmitter vehicles is fixed due to the way the sweet spot was angled. As a result, the cache hit rate and the content delivery rate guarantee are affected.

Arsalan and Rehman [36] developed a technique to mitigate the broadcast storm issue, called BSAM (Broadcast Storm Avoidance Mechanism). BSAM outlines a counter value that is given for each vehicle by calculating its distances from the sender vehicle. BSAM offers the lowest data packet delay (compared to a traditional VNDN protocol) due to only the farthest sender node from the consumer node having Pending Interest Table (PIT) entries. This means that the BSAM scheme decreases the average number of interest packets transmitted.

Boukerche and Coutinho [37] presented an architecture to improve the cache discovery process and reduce the broadcast storm problem in intelligent vehicular networks, called LoICen (Location-based and Information-Centric). In LoICen, the receiver vehicles obtain the location of the vehicles that might have an interest packet in their cache. Whenever possible, this location information is available to be used during a cache discovery process. The location-oriented approach employed in LoICen and selecting only the most suitable neighboring vehicle to continue forwarding the interest packet is possible.

Guo et al. [38] proposed a scheme to mitigate the broadcast storm problem of interest packets, named BRFD (Bayesian-based Receiver Forwarding Decision scheme for the interest packet). In BRFD, the forwarding of an interest packet is decided based on knowledge of network operation conditions learned by the Bayesian decision model. The model considers the distance between a sender node and a receiver node, vehicle speed, and the one-hop neighborhood degree. Thus, BRFD suppresses the interest broadcast storm issue that could flood the VNDN network.

Burhan and Rehman [39] proposed a strategy called BSMS (Broadcast Storm Mitigation Strategy) to mitigate the broadcast storm problem. BSMS also tackles the issue of the disconnect link by using a receiver timer counter. Moreover, BSMS relies on the distance and speed between receiver and sender vehicles to obtain this timer counter. Thus, the farther vehicle among neighboring vehicles transmits the interest packet by the network. When the interest packet is not received by the requesting vehicle, BSMS uses a forwarder timer counter. The interest broadcast operation is repeated when the forwarder timer counter finishes.

To address the transmission prioritization process, several research studies presented in this section used the forwarding strategies of interest packets based on the distance and link stability between receiver vehicles and the current sender. We also show approaches that consider a timer counter to prioritize the forwarding of interest packets among neighboring vehicles. Unlike these strategies, OVERT VNDN advances the state-of-the-art by using computational geometry and degree centrality concepts to tackle the broadcast storm problem that arises during inter-vehicle communications efficiently, as shown below.

3. OVERT VNDN: Towards an Efficient Cache Discovery Protocol

This section introduces OVERT VNDN, a cache discovery protocol that harnesses both the computational geometry and degree centrality concepts to tackle the broadcast storm problem in VNDN. OVERT VNDN has as its main goal to improve the content delivery ratio while maintaining a high cache hit rate on searching by the content with fewer transmissions of interest packets. The following describes the development of OVERT VNDN, including the problem formulation, the proposed protocol, and its operations.

3.1. Problem Formulation

The broadcast storm problem is critical in ad-hoc wireless networks since it causes inefficient use of network resources. In regards to the VNDN technology, the propagation occurrence of interest packets needs to be done in a controlled manner with the prospect of reducing one of the main challenges in inter-vehicle communications, packet collision incidence. Redundant transmissions of interest packets result in more packet collisions in the network, increasing rates of both content delivery delay and packet losses, and jeopardize VNDN application performance. Figure 1 shows a general VNDN scenario for which the broadcast storm occurs.

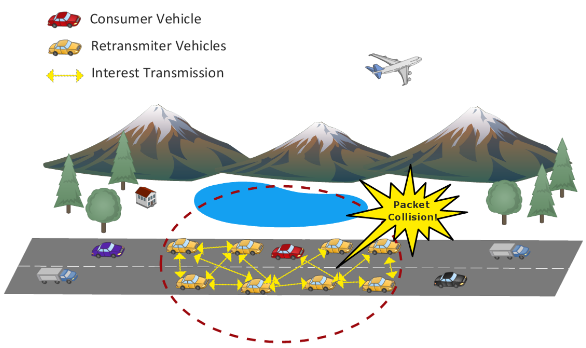


Figure 1. Occurrence of a broadcast storm in a general VNDN scenario.

From Figure 1, the consumer vehicle initially transmits an interest packet specifying the content's name on the network. Then, the neighboring vehicles receive the packet. Since they do not have the corresponding data packet in the cache, all receiver vehicles will simultaneously retransmit the interest packet on the network. The result of these multiple retransmissions is the collision of packets. It is necessary to develop VNDN-tailored interest packet forwarding intelligent solutions, with the ability to reduce excess transmissions and enhance the efficiency in content delivery, in an attempt to mitigate the occurrence of a broadcast storm.

3.2. Proposed VNDN Protocol Model

Based on the problem formulation, the definition of the proposed protocol is described in the following.

Definition 1. *We consider an urban VNDN scenario composed of n vehicles. Each vehicle v_i has an ID ($i \in [1, n]$) and is equipped with a communication interface compatible with the IEEE 802.11p standard. Such vehicles are modeled by a dynamic graph $G = (V(G), E(G))$, which represents the asymmetric wireless links between vehicles, where $V(G)$ represents the set of vehicles and $E(G)$ represents the communication link between neighboring vehicles. Each vehicle $v_i \in V(G)$ knows its position in progress p_v using a Global Positioning System (GPS). Furthermore, the set of neighboring vehicles $N_v \subseteq V(G)$ is composed of neighbors at one hop of v_i. The set $E'_v \subseteq E(G)$ represents the communication link between v_i and its neighbors. Finally, let $Q = V(G)$ be the set of points containing the vertices of G.*

Definition 2. *We consider each vehicle continuing to propagate the interest packet as a point p in the convex hull of the set of points Q. For this, we assume that a polygon is convex when there is no straight line between two points inside the polygon that reaches the outside of the polygon. The convex hull of Q consists of the smallest convex polygon $CH(Q)$ such that every point belonging to Q is inside or on the edge of $CH(Q)$.*

OVERT VNDN aims to reduce the number of transmissions of interest packets while maintaining a high cache hit rate and an increase in the content delivery rate. For this purpose, OVERT VNDN is based on the concept of computational geometry and degree centrality to choose the vehicles transmitting interest packets. In this case, the problem of finding the convex hull in a given set Q of points was applied. This was done because the application of the convex hull can be made dynamically and independently of the scenario in question. Next, we present the functioning of OVERT VNDN to propagate interest and data packets.

3.3. OVERT VNDN Operations

To propagate interest packets, each vehicle v_i transmits periodic beacons containing its identification ID and its current position p_v. The idea is that v_i contributes to contextual knowledge about its neighbors. Upon receiving a beacon, v_i saves this information in its list of neighbors N_v. v_i generates a set of points Q when it needs to transmit the interest packets. Then, v_i calculates the convex hull $CH(Q)$ having as a parameter Q with the Graham scan algorithm, whose time complexity is $O(nlogn)$ [40]. After applying the Graham scan algorithm, among the vehicles that make up the minimum convex polygon, vehicles with higher degree centrality are selected to propagate the interest packet in the network, as presented in Figure 2. The degree centrality is the number of vehicles neighboring the receiver vehicle, which is computed based on the beacon message. Degree centrality is an essential metric for understanding the importance of a node in the network [41]. Next, the receiver vehicle inserts $CH(Q)$ in the interest packet. When neighboring vehicles receive the interest packet, they check if they are relay vehicles, making sure their IDs are contained in $CH(Q)$. According to its degree centrality, such vehicles are selected to continue the process of retransmitting interest packets. Otherwise, they will discard interest packets.

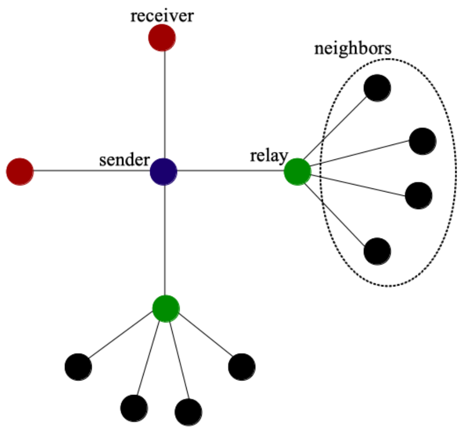


Figure 2. Cache discovery strategy.

Algorithm 1 shows the cache discovery mechanism's operation to continue the transmission of the interest packet. When the packet received is an interest with particular content, it is necessary to check if such the interest is duplicated. For this, a search on the Pending Interest Table (PIT) is done (Line 3). PIT is used to maintain interests that have not yet been served with the corresponding data packets. If the interest is duplicated, it means that the same interest already exists in the PIT, and therefore, the interest received is discarded (Line 23). If there is any transmission scheduled for the interest stored in the PIT, the transmission will be canceled (Lines 21–22). This occurs due to a previous transmission of an interest packet by a neighboring vehicle. If the interest packet is not duplicated, the vehicle will consult the Content Store (CS) for the corresponding data packet (Line 4). CS is used to store the data packets according to the Time-To-Live (TTL) of the content. If the vehicle has the data packet, it means that there was a cache hit. Consequently, the vehicle sends the data packet to the vehicle that requested the content (Line 19). Otherwise, there will be a cache miss. With this, the vehicle inserts the interest in the PIT (Line 5). In the next step, the vehicle checks if it is a relay node (Line 6), checking in the received interest packet whether the ID appears in the set $CH(Q)$ corresponding to the relay vehicles. If the ID is contained in $CH(Q)$, it means that the vehicle is part of the convex hull and, therefore, will transmit the interest packet according to its degree centrality (Lines 12–13).

Algorithm 2 shows the processing of the proposed protocol's data packet. When a vehicle receives a data packet, it checks if there is any interest related to that content in the PIT (Line 2). If any interests are pending in the PIT, the vehicle checks if there is any schedule for the transmission of these interests. If so, the vehicle cancels such appointments (Lines 3 and 4). In this case, the vehicle transmits the data packet to the vehicles interested in that content and removes such interests from PIT (Lines 5 and 6). Furthermore, in the processing of the data packet, whenever a vehicle receives a data packet, it stores it in the CS (Line 7). With this, the vehicles operate as data mules transporting the content to another region to meet future requests and keep the content closer to potential vehicles interested in that content. This approach is also known as store-carry-forwarding.

It should be noted that the main contribution of the proposed protocol is given by the developed cache discovery strategy, which is based on the convex hull and the degree centrality of the neighbors to choose the best relay vehicles. As a result, it is possible to maximize the spread of interest, maintaining a high cache hit rate in the cache discovery process with fewer transmissions of interest packets, as will be presented in the next section.

Algorithm 1: Received `Interest` packet.

```
Input: Interest [Name, Selector(s), NONCE, transmiterVehicles]
begin
    relays ← ∅;
    if Name ∉ PIT then
        if Content ∉ CS then
            PIT.insert(Interest);
            if myID ∈ Interest.transmiterVehicles then
                // Q represents neighboring vehicles
                relays ← convexHull(Q);
                Interest.transmiterVehicles.add(relays);
                d ← getDistance(receiver, sender);
                g ← getDegree();
                if receiver vehicle has neighbors then
                    T ← 1/(d + g);
                    scheduleAt [Interest, simTime() + T];
                else
                    discard Interest;
            else
                discard Interest;
        else
            Send DATA;
    else
        if Interest is scheduled then
            Cancel Interest transmission;
        discard Interest;
```

Algorithm 2: Received `DATA` packet.

```
Input: DATA [Name, MetaInfo, Content]
begin
    if Name ∈ PIT then
        if Corresponding Interest is scheduled then
            Cancel Interest transmission;
        Send DATA;
        PIT.remove(Interest);
    CS.insert(DATA);
```

4. Performance Assessment

In this section, the performance of OVERT VNDN is evaluated by comparing it with Vanilla VNDN [42]. The simulation tools, the mobility scenario, the chosen metrics, and the obtained results are presented below.

4.1. Simulation Setup

The proposed protocol assessment was carried out leveraging computer simulations. In light of this, the OMNeT ++ 4.6 (http://www.omnetpp.org/) and the Vehicles in Network Simulator (Veins) (http://www.veins.car2x.org/) tools were used to reproduce the behavior of the implemented protocols. The Canadian Ottawa city map (importing the city area (2 km^2) through the OpenStreetMap (http://www.openstreetmap.org)) was defined to generate vehicle mobility patterns using the Simulation of Urban Mobility (SUMO) 0.21.0 (http://www.dlr.de), as shown in Figure 3.

Figure 3. Downtown area of Ottawa, Canada [43].

To achieve a fair comparison among the protocols participating in the simulation trials, we assumed that 30% of the vehicles operated as consumer nodes, as modeled in the compared works. These vehicles were selected at random during the simulation startup. A variation of producer vehicles was made in 5%, 10%, 15%, 20%, and 25%. Furthermore, a varying vehicle density of 100, 200, 300, 400, 500, and 600 was set to assess the resulting impact on the protocol content delivery ratio. Similarly to consumer vehicles, producer vehicles were selected at random during the simulation startup. As both the data packet and interest packet size were small, namely 8192 and 400 bits, and they were stored only for the TTL time (25 s), it was assumed that the vehicles which supported this type of communication would have enough storage capacity to handle these messages. The other sets of parameters to perform the simulation trials are shown in Table 1, following the KPIs considered for the evaluation of the protocols: (i) cache hit rate; (ii) content delivery rate; (iii) delay in the content delivery; (iv) packet collision rate; and (v) interest packet transmission rate.

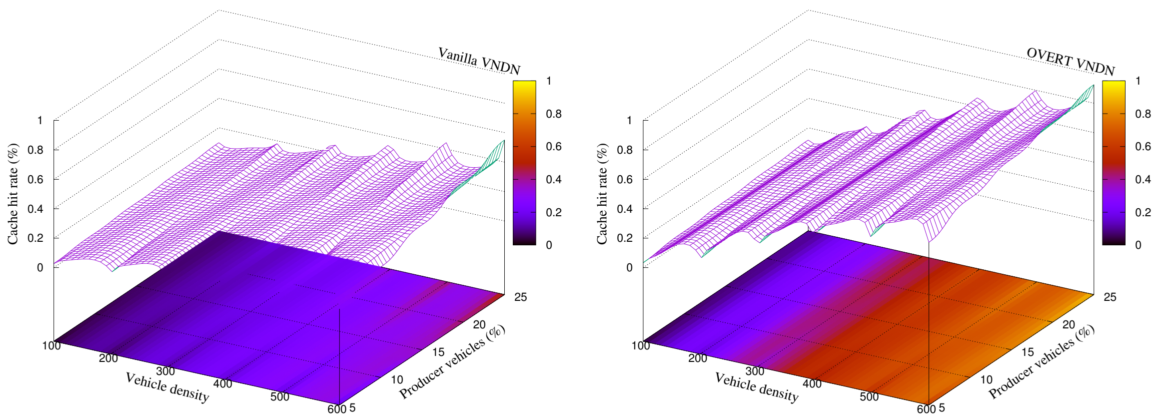
The main goal was to analyze the efficiency of OVERT VNDN in terms of content delivery rate from the beginning of the broadcast storm incidence, which happens during the communication between vehicles participating in the VNDN scenario. To do that, each simulation trial was run 33 times to obtain a 95% confidence level based on the t-test. The results obtained from their discussions are presented below.

Table 1. Simulation parameters.

Parameter	Value
Simulation area	Downtown Ottawa (2 km^2)
Transmission power	1.6 mW
Transmission range	250 m
Frequency band	5.9 GHz
Frequency of beacons	1 Hz
Communication technology	IEEE 802.11p
MAC	IEEE 1609.4
Bit rate	6 Mbps
Data packet size	8192 bit
Interest packet size	400 bit
Interest timeout	15 s
Number of chunks	10
Interest lifetime	25 s
Executions	33
Number of consumers (%)	30
Number of producers (%)	5, 10, 15, 20, 25
Simulation time	350 s

4.2. Results Assessment

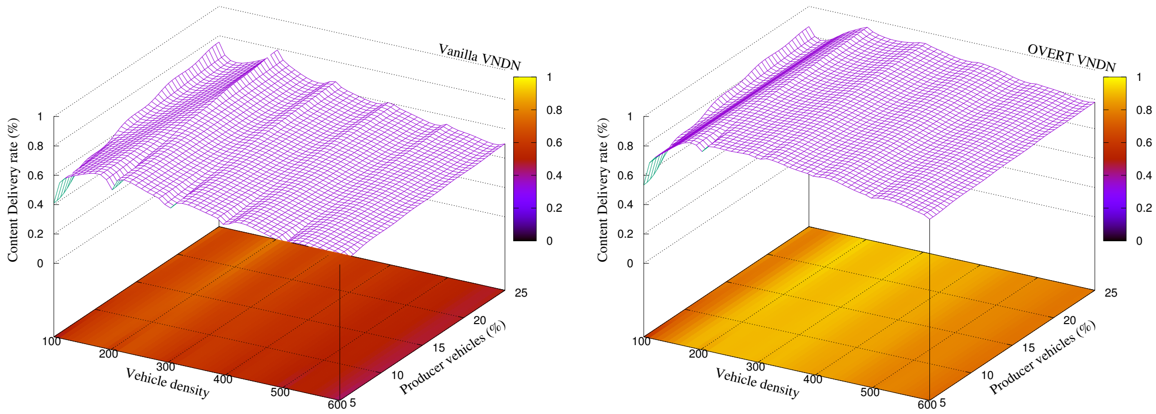
The cache hit arose as to the first KPI, due to its usage in assessing the protocols' capabilities during the cache discovering process in VNDNs. Figure 4 depicts the outcomes that both Vanilla VNDN (Figure 4a and OVERT VNDN (Figure 4b) benchmarking solutions allowed obtaining. It is possible to notice that there was a positive correlation between the vehicle's density degree, the number of producers, and the cache hit. In other words, as the vehicle density and producers increased, the cache hit level also increased. The proposed OVERT VNDN protocol outperformed Vanilla VNDN in both vehicle density degree and the number of producers. On average, OVERT VNDN reached more than double (a 120.47% increment) the cache hits as the Vanilla VNDN protocol. The heat map clearly shows this considerable difference. The adopted cache discovery strategy enabled this behavior since it used computational geometry modeling plus degree centrality to select the relay vehicles. The choice of the next vehicles that would continue to propagate interest packets in the network was made dynamically and regardless of the scenario. To improve on this, the OVERT VNDN protocol applied the problem of finding the convex hull to determine the next relay vehicles. Upon finding the vehicles that formed the minimum convex polygon, it applied the degree centrality metric to prioritize those vehicles that highlighted a significant number of neighboring vehicles. A reduction in the broadcast storm incidence was allowed, while the cache hit rate increased on the network.



(**a**) Percentage of cache hits—Vanilla VNDN (**b**) Percentage of cache hits—OVERT VNDN

Figure 4. Percentage of cache hits (%). OVERT, discOVEry pRoTocol.

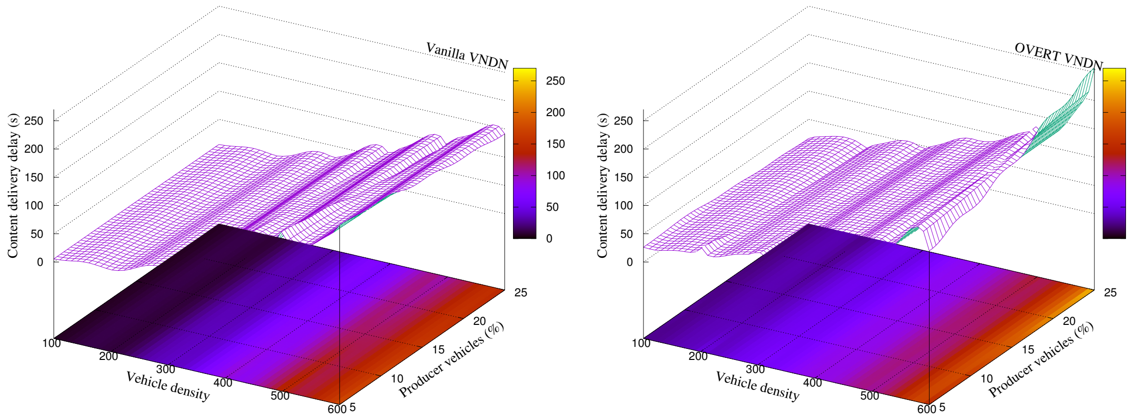
Figure 5 shows the content delivery KPI. In the beginning, which showed a reduced vehicle density (100), as well as a small number of producers (5%), the content delivery rate was low for both Vanilla VNDN (Figure 5a) and OVERT VNDN (Figure 5b). However, as the number of producers increased from 5% to 25%, the content delivery rate also increased. Nevertheless, OVERT VNDN outperformed the Vanilla CNDN solution regardless if the variation of both the vehicles' density and the number of producer vehicles used, for which the heat map provides evidence. On average, OVERT VNDN reached 83.33% of the content delivery rate against the 58.02% of Vanilla VNDN, which revealed an improvement index of more than 43%. The cache discovery strategy that OVERT VNDN adopted, which allowed minimizing the broadcast storm problem during the coarse of the cache discovery process, suggested the reason behind this improvement. Furthermore, as the vehicle density increased in the network (from 100 to 300 vehicles), the coverage rate also increased. However, when the scenario became denser (from 400 to 600 vehicles), the trend was that the performance rate of both protocols began to degrade in regards to content delivery. The existence of many vehicles transmitting interest and data packets on the network, which consequently resulted in higher packet collision incidence, hinted at the cause.



(**a**) Content delivery metric—Vanilla VNDN (**b**) Content delivery metric—OVERT VNDN

Figure 5. Content delivery metrics.

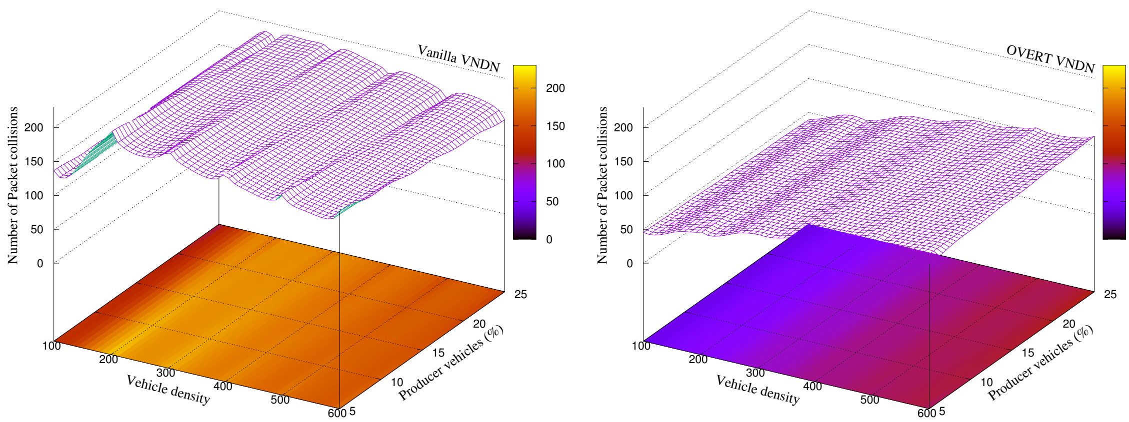
Figure 6 sketches the behavior of the content delivery delay obtained in the simulation trials. In the low-density scenarios (from 100 to 300), the time to receive the content decreased as the number of producer vehicles increased. The cause could be explained because more content, closer to consumer vehicles, was being produced. On the other hand, as vehicle density increased on the network, the content delivery delay also increased. The incidence of packet collision on the network arose as the main reason, because of the resulting rates in packet losses and content delivery delays. Although OVERT VNDN (Figure 6b) had a longer delay in retrieving content in comparison to Vanilla VNDN (Figure 6b), it was still more effective in discovering and delivering content to consumer vehicles. Therefore, OVERT VNDN guaranteed greater efficiency during the content discovery and recovery stages, one of the critical challenges in VNDN communication.



(**a**) Delay in the content delivery—Vanilla VNDN (**b**) Delay in the content delivery—OVERT VNDN

Figure 6. Delay in the content delivery.

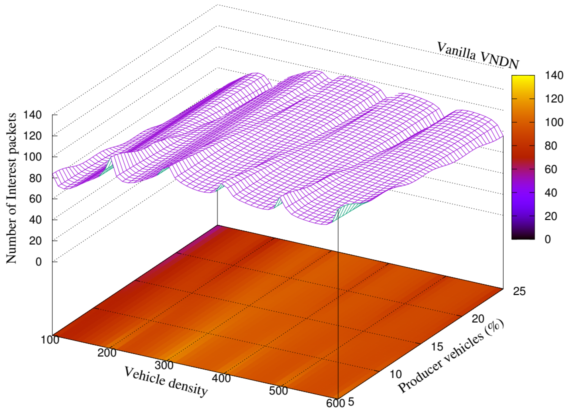
Figure 7 depicts the packet collision rate for both Vanilla VNDN (Figure 7a) and OVERT VNDN (Figure 7b). As expected, the number of collisions increased as the scenario became denser. This was especially true for Vanilla VNDN trials, which had a faster and higher gain in this KPI. The lack of coordination of relay vehicles during the cache discovery period was the leading cause of this behavior. The OVERT VNDN proposal was able to reduce the packet collision incidence rate considerably by more than 50%, on average. It also managed to distribute the losses better, presenting a stable increment according to the vehicles' density. However, because OVERT VNDN was more efficient in the cache discovery process, reaching a more significant number of producer vehicles also increased the packet collision, as these vehicles would even start to transmit. While this was true, the overall benefits of OVERT VNDN atoned for the packet collisions.



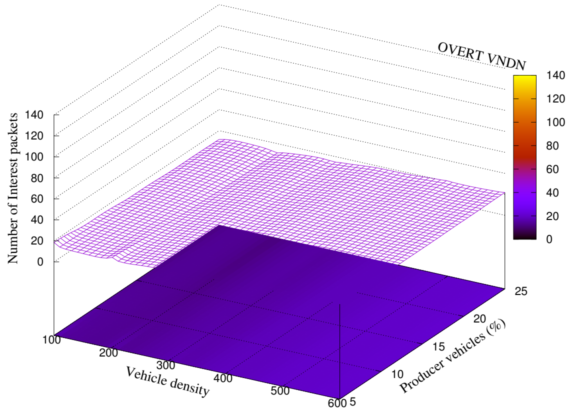
(**a**) Packet collision rate—Vanilla VNDN (**b**) Packet collision rate—OVERT VNDN

Figure 7. Packet collision rate.

The average number of interest packets transmitted in the cache discovery process, to retrieve the desired content (Figure 8), was the last KPI assessed. As anticipated, when the number of producer vehicles increased on the network, the number of interest packets transmitted decreased in the stage of searching for content. On average, OVERT VNDN (Figure 8b) reduced by 80.99% the number of transmitted interest packets in comparison to Vanilla VNDN (Figure 8a). This reduction was achieved because of the interest forwarding strategy that relay vehicles adopted, which was based on the computational geometry and degree centrality of the receiver vehicle. This strategy owed the ability to cancel already scheduled interest packets that no longer needed. Besides, the proposed approach allowed only vehicles that had neighbors to continue to propagate the interest packet through the network. On the other hand, vehicles without neighbors discarded the interest packet because they would not reach potential producer vehicles.



(**a**)Interest packet transmission rate—Vanilla VNDN



(**b**)Interest packet transmission rate—OVERT VNDN

Figure 8. Interest packet transmission rate.

5. Conclusions

The VNDN technology enables a high performing large-scale content distribution in IP-centric VANETs. There are still many challenges that need to be addressed in this field. This work tackled the negative effect of the broadcast storm during communication between vehicles in the VNDN cache discovery process. OVERT VNDN protocol's main goal was to minimize the interest packet broadcast storm issue in VNDN. This allowed maximizing the content delivery rate on the network. To accomplish such an objective, OVERT VNDN took advantage of the computational geometry and degree centrality concepts to choose the relay vehicles dynamically. With that, it was possible to tackle the broadcast storm problem that arises during inter-vehicle communications. This process happened regardless of the scenario in question allowing for better propagation of the interest packets on the network. The simulation results showed that the proposed protocol outperformed its competitor. It improved the cache discovery process by 120.47% as well as the content delivery rate by 43%. At the same time, it reduced the number of interest packets by 80.99%.

As further work, we intend to compare OVERT VNDN with other works in the literature. Moreover, a new protocol is going to be developed to improve the data packet forwarding strategy based on the problem of finding the convex hull. The new protocol will disseminate the data packet based on the density of the urban road. Furthermore, a new implementation of the content replacement policies based on its popularity also is going to be proposed, as well as security and privacy issues are going to be considered.

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