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# ICN clustering-based approach for VANETs

Lamia Chaari Fourati<sup>1</sup>, Samiha Ayed<sup>2</sup>, Mohamed Ali Ben Rejeb<sup>1</sup>

In recent years, the use of information-centric networks (ICNs) within vehicular ad hoc networks (VANETs) has been shown to be a favourable and deployable future Internet paradigm. Within the context of VANETs, the use of ICNs has many advantages. Indeed, ICNs offer the benefit of in-network content caching and strategies. In addition, ICNs accelerate content retrieval based on the caching of different nodes. Cache deployment within VANETs can be performed at low cost and with low energy consumption. However, the use of ICNs within the VANET context may be challenging. In fact, it may impact network mobility and continuity. Thus, traditional clustering algorithms are not suitable in the context of ICN-based VANETs. In this paper, we propose a new clustering-based approach integrating ICN, called VC-ICN. The aim of our approach is to guarantee network continuity without impacting its mobility when the ICN paradigm is used. We show through simulation, considering scenarios in real-world contexts, that VC-ICN allows vehicles to enhance their content delivery ratio, the average delay for content delivery and the transmission overhead.

**Keywords** Clustering · Information-centric network · Vehicular networks

## 1 Introduction

The automotive industry is a significant component of economic benefits. The global market for smart connected vehicles is projected to exceed 342.6 million in 2023. In recent years, the transition to connected driving has been accelerated by cross-sector synergies with enablers such as the IoT (Internet of Things) and 5G/6G. This evolving domain continuously brings a strong motivation for more proficient transport systems. In fact, VANETs offer sophisticated applications for more efficient transportation systems, ranging from navigation systems, safety, and diagnostics to in-car entertainment and comfort. The

rapid evolution of ITS services and their characteristics bring new requirements for communication efficiency. Enhancing communication efficiency may offer a better user experience and improve the quality of service (QoS) offered by connected vehicles. Apart from the advances offered by 5G/6G to enhance communication efficiency, there are initiatives in the literature that aim to implement different approaches. Recently, adopting information-centric networks (ICNs) [1] has shown better results for content distribution than traditional host-centric networks. The ICN paradigm consists of changing the addressing scheme within a network architecture. Instead of basing the network architecture on the IP address to forward data packets, ICN focuses on directly addressing the identified data (information or content). The main advantages of the ICN approach compared to the host-centric approach are that the ICN approach offers better connectivity within the network, facilitates mobility and offers better scalability. Improvements are facilitated through the caching technique that the ICN approach offers. Data caching helps to speed up information retrieval based on the caching of different nodes at fairly low cost. These ICN advantages lead to improved efficiency since the data are no longer location-dependent. The expected benefits of the ICN paradigm encourage researchers to investigate its applicability within different domains.

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✉ Samiha Ayed  
samiha.ayed@utt.fr

Lamia Chaari Fourati  
lamiachaari1@gmail.com

Mohamed Ali Ben Rejeb  
medali99@live.com

<sup>1</sup> Digital Research Center of Sfax-SM@RTS, University of Sfax, Sfax, Tunisia

<sup>2</sup> University of Technology of Troyes, LIST3N, Troyes, France

Many initiatives propose integrating the ICN as a new paradigm into numerous emerging smart applications [2], particularly for smart transportation [3]. The challenges that the ICN paradigm addresses are crucial within the context of VANETS since these environments are based on connectivity, mobility and scalability that can be enhanced using an ICN approach. However, adopting the ICN paradigm in VANETs is not an easy task due to vehicular network characteristics, such as their dynamic topology as well as their irregular connectivity signals. One integration approach of ICNs within VANETs is to consider ICNs for the clustering mechanisms that serve to improve the connectivity and mobility of the network.

In the literature, many VANET cluster-based protocols have been proposed to reduce the number of control messages by dividing vehicles into groups called clusters where each cluster is led by a head (CH). However, to our knowledge, most of the proposed approaches are IP-based, and few contributions have focused on ICN-based clustering mechanisms. The authors in [4, 5] designed a clustering algorithm to assemble vehicles with similar mobility patterns based on mobility prediction and proposed a cooperative caching strategy to construct inter-cluster and intra-cluster communication over vehicle clusters. The authors in [6] proposed a topic-based clustering mechanism that realizes information retrieval and shares by delegating this task to vehicles that have infrastructure access and are ready to provide the service to their neighbouring vehicles. The transport protocol used is based on the ICN paradigm, which was proven to be perfect for information retrieval with the proposed topic-based clustering. Hence, in this paper, we propose a new ICN-based clustering approach for vehicular networks. The main contributions of this paper concern our new clustering scheme called VC-ICN (Vehicular Clustering scheme based on ICN), and they can be summarized as follows:

- It provides a comprehensive description of content dissemination in VANETs based on the ICN paradigm.
- It highlights and presents recent clustering techniques in VANETs that have been published during 2018-2020.
- It details the basic concepts of the proposed VC-ICN clustering approach.
- It compares the performances of our proposed VC-ICN algorithm over different mobility scenarios in two cases: (1) nodes support only the ICN without a clustering mechanism and (2) nodes support the ICN with K-means as the clustering mechanism.

The remainder of this paper is organized as follows: Section 2 presents the content dissemination in VANETs based on the ICN paradigm. Section 3 introduces the main concepts of clustering in VANETs, highlights, and compares some recent related works focusing on clustering

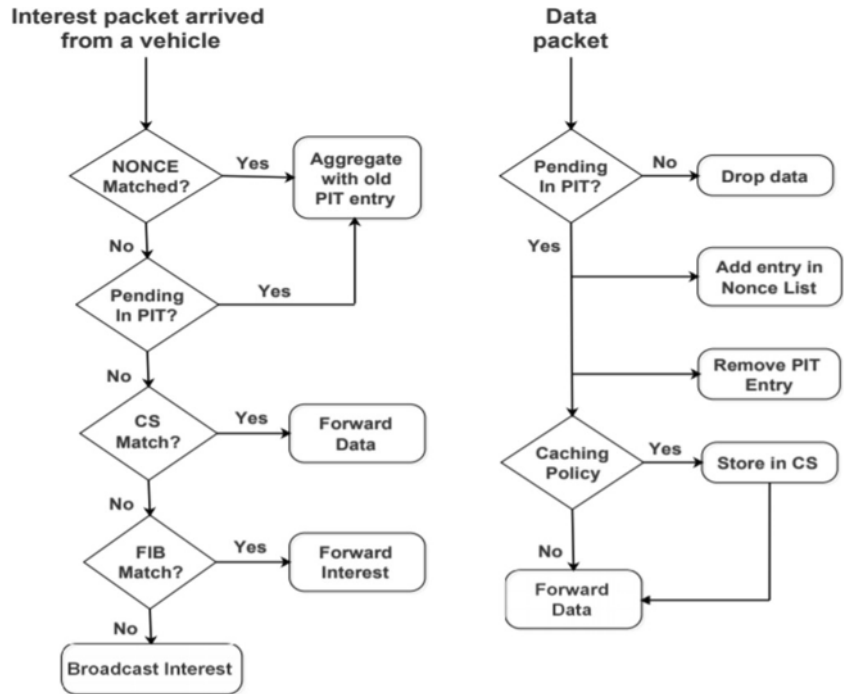
in VANETs. Section 4 depicts the clustering scheme VC-ICN designed for VANETs in this work. Section 5 addresses VC-ICN performance evaluation and provides simulation results and discussion. Finally, Section 6 concludes the paper.

## 2 Content dissemination in VANET based on ICN

The ICN is a receiver-driven networking model. It consists of requesting interests by end-users based on content names. ICN is based on two types of packets: interest packets and data packets. An interest packet is sent by users or ICN nodes to carry the name of requested content. The data packet contains the corresponding content sent by the origin server or an intermediate ICN node. Every ICN node implements three data structures: pending interest table (PIT), content store (CS), and forwarding information base (FIB). The CS temporarily stores the locally cached data that are checked for each future interest request. The PIT stores the data name carried by the interest packet and the incoming and outgoing interfaces. The FIB table acts as the routing database that associates the outgoing interfaces with the reachable prefix names. CS, PIT, and FIB are involved in the interest forwarding process; however, only CS and PIT are considered in the data forwarding process. Figure 1 presents a flow diagram of interest and data packet processing. When an interest packet is received, the node checks if an entry corresponding to the same name of the requested data exists within the PIT table. In this case, the request will be aggregated with this entry. Otherwise, the CS is checked to verify if there is any matching entry with the received packet. Then, the data are forwarded to the consumer node. If not, the FIB table is checked to search for a corresponding outgoing interface to the data name of the received packet. If an entry exists, then the interest packet is forwarded to the corresponding interface. Otherwise, the interest packet is broadcasted. When a data packet is received, the PIT table is checked first. If no entry corresponding to the received packet exists, then the data are discarded. Otherwise, the data are stored in the content store (if a caching policy is applied) and forwarded. To highlight the content dissemination over a VANET-ICN network, we consider the scenario illustrated in Fig. 2.

Vehicle A sends an interest packet for/traffic.com/today.html (arrows 1, 2 and 3). If the PIT table already contains an entry for the same name of the requested data, then the router adds the incoming interface to this PIT entry. When an information object matches with the requested data name at a publisher node or in a CS of one of these nodes, the interest packet is neglected, and the data packet is forwarded back to Vehicle A based on the references stored in the FIB and PIT

Fig. 1 Flow diagram of interest and data packets



tables. When an intermediate vehicle receives a data packet, it stores it in its CS, forwards the data packet to the adequate interfaces, and deletes the request entry from the PIT (arrows 4, 5 and 6). We sketched the state of the art focusing

on data dissemination through VANET-ICN networks, and we noticed that only a few works have been proposed. In this context, the authors in [7] proposed a routing protocol for data dissemination in VANET-ICN. It discovers content

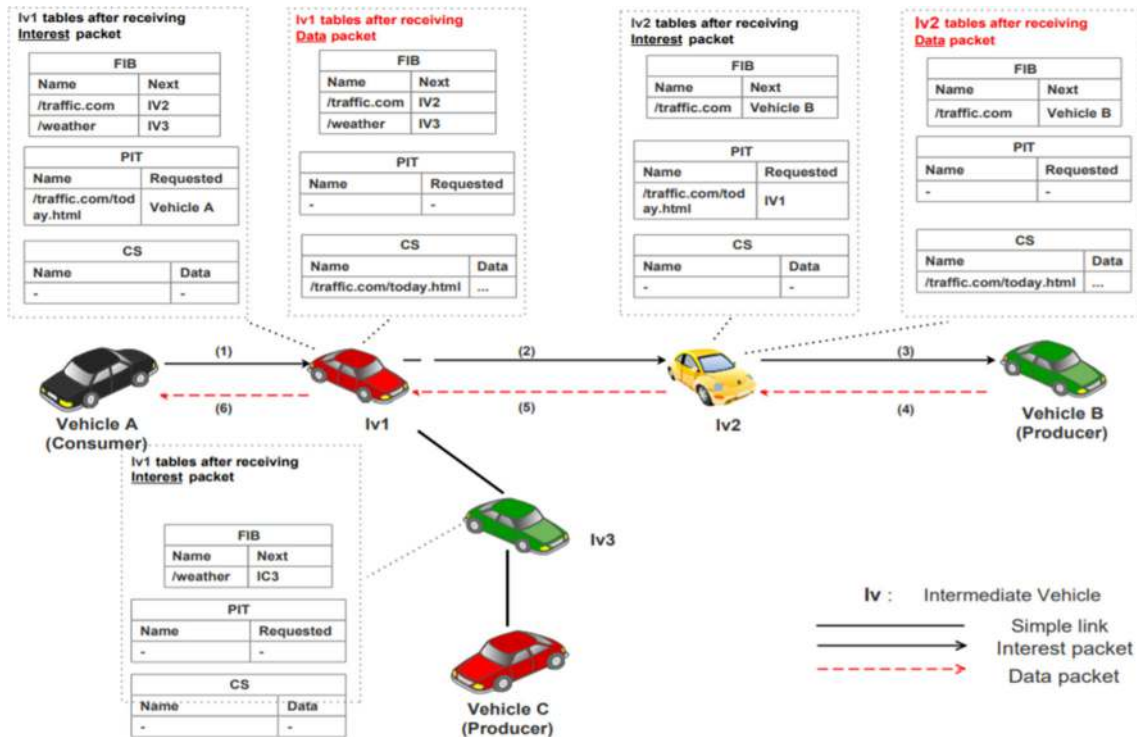


Fig. 2 Content dissemination in VANET based on ICN paradigm

sources, creates paths and forwards messages based on the information received from the paths. The main advantage of this scheme is avoiding redundant retransmissions by adding a unique identifier to each node (MAC address), which is also added to the PIT and FIB tables. In [8], the authors conceived the CCVN (content-centric vehicular networking) protocol. In CCVN, the path state information is kept into new data called the content provider table (CPT). CPT keeps track of the entire reachable content provider and replaces the traditional FIB table. CCVN has proven to be more efficient in VANETs in terms of reducing congestion and enhancing content delivery delay. In [9], the authors proposed a dynamic unicast scheme for information-centric multihop routing in MANET in which the requester node performs flooding to find the content source and then forward future requests directly to the same source as unicast. This scheme does not maintain source flexibility for every single interest packet. The authors also introduced a new data structure called Content Request Tracker (CRT) that keeps track only for the incoming unicast request to replace multiple unicast transmissions with just one broadcast transmission. Clustering has many advantages, and it improves the scalability of the network. Accordingly, in the next section, we will focus on clustering approaches for VANETs based on the ICN paradigm.

### 3 Clustering in VANETs

#### 3.1 Main concepts

Despite the diversity of clustering algorithms in the literature, these algorithms follow the same procedural phases. The clustering algorithm divides the network into groups (named clusters). The nodes having approximately the same characteristics (velocity, direction, etc.) are regrouped together in the same cluster. The fundamental clustering procedures are cluster head (CH) selection, cluster formation and cluster maintenance. To form clusters, several fundamental procedures should be applied: (i) neighbourhood discovery, (ii) cluster head selection, and (iii) node affiliation and cluster maintenance. In the following sections, we highlight these procedures. Each node participating in clustering will execute some or all of the procedures described below.

- Neighbourhood discovery: Initially, when a vehicle joins the road, it needs to communicate with the other vehicles present in the same network. Each vehicle begins by announcing its existence to its neighbours in the same network through a periodic broadcast message, and it simultaneously gathers information from other vehicles by listening to neighbour solicitation

requests or to their broadcast messages. Collected information, such as position, velocity and direction, is stored in a neighbour table to be used by the clustering algorithm.

- Cluster head (CH) selection: The next step after collecting and extracting data from a neighbour's table is to find the suitable node that will play the role of the CH. The CH serves as a local coordinator for its cluster. The cluster head (CH) is selected to manage the communication inside or outside its cluster.
- Node affiliation: The CH is responsible for affecting and maintaining nodes in the cluster. The cluster size generally depends on the transmission range of the wireless communication devices used by the nodes.
- Announcement: The vehicle, having determined itself to be the most suitable CH, sends an announcement message to its neighbours to start the formation and assignment process.
- Cluster maintenance: After forming the cluster, the maintenance of the cluster is carried out in two different parts: (i) maintenance as a CH and (ii) maintenance as a member node. The maintenance process allows the CH to change, merge with other clusters and track lost links of the members.

#### 3.2 Clustering approaches

In this section, we address the existing clustering approaches within VANETs (Tables 1 and 2). Globally, such approaches are characterized by a specific number of cluster heads (CHs) as well as their selection procedure. In addition, they can differ in terms of the considered metrics for CH selection, such as speed, number of neighbours, trust degree, position and acceleration. The authors in [10] propose a new data dissemination approach using a probabilistic broadcasting (CPB) scheme. Then, they associate the built scheme to their clustering strategy. For that, they consider, during cluster creation, the driving directions of different vehicles. In their scheme, the authors define the data dissemination among vehicles based on a probabilistic forwarding strategy. To respect the defined strategy, a cluster node forwards a data packet to its cluster head according to a calculated probability. That value corresponds to the number of times the same packet was received during one specific interval. The authors in [11] build their clustering scheme based on the trust concept. The authors associate trust values to different nodes within each cluster. Then, the cluster head is elected as the most trustworthy node having the highest trust value. Likewise, the authors in [12] use the trust concept to select the best nodes that will be responsible for forwarding the packets. In addition, other approaches aim to propose clustering mechanisms to satisfy the stability

**Table 1** Related clustering approaches

Ref	Objectives	Scenario	Forwarding strategy	Simulation	Advantage
[10]	Data dissemination scheme: (1) Directional clustering, (2) Probabilistic Broadcasting	Highway	Probabilistic Broadcasting	NS2	Enhances packet delivery ratio; information coverage and average transmission delay
[11]	Trust-based authentication Technique (TBAT) for clustered VANET	Highway with 2 bands and each band having 3 lanes and each lane having 3 clusters	Consider only trusted nodes	NS2	(1) Enhances security by electing as CH only trusted nodes, (2) less overhead and delay
[12]	Clustering routing protocol based on the QoS (Quality of Service) requirements.	Highway scenario	Trust value introduced to select nodes as gateways for forwarding the packets	NS2	It specifies a reliable and stable cluster and increases the stability and connectivity during communications
[13]	Evolutionary Game Theoretic (EGT) framework for automatic clustering formation and CH election	Static and mobile scenario (Manhattan grid as a mobility model)	According to 802.11p standard	MATLAB	(1) Efficient and stable routes for data dissemination, (2) Reduces frequent cluster reformation due to frequent change in topology.
[14]	Mobility-based clustering algorithm that considers vehicle speed, position, direction, link expiration time and the signal-to-noise ratio	(1) Highway with 2 directions each one have 6 lanes; each lane is divided into a number of edges, (2) A real highway (5 km), the Katy Freeway in the southern US	According to 802.11p standard	NS3 + SUMO	(1) Enhances performance and stability features, during the cluster maintenance phase, (2) Enhances reliability.
[15]	The clustering approach is based on the required information about a vehicle's multihop neighbours obtained from the RSU.	Not specified	Based on a Breadth-first search (BFS) algorithm	NS2 + VanetMobiSim	It strengthens clusters' stability through the selection of a Slave Cluster Head in addition to the Master Cluster Head.
[16]	Fuzzy-based cluster-management system that compares two fuzzy-based system models: FBCMS1 and FBCMS2 for clustering of vehicles in VANETs	The selection of the cluster head is based on varying the parameters: group speed (GS), relative acceleration (RA) and security (SC)	Not specified	Not specified	By selecting vehicles with high parameter values, the vehicles have high connectivity with other vehicles and are more secure.

of VANETs [13, 14]. For instance, the authors in [13] propose an evolutionary game theoretic (EGT) framework to evaluate cluster stability in large-scale VANETs. Good performances were presented for the proposed scheme based on varying the number of clusters. In [15], the authors propose an approach based on a breadth-first search (BFS) algorithm for traversing a graph based on a mobility rate that is calculated according to mobility metrics. Fuzzy approaches have also been studied in [16]. Moreover, clustering approaches have been proposed to improve the routing within VANETs [17–20]. In this context, the clustering mechanism helps to find the optimum route with minimal energy consumption [21].

## 4 VC-ICN: new ICN-based clustering algorithm

### 4.1 Assumptions

For our proposal, we utilize V2V communications. In our context, we do not consider the infrastructure components. We also consider that the communications between the vehicle nodes are based on the ICN paradigm applied within their transmission range. To discover their neighbours, the vehicles broadcast beacon messages. Moreover, each vehicle is equipped with (1) global positioning system (GPS); (2) processing unit (PU) and (3) a wireless unit

**Table 2** Related clustering approaches (continued)

Ref	Objectives	Scenario	Forwarding strategy	Simulation	Advantage
[17]	(1) Clustering-based reliable low-latency multipath routing (CRLLR), (2) Employing ant colony optimization (ACO) to compute the optimal routes, (3) Link reliability used as criteria for cluster head (CH) selection	(1) Highway with 2 directions each has 3 lanes for 5000 m, (2) The average velocity of each vehicle is in the range of 20 to 100 km/h	According to 802.11p standard	MATLAB + NS-3.25	(1) Reduces the end-to-end latency, (2) enhances the reliability by eliminating excessive RREQ messages.
[18]	(1) K-Medoid clustering model to cluster the vehicle nodes, (2) Energy-efficient nodes are selected for compelling communication, (3) Efficient nodes are recognized from each cluster using Enhanced Dragonfly algorithm	Not specified	Not specified	NS2	(1) Enhances energy efficiency in routing protocol, (2) Improves node lifetime and link lifetime.
[19]	Improve the routing efficiency in the cluster and among clusters	The roads were 1.74 km <sup>2</sup> and were composed of several trunk roads, sub trunk roads, slip roads, and intersections	Based on the PSO (Particle Swarm Optimization)	NS3 + SUMO	It has a 20% increase in packet delivery ratio (PDR) and a 47% decrease in delay
[20]	(1) Employing grey wolf optimization, (2) The linearly decreasing factor of grey wolf nature enforces earlier convergence	Not specified	Not specified	MATLAB	(1) Optimized number of clusters, (2) It minimizes the routing cost for the communication of the entire network

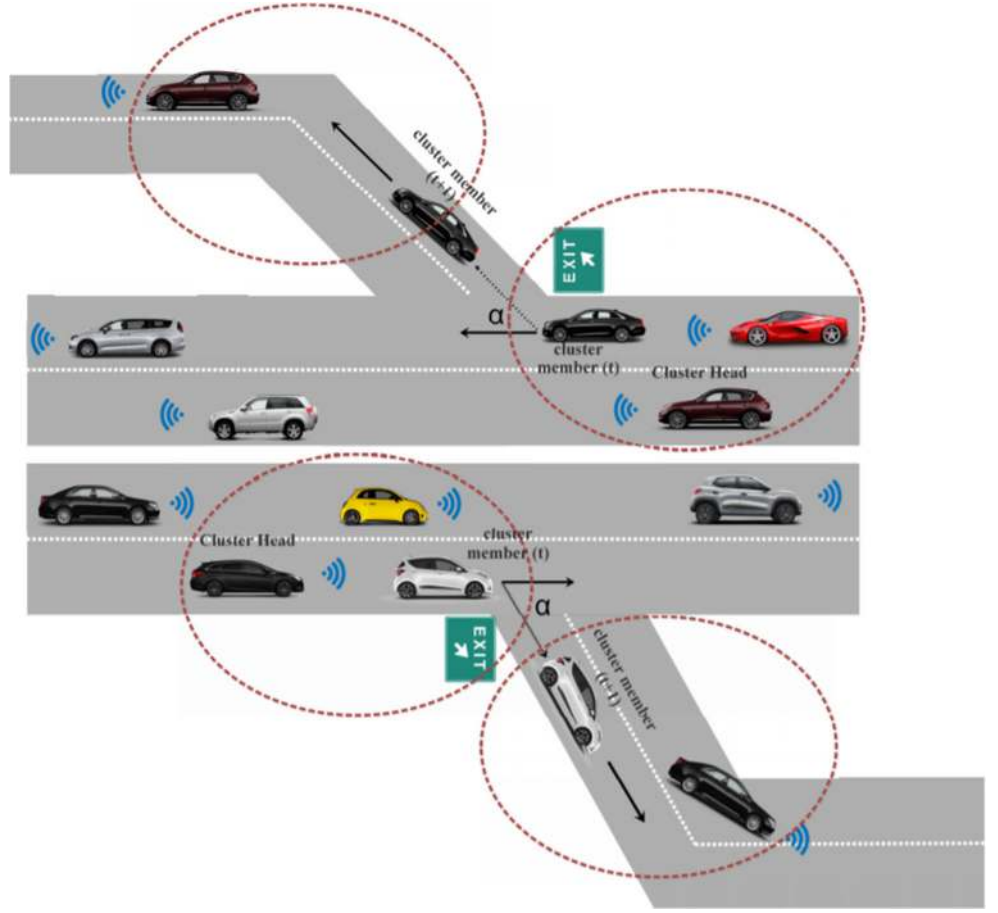
implementing ICN. Our solution is based on a distributed algorithm that is run by each vehicle independently. The approach can be applied either within highways or urban environments. Finally, we consider that the roads are bidirectional and have multiple lanes.

#### 4.2 Cluster formation and CH selection

First, all vehicles continuously join the road. When arriving on the road, a vehicle sends a periodic hello message if it is interested in joining the VANET. The hello message serves to announce the presence of the vehicle to its neighbours and to share its mobility information with them: vehicle ID, position, cluster ID and eligibility to be elected as a cluster head. The neighbours of a specific node are classified into two classes: consistent neighbours and inconsistent neighbours. This classification is based on the calculation of the angle between the direction of the vehicle and its neighbour. The consistent neighbour class of node  $i$  is composed of nodes having a direction angle with node  $i$  less than 45 degrees. If the direction angle with node

$i$  is greater than 45 degrees, then the neighbour belongs to the inconsistent neighbours class. In the following we give details about this process. To reach stability within different clusters, we base the cluster creation phase on the vehicle's directions. Four directions are possible for each vehicle: (1) straight, (2) left, (3) right and (4) U-turn. For this paper, we consider the scenario of a highway with different exits, as shown in Fig. 3. The directions of different vehicles are provided by GPS devices. For each vehicle, we associate a direction vector indicating the actual and future positions of the vehicles. The direction vector is denoted  $((x, y), (x', y'))$ . The calculation of the angle  $\alpha$  between two vehicles allows determination of whether the two vehicles are moving in the same direction. As an example, let us consider two vehicles  $V1$  and  $V2$ . At a specific time  $t$ , we suppose that the vehicles are in positions  $(x_1, y_1)$  and  $(x_2, y_2)$ . At  $(t + \delta t)$ , their corresponding positions are  $(x'_1, y'_1)$  and  $(x'_2, y'_2)$  as depicted in Fig. 4. We consider that if the angle between the directions of the two vehicles is less than 45 degrees, they belong to the same cluster, otherwise, they are grouped into two

Fig. 3 Highway scenario



different clusters. The calculation of this angle between the two vectors is expressed in Eq. (1) and Eq. (2).

$$\vec{OA} \cdot \vec{OB} = \|\vec{OA}\| \times \|\vec{OB}\| \times \cos(\alpha) \quad (1)$$

$$\alpha = \arccos\left(\frac{\Delta x_1 \times \Delta x_2 + \Delta y_1 \times \Delta y_2}{\sqrt{\Delta x_1^2 + \Delta y_1^2} \times \sqrt{\Delta x_2^2 + \Delta y_2^2}}\right) \quad (2)$$

where  $\Delta x_1 = x'_1 - x_1$  and  $\Delta y_1 = y'_1 - y_1$ ;  $\Delta x_2 = x'_2 - x_2$  and  $\Delta y_2 = y'_2 - y_2$

After the exploration phase, each vehicle has the required information about its surrounding neighbours. Then, each node is able to elect the best cluster head belonging to the consistent neighbours class. Our election process is based on the Floyd-Warshall algorithm [22]. Each vehicle considers its consistent neighbours class and calculates its distance with its different consistent neighbours. The node corresponding to the shortest distance will be elected as the cluster head. After receiving a positive acknowledgement, the node sends a joint request and updates its status to a cluster member.

### 4.3 Cluster maintenance

Since VANETs are characterized by their high mobility and dynamic topology, their clusters have to be updated periodically. During cluster maintenance, some nodes may leave the cluster, and new nodes may join that cluster. For

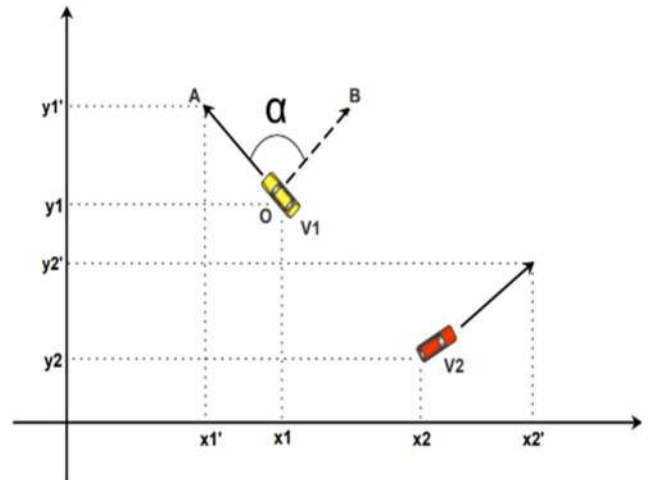


Fig. 4 Mobility direction angle



that, each cluster head periodically broadcasts a message inviting vehicles to join its cluster. The vehicles interested in joining that cluster will respond with a message containing the ID, the current position, the old position, the speed and the direction angle. When receiving this message, the cluster head checks the condition to join its cluster consisting of the calculation of the direction angle of the joining vehicle with the cluster head. If the direction angle is less than 45 degrees, then the condition is satisfied. Thus, the cluster head approves the vehicle request to join its cluster, so the vehicle is considered a cluster member.

#### 4.4 Data gathering

During this phase, we are mainly interested in how the required content by a consumer node is provided by producers based on our clustering technique. First, when an interest packet is sent by a node belonging to a specific cluster, the CH and the nodes of that cluster look to satisfy the received request. Thus, each node checks if it has the required data in its temporary content store (CS). If one of the cluster members is able to provide the required content, then the data are directly forwarded to the requester belonging to the same cluster, and the cluster head is notified. Otherwise, if none of the cluster members is able to satisfy the received request, then the cluster head forwards the received request to the nearest cluster head. The received request is forwarded until it is satisfied. When a member of another cluster is able to provide the required content, the data are then sent through the different cluster heads used to forward the initial request.

#### 4.5 VC-ICN: key innovations

The main innovation of our VC scheme consists of defining a clustering technique within an ICN-based architecture. Many clustering techniques exist in the literature (see Section 3.2). However, they are applied within a classic vehicular architecture that is based on a host-centric

approach. An ICN approach offers the possibility to access the required data independent of its location. Moreover, the metric that we choose to form our clusters brings good proximity to different cluster members. Thus, the exchanges within the network are more reliable. Associating the caching technique through the use of the ICN approach with the direction angle metric improves network connectivity and continuity. Thus, it helps resolve these two challenges that are critical within vehicular networks.

### 5 Performance evaluation

To evaluate the performance of our proposed scheme, we define a simulation test environment that reproduces the main characteristics of VANETs, mainly related to mobility. This choice has been made since an experimental evaluation in a real environment is not possible. To undertake our tests, we rely on software-based simulations allowing us to measure and evaluate the performances of different approaches while keeping the same test conditions. For that, we define the network topology, the mobility parameters and the different metrics to be evaluated.

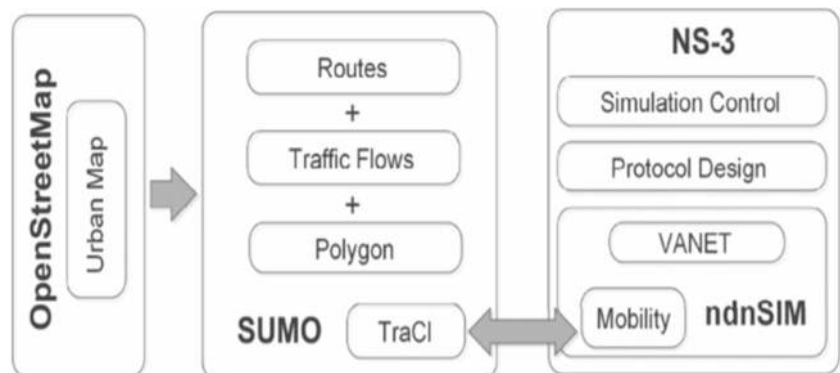
#### 5.1 Simulation environment

To define our simulation environment and to define its different characteristics, we use the following tools:

- Simulation of Urban MObility (SUMO) [23].
- OpenStreetMap [24].
- Network Simulator: ndnSIM +NS3.

SUMO is coupled to NS3 as an external communication simulation via TraCI. To obtain a functional environment for the simulation of vehicular communications according to the ICN paradigm, the framework ndnSIM is integrated within NS3. In Fig. 5, we illustrate the correlation between the different deployed tools.

Fig. 5 Simulation environment



### 5.1.1 SUMO

SUMO [23] is an adequate tool to simulate vehicle traffic at the microscopic level. A SUMO network is an oriented graph in which the nodes represent the crossing junctions and the sides represent the roads. In addition to basic information, a SUMO network contains other additional information. In SUMO, each street has a collection of lanes. We can characterize every lane by a lane identifier, lane length, shape, position and speed limit. SUMO offers the possibility of drawing lanes as a shape. Each side of the lane is a one-way direction. SUMO saves data and parameters generated during the simulation into an XML file. The output of SUMO is a trace file mobility describing the traffic related to the map used during the simulation. It contains information concerning roads, intersections and traffic light positions. SUMO road networks can be generated either by importing a digital road map or by using an application named “netgen”. The road network importer “netconvert” allows us to read networks from other traffic simulators.

### 5.1.2 OpenStreetMap

Our simulation scenario is based on the use of a real-world area generated with OpenStreetMap [24]. The considered area for simulation is the Tunis-Sfax-Gabes highway, as shown in Fig. 6.

### 5.1.3 ndnSIM and NS3

NS3 is an open-source simulation platform for computer networks based on discrete event scheduling and written in C++. Using NS3, researchers can create their own simulation topologies with custom nodes and link parameters. NS3 integrates the full TCP/IP protocol stack, traces, collects and visualizes simulation data. ndnSIM is based on the

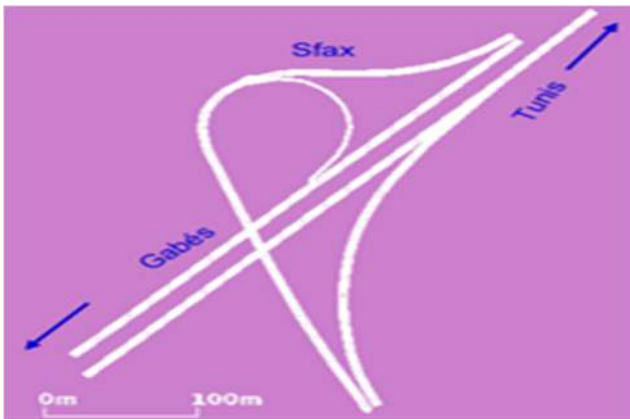


Fig. 6 Area: highway Tunis-Sfax-Gabes

NS3 simulation framework. To add the core NDN forwarding functions, ndnSIM adds NFD, ndn-cxx codebases, event processing and network operations to the NS3 routines.

## 5.2 Simulation parameters

We have considered a variable number of vehicles (100, 200 and 300) following the mobility trajectories generated randomly by SUMO. However, for each number of vehicles, we vary the percentage of the content producers (set to 6%, 12%, 18%, 24%, and 30%) and we select the rest of the vehicles as content consumers (clients). The remainder of the simulation parameters are shown in Table 3.

## 5.3 Metrics

The objective of our simulation tests is to evaluate the impact of our clustering approach on network mobility and continuity. For that, we choose to evaluate the content delivery rate, the average number of data and interest packets, the average transmission delay and the transmission overheads. The first two parameters evaluate the performance of the ICN approach that we propose. The second two parameters indicate whether our ICN-based approach impacts network performances related to mobility and continuity.

After running a simulation scenario, we collect and save the obtained results into different CSV files. The collected information consists of producers, consumers, device faces, FIB, PIT and CS tables. We implement a Python script to analyse the CSV data generated during the simulation. To evaluate our proposed scheme, we consider the following metrics:

- The content delivery rate (%) (CDR) calculates the percentage of nodes considered consumers who correctly received the requested content. Let us consider  $\mathcal{X}$  to be the number of data packets correctly received

Table 3 Simulation parameters

Parameter	Value
Simulation time	150s
Number of runs	10
MAC protocol	802.11p
Bit rate	18 Mbps
Transmission range	300 m
Data message size	10 Kb
Propagation model	Two ray ground
Total number of vehicles	100, 200, 300 vehicles
Speed	70–120 km/h
Percentage of consumers (%)	94, 88, 82, 76, 70

by consumer nodes and  $\mathcal{Y}$  to be the number of interest packets sent by all producer nodes. The CDR is calculated as the sum of  $\mathcal{X}$  divided by the sum of  $\mathcal{Y}$  during the simulation time. The formula for calculating CDR is described in Eq. (3).

$$CDR = \frac{\sum In\_Data}{\sum Out\_Interest} \times 100 \quad (3)$$

- The average number of data (AVG-Data) and interest (AVG-Interest) packets represents the average of the exchanged data packets and interest packets during the simulation time. The average number of In\_Data received by all VANETs nodes is expressed in Eq. (4). The average number of interest packets sent by all VANET nodes during the simulation time is formulated in Eq. (5).

$$AVG - Data = \frac{1}{n} \sum In\_Data \quad (4)$$

$$AVG - Interest = \frac{1}{n} \sum Out\_Interest \quad (5)$$

- The average transmission delay (ATD) (s): this represents the average delay to deliver data. It corresponds to the time separating the time of sending the first interest packet requesting content and the data packet arrival time, as described in Eq. (6).

$$ATD = \frac{1}{n} \sum TIn\_data - TOut\_Interest \quad (6)$$

- Transmission overheads (%) (TRO): the percentage of lost data sent from a producer vehicle to a content requester node. It is expressed by the formula of Eq. (7).

$$TRO = 100 \times \frac{\sum In\_data}{\sum Out\_Data} \quad (7)$$

## 5.4 Simulation results

To evaluate the performance of our VC-ICN scheme, we consider two other scenarios during the simulation

phase. Thus, we implemented, under the same simulation conditions, the following two scenarios that will be used for comparison:

1. ICN-based scenario without a clustering mechanism: in this scenario, we consider the ICN-based architecture described in Section 3 without implementing our clustering technique. Our network architecture is based on an ICN approach to address the data instead of being based on the location. This scenario is mainly implemented to evaluate the performance of an ICN approach within a VANET architecture without any clustering technique.
2. ICN-based scenario using K-means clustering: In this scenario, we consider the K-means clustering technique that we implement within our ICN-based architecture. A detailed description of the implemented algorithm can be found in [22]. The cluster formation is based on three division points. When a vehicle wants to join a cluster, it will choose the nearest division point and integrates that cluster. The difference between this scenario and our scheme is that only 3 clusters are considered. Moreover, vehicles belonging to the same cluster may run in different directions. The proximity between different cluster members is not truly respected.

The following items give the results for the different metrics that we defined in the previous subsection.

- The content delivery rate (CDR): Figure 7 shows the performance result of the content delivery rate. Figure 7 shows the impact of the vehicle density on the CDR. The CDR represents the percentage of nodes considered consumers who correctly received the requested content. We consider three different vehicle densities: 100 vehicles, 200 vehicles, and 300 vehicles. Then, for each density, we calculate the CDR based on different producer percentages (6, 12, 18, 24, 30 and

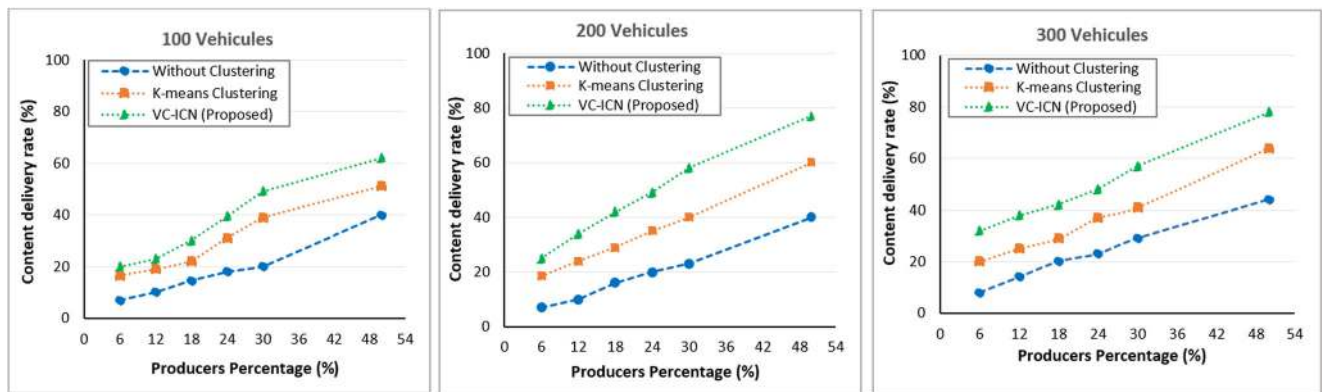


Fig. 7 Content delivery ratio

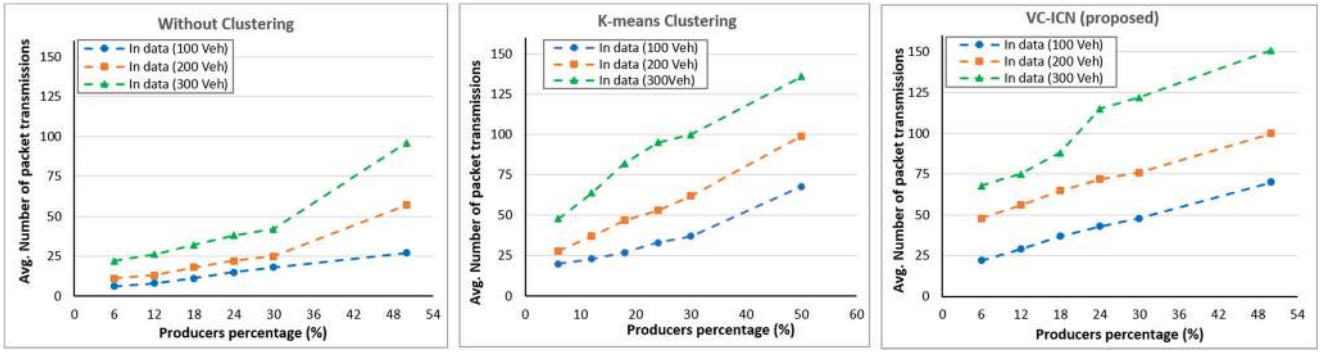


Fig. 8 Average number of In-Data

50). When the content producer percentage increases, the CDR increases. Thus, the density positively impacts the percentage of receiving correct requested content since the information is available in the cache of more nodes when the density increases. Compared to the two considered scenarios, VC-ICN shows better results. For instance, if we consider the scenario where the considered VANETs are composed of 300 nodes, VC-ICN improves content delivery by 37% compared to the first scenario that does not consider clustering. In this case, the ICN clustering technique improves the access of requested data by searching the required information within the cluster. When the vehicle number increases, the probability of providing the required content is greater within a specific cluster. Moreover, the ICN approach improves content delivery by 18% compared to the K-means technique when considering a scenario of 300 vehicles. Indeed, the proximity offered when using our clustering metric (the direction angle) provides better availability of the required content. In addition, the caching technique used by the ICN approach also facilitates access to the required data.

- The average number of packet transmissions: in Fig. 8, we evaluate the average of the transmitted data as a response of a fixed number of interest

packets. To calculate the average of the packet transmissions, we consider three different numbers of vehicles for each scenario (without clustering, K-means and VC-ICN). For all scenarios, the average number of packet transmissions increases when the vehicle number increases. Indeed, when the number of vehicles increases, the different VANETS nodes have a greater probability of providing the required content to satisfy the received request. Figure 8 also shows that for the three cases (100, 200 or 300 vehicles), the VC-ICN gives better performances for the average of packet transmissions. For example, if we consider 300 vehicles with 50% producers, we can achieve more than 150 packets as an average for the packet transmissions. For the same conditions, the K-means scenario reaches approximately 135 packets as an average, and the without clustering scenario reaches less than 100 packets as an average for the packet transmissions. These performances are mainly related to the possibility of using the cache with the ICN-based approach. Moreover, having good proximity between different cluster nodes makes satisfying the received request easier.

- The average transmission delay (ATD): We represent the ATD performances in Fig. 9. The graphs represent the delay to obtain the requested data from a producer

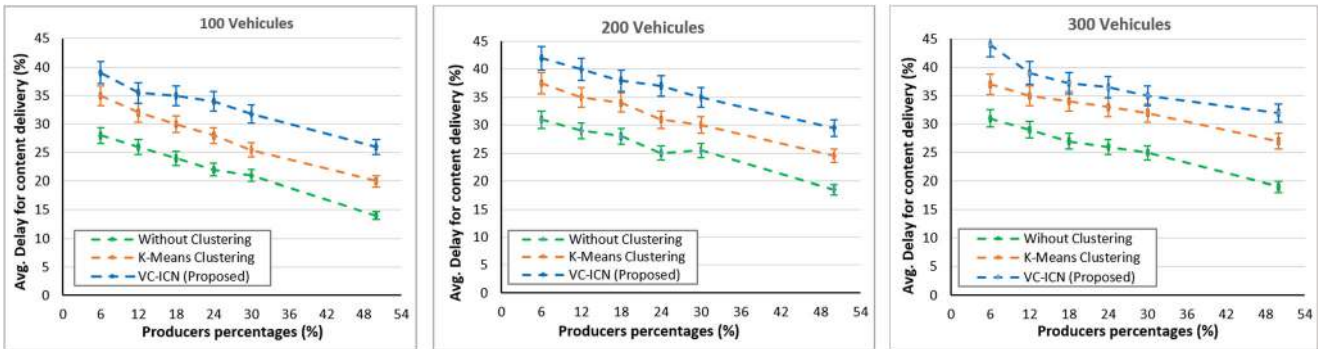


Fig. 9 Average delay for content delivery

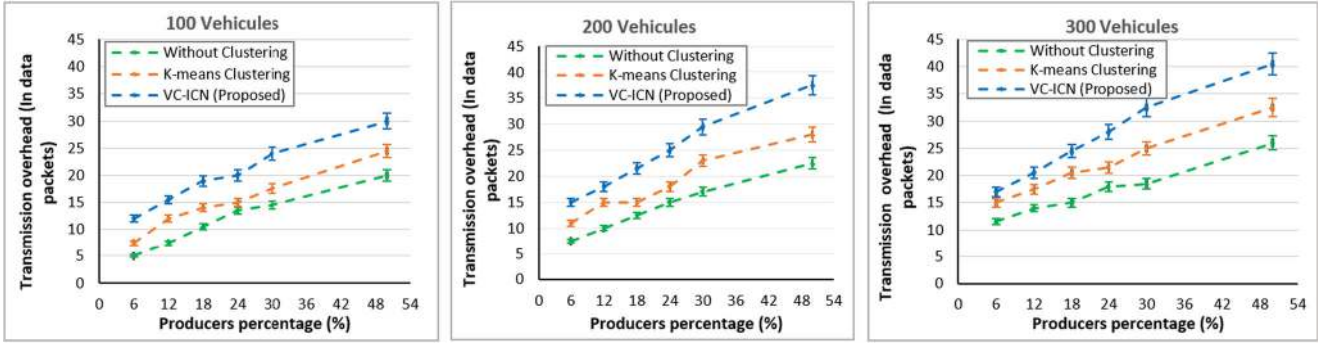


Fig. 10 Transmission overhead

node. The results show that increasing the proportion of producers in VANETs improves the probability of finding and correctly delivering the content. Thus, it improves the ADT for content delivery. For this metric, our scheme gives better results only for the ICN-based scenario without considering any clustering technique. Indeed, for some specific scenarios, when the content is available within the cluster, the cluster head satisfies consumers instead of looking for the data packet within the connected vehicles. Consequently, the delivery time is improved. The simulation results of Fig. 9 show that when increasing the number of vehicles, the average delay for content delivery increases for the three considered scenarios. For example, for our proposed scheme, the average delay is approximately 31 s when we consider 300 vehicles and approximately 27 s when considering only 100 vehicles. Indeed, the treatment process takes more time since the number of cluster members increases when the vehicle number increases. However, we note that the scalability of the network still gives respectable results with the calculated average delays.

- Transmission overheads: Fig. 10 shows the transmission overheads that occurred during the simulation time related to the incoming data for consumers. The transmission overheads are calculated based on the sent data from the producers and on the correctly received data by the consumer. In other words, the transmission overheads evaluate the lost data between producers and consumers. Figure 10 shows that when applying a clustering technique, this rate is improved. Clustering techniques improve the connectivity of the network and its continuity. As a result, fewer packets could be lost between nodes. Concerning the applied clustering techniques, Fig. 10 shows that our VC-ICN scheme proposes a better performance related to the loss rate. Indeed, having closer clusters when applying an ICN

approach improves the forwarding capacity of the network. Moreover, we notice that increasing the vehicle number leads to an increase in the loss rate. In fact, network scalability can negatively impact network performance. Thus, when considering 300 vehicles and 50% of producers, the loss rate may reach 25% for our scheme and approximately 32% for the K-means scheme.

## 6 Conclusion

The use of clustering techniques has been widely investigated to offer solutions for the high mobility and dynamic topology of VANETs. On the other hand, previous investigations evaluated how the data-centric paradigm ICN outperforms TCP-IP-based approaches. In this context, we evaluated the use of ICNs for data delivery in VANETs based on a clustering technique. Our proposal, called VC-ICN, is mainly based on a location-based clustering technique. To form clusters, we utilized the direction angle metric. Our choice leads to a set of clusters sharing good proximity to enhance network connectivity and continuity. The caching technique implemented through our ICN-based scheme provides better results to satisfy received requests. Indeed, producers are able to rapidly provide the required content based on their content store when needed. The performance evaluation of the VC-ICN scheme has been compared to two existing schemes: the no clustering scenario and K-Means scenario. The simulation scenarios considered different percentages of data producers and different numbers of vehicles. The simulation results showed better evaluation of the content delivery ratio, the delivery delay, the overhead and the packet transmission rate. In future work, we intend to evaluate the security of our clustering scheme when considering larger networks. For that, we will be interested in studying the performances of our scheme within the context

of cache poisoning attacks. As a next step, we will propose a solution to mitigate this type of attack considering our VC-ICN scheme.

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