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Stabilized Clustering Enabled V2V Communication in an NDN-SDVN Environment for Content Retrieval

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ABSTRACT Content retrieval is becoming an emerging application on an integrated network structure referred to as Software Defined Network and Vehicular Ad hoc Network (SDVN). The SDVN is expected to flexibly provide efficient packet routing without deploying road side units. In such the infrastructure-less environment, however, it is challenging to retrieve contents from dynamic networks clustered with vehicles on roadways. As a solution to the problem, we propose a new network design by conjoining Named Data Network (NDN) with SDVN (NDN-SDVN). The new NDN-SDVN is designed as to improve stableness of the cluster formation and hence enables to efficiently perform the content retrieval over Vehicle-to-Vehicle (V2V) communications. Note that one of the most important problems in the V2V is how to select a cluster head. The proposed NDN-SDN adaptively determines the cluster head by using the SDN controller under the maximum Quality of Service (QoS) criterion, while reserving an assistance head based on a Moth Flame Optimization (MFO) algorithm to immediately recompose a new cluster with the back-off time. Moreover, the content retrieval in the NDN-SDVN can be performed over both intra- and inter-cluster communications. To this end, a Kalman filter with Neural Network (KF-NN) is applied for selecting a certain number of preferable vehicles in 1-hop in order to mitigate the broadcast storm problem that often occurs in an NDN. Content retrieval is initiated by sending interest packets including two additional fields of the timestamp and the target MAC address. The head vehicle of the SDN controller maintains ontology regarding the content information cashed by other vehicles, which significantly improves the packet delivery ratio. This NDN-SDVN design is developed on the OMNeT++ simulator and their advantageous results are evaluated in terms of the head lifetime, the cluster lifetime, the satisfactory rate, the latency and the packet delivery ratio.

INDEX TERMS Broadcast storm, content retrieval, SDN controller, stable clustering, QoS.

I. INTRODUCTION

A vehicular ad-hoc network (VANET) is a type of ad-hoc network that can provide both safety and non-safety applications while driving [1]. Recently, infrastructure-less communication has focused on communication between vehicles without the participation of a road side unit (RSU). Varying vehicle velocities are managed by clustering, and transmission of messages between vehicles is based on the establishment of intra- or inter-cluster communication. A broadcast storm is a serious problem that significantly drops the packet delivery ratio [2], and it can be minimized by selecting a leader. Because of the requirements of a VANET, it is convenient to integrate its prospective processing into a software defined network (SDN) and a named data network (NDN).

An SDN-based VANET, known as an SDVN, explores the potential flexibility and management capabilities achieved by deploying SDN-controllers in vehicles [3]. Data transmission

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in SDVN is applicable for multi-hop routing with the objective of minimizing end-to-end delays [4]. An SDVN incorporates source routing-based flow instantiation (FI) using link stability.

The VANET environment is capable of managing highly dynamic vehicles with enhanced performance. The VANET deals with both urban and highway scenarios in which the vehicles move at different speeds. The exchange of information is greatly increased, and an SDN-VANET balances the velocity of the vehicles in terms of cluster formation, which enables the network to control the capabilities to be achieved [5]. Constraints, such as the angle of arrival (AOA), received signal strength (RSS), and distance, are involved in creating adaptive clusters. Clustering requires the selection of a cluster head (CH) using certain significant parameters that indicate the eligibility to act as head. Each selected CH is responsible for carrying topological information to maintain network connectivity. In some studies, dual CHs are chosen for better efficiency.

SDVN routes the data packets that satisfy QoS based on a determination of the most stable and shortest route [6]. The tribrid routing protocol assists with unicast, broadcast and store, carry, and forward based data transmission. Clustering also impacts the routing performance. An SDVN is modeled on a hierarchical system designed for performing pre-defined operations [7], [8]. In this hierarchical model, the information is shared by means of introducing an NDN. The nodes employed in this NDN are composed of the following three entities: a pending interest table (PIT), a content store (CS), and a forward information base (FIB). However, in these studies, the SDN controller is deployed as a separate entity in the system.

The NDN is involved in wireless heterogeneous networks that use promising forwarding techniques to retrieve content. A geographic interest-forwarding scheme is adapted with a greedy forwarding strategy [9]. The naming schemes include information about the identity, location, and data prefixes. The interest packets are pushed to retrieve content. The intelligent transportation system (ITS) assists with gathering information by adopting the SDN and NDN, which is the ideal choice to ensure scalable data retrieval [10]. Pre-defined rule-based forwarding over the geographical area is challenging. Vehicles move quickly, which means that managing the topology is a complex task. However, an SDN is incorporated to support highly mobile vehicles. Vehicles using ITS are also equipped with sensors that collect information, and those data are shared with other vehicles along the route. Machine learning algorithms and fuzzy logic are also extensively used for route selection [35]–[40].

In this study, an SDVN is integrated into an NDN to retrieve the required content from vehicles in a short period of time. This work concentrates on using stable clusters and V2V communication for efficient content retrieval using ontology and novel packet format. The efficiency is measured in terms of significant network parameters.

A. CONTRIBUTION OF THIS PAPER

The major contributions of the proposed NDN-SDVN are discussed below.

- A combined NDN-SDVN architecture is developed for efficient information retrieval by managing vehicles in clustered circumstances. NDN-SDVN is constructed with a CH and assistance CH in order to manage the failure of head controllers. CH is elected from the estimated values of centrality and QoS, then the selected CH is responsible to choose an assistance CH using MFO algorithm.
- CH is elected within the back-off time which is calculated based on the size of the contention window that is given in accordance to the vehicle's interest to become a head. The selected CH is activated with the functionalities of SDN-controller. Stable CH selection is followed by cluster formation by considering link stability, speed difference and relative mobility between the head and the neighbor vehicle.
- Content retrieval is accomplished by V2V communication that is initiated by CH which maintains ontology of content belonging to each vehicle. From this information, the content holding vehicle is identified using target MAC address by the requesting vehicle. The use of additional information of target MAC address and timestamp enables to retrieve required content at a short period of time.
- Broadcast storm is mitigated by selecting specified number of 1-hop neighbors from KF-NN algorithm operated with residual lifetime, satisfactory rate and forwarding score.

B. ORGANIZATION OF THIS PAPER

The rest of this paper is organized into the following sections as: Section 2 is composed with the detailed discussion of previous research works Section 3 defines the problems that exist in these prior works; Section 4 illustrates the proposed NDN-SDVN architecture design, including the proposed clustering and content retrieval; Section 5 describes the simulation environment including comparative results; and Section 6 concludes the research work and explains how it might be extended in the future.

II. RELATED WORKS

In this section, we examine previous research related to VANETs and the combination of an SDN and NDN with a VANET. Stable and optimal cluster formation in VANETs was presented in [11], and evolutionary game theoretic (EGT) approach-based clustering was shown to be applicable for different populations and speeds. The cluster with a throughput less than the threshold will be involved in CH re-election to obtain a stable cluster construction. However, throughput-based clustering requires prior knowledge of the vehicle's data transmission. Thus, consideration of throughput for

CH election was not optimal in vehicular communication. To construct stable clusters, a hybrid clustering protocol was proposed that combines geographic and context-based clustering approaches [12]. The CH in each segment was selected by determining its location, direction, velocity, destination, point of interest, and residual lifetime. Furthermore, the CH was selected optimally, where the cluster was based on the segmented road lanes. Hence, if a CH moves to next segment, then it is essential to select a new CH. Therefore, the static road segments used in this study require frequent CH selection. A moth flame optimization (MFO) algorithm has also been used for CH selection [33], [34]. In this case, the CH was selected using residual energy or speed, but it is not sufficient to consider a single parameter when selecting a CH. This is also associated with an unstable cluster formation.

Clustering was designed by taking into account traffic flow with respect to naïve Bayesian probabilistic estimation [13]. The following parameters were utilized in the process of CH selection: direction, speed, lane number, distance, traffic weight, and connectivity. A naive Bayes algorithm was performed using the Bayesian theorem to predict future events. The independent nature of the naïve Bayes algorithm causes accuracy degradation, so it was not appropriate to use the algorithm to select an optimal CH. Retrieval of data from vehicles can lead to a broadcast storm. Therefore, a two-phase algorithm was proposed [14], with the following two phases: a distance adaptive resource management phase (DAR) and a talking phase. When an accident occurs on the road, vehicles are grouped to provide other vehicles with content information. Broadcasting the content produces replicas of messages and, therefore, creates a broadcast storm.

The advantages of a VANET are combined with those of an SDN to allow efficient data transmission via V2V communication. To achieve better performance, many previous studies separated the road into segments and grids, and this was followed by geographical routing [15], [16]. The grid-based divisions were presented, and this was followed by data transmission using the hierarchical geography routing protocol. The path cost function was estimated with respect to the load, and then a path was chosen for routing packets. In the first stage, the overall state was computed, and the grid was scored. Then, the vehicle with the highest overall state was selected as a neighbor. Here, because an individual vehicle must update the information transmitted to controllers, maintaining information about all the vehicles in a single controller is complicated.

The Parked Vehicle Assistant Relay Routing (PVARR) algorithm, which was used to enhance the quality of communication, was examined [17] by exchanging hello packets between 1-hop neighboring vehicles. For transmitting data between vehicles, relay nodes were selected by estimating the link quality. An increase in the exchange of hello packets creates congestion among the packets. Data transmission for content retrieval in the VANET-SDN has also been associated with NDN [18], where interest packets were broadcast using different forwarding strategies to retrieve the required content. The MobiVehicular NDN (MobiVNDN) routing mechanism was enabled to perform multi-hop data transmission [19]. Using the mechanism, each vehicle selects its next hop using the delay/timer approach, which sets the time based on the distance to the destination vehicle. The proposed MobiVNDN routing mechanism was receiver based and beacon-less. Messages are processed based on a vehicle's needs. In this work, a sweet spot was determined in the road lanes where the transmitted message was able to reach a large number of vehicles. However, a broadcast storm occurs, owing to the broadcasting of the packets.

A hop limit based adaptive PIT entry lifetime (PEL) scheme was proposed in [20] that concentrated on adaptively evaluating the PEL over the interest-forwarding vehicle. Here, if an interest message is lost, then the PEL scheme computes an adaptive value to manage the upcoming PEL with a back-off adjustment. If the content storage and PIT failed in searching, then the interest message was forwarded to all the vehicles. RSU assisted NDN (RA-NDN) was developed [21], where the RSU was operated based on standalone RSU (SA-RSU). The SA-RSU broadcasts the polling message to all the vehicles. The forwarding decision was enabled with a timer-based mechanism that estimates the expiration time and distance. This entails frequent retransmission, as the farthest vehicle that was selected for forwarding has a shorter waiting time. If the timer expires, then rebroadcasting must be performed repeatedly.

The VANET-NDN was built in an urban scenario for retrieving content based on a preferred route. Routes were selected based on link quality in order to mitigate unnecessary retransmission [22]. Link quality was determined from the link expiration time and link availability probability. The PIT includes the two new entries of receive time and tolerance time. Multiple mathematical equations were used to create a model to estimate link quality, which consumes more time when transmitting a request. In [23], the network architecture was constructed with a border access router, access routers, access points, and vehicles. Each entry was stored in the content table of the vehicle, and this table is comprised of the content ID, content value, network prefix, and lifetime. The requested content was delivered based on the data maintained in the table. This work follows unicast, as broadcast increases the content acquisition cost and delay. However, unicast takes more time to retrieve data because the content carrying destination cannot be determined accurately all the time.

A VNDN, which aimed to satisfy several user interests, was developed using a link-stability based interest forwarding strategy [24]. The estimated link lifetime function depends on a kinetic graph framework, and this estimation includes parameters such as transmission range, velocity, and position of the vehicle. However, when the link quality was measured, the existence of a broadcast storm was detected. A caching-based strategy was proposed in VNDN for retrieving requested content [25], [26]. The cache was focused on an estimation of the popularity of the content [27].

Here, the significant network parameters were ignored and the cache storage space was not considered an issue. Then, a traffic violation assisted VNDN was proposed based on monitoring and maintaining ticket entries. Here, the interest packets were broadcast, and the violation entries were stored in the local memory of vehicles. However, broadcasting interest packets will cause a broadcast storm that degrades the performance of the network.

In [38], fuzzy logic based directional greedy forwarding was proposed by taking into account the position, direction, expected transmission count, and achievable throughput. The estimation of these metrics for individual vehicles one after another consumes more time during route selection. In [39], an artificial neural network (ANN) was designed to predict the mobility, and routing was performed using this network. An ANN enabled parallel computation to be performed, but the prediction of a vehicle's path was not static. Hence, the ANN must be operated continuously, and a small change in the path leads to increased packet drop. A hybrid intelligent routing method was designed by combining an improved fuzzy and cuckoo approach [41]. Based on the fitness function, the optimal route was chosen. However, the processing of these two methods prolongs the route selection time.

Previous research studies related to VNDNs and SDVNs have been subject to certain problematic and challenging issues in clustering and content retrieval, such as broadcast storms and time consumption, among others. From this survey, a set of major problems can be defined, and these problems are solved by the proposed system.

III. PROBLEM DEFINITION

SDVN systems have used the process of clustering to achieve stable management of vehicles for communication. A social-aware clustering algorithm was designed using a semi-Markov model that predicts patterns [28]. Clusters were constructed in accordance to their similarity and dissimilarity in a social pattern. However, vehicles with dissimilar social patterns at larger distances were left idle, and hence, they could not participate in communication. Highly dynamic vehicles were addressed with scalable cluster-based architecture in SDVN environments [29]. Clustering and reliable fallback recovery mechanisms were followed in this study. Clusters were constructed by segmenting the road lane, which requires repeated selection of a CH, owing to the mobility of vehicles.

A cluster-based cooperative caching method that predicts mobility for inter- and intra-cluster communication in a VNDN was developed [30]. A weight value was computed and used to select a CH. However, if a vehicle moved from a cluster, then clustering was performed again. Since repeated clustering and CH selection was performed, the cluster was unstable. Data transmission in the VNDN was initiated with interest packets, which is essential to retrieve content that was obtained using an improved multihop, multipath and multichannel [31]. Two additional fields are included in interest packets, but broadcasting of interest packets in a VANET leads to a broadcast storm.

Previous research on stable clustering and content retrieval failed due to the partitioning of road lanes and broadcasting of interest packets. The shortcomings of the prior research methodologies are addressed by the proposed NDN-SDVN architecture.

IV. PROPOSED NDN-SDVN

A. SYSTEM MODEL

The proposed NDN-SDVN is a combination of an NDN and an SDVN to facilitate efficient content retrieval by constructing stable clustering in an infrastructure-less environment. This network design can be deployed in dynamic vehicles moving on the road lanes. Let $\boldsymbol{V}_n$ be the total number of vehicles participating in the system, where $n = 1, 2, 3, \ldots, N$. Among the vehicles, CHs are selected and provided with the functionalities of an SDN controller in order to manage the vehicles and assist with content retrieval. Figure 1 depicts the constructed road lane in which the vehicles are clustered, and a CH and assistant CH are chosen for content retrieval.

The system model is composed of stable clusters that include an optimally selected CH. It also focuses on mitigating the failure of SDN controllers by selecting an assistant CH. Once the heads are selected, clusters are formed. In this work, the vehicles move in both directions, and vehicles moving in the same direction will be clustered. The vehicle requesting content will give an initial request to the CH, which maintains the ontology of the contents of the other vehicles. Based on the requested content, the target vehicle is identified based on which V2V communication is established.The contents are then retrieved by the requesting vehicle.

B. CLUSTERING

The main aim of this work is to construct stable clusters with low levels of failure. Therefore, the lifetime of clusters needs to be increased, which is achieved by optimal CH selection that accounts for failure mitigation and cluster time sustainment in the selection process. Clustering is performed in three phases: the CH selection, assistant CH selection, and cluster formation phases.

CH selection phase: In this phase, a CH is selected by determining a centrality factor and QoS metrics. The QoS metrics are composed of the three significant metrics of energy level, availability, and reliability. A larger QoS for a particular vehicle indicates a higher probability that it could become a CH that is able to function as a CH for a longer time period. Vehicles within the communication range R exchange information to select a CH. The vehicle with a high centrality factor and QoS is self-elected as CH. Centrality defines the number of inward and outward links for a particular vehicle. Centrality is formulated as

$$C_i = C_i^{in} + C_i^{out} \tag{1}$$

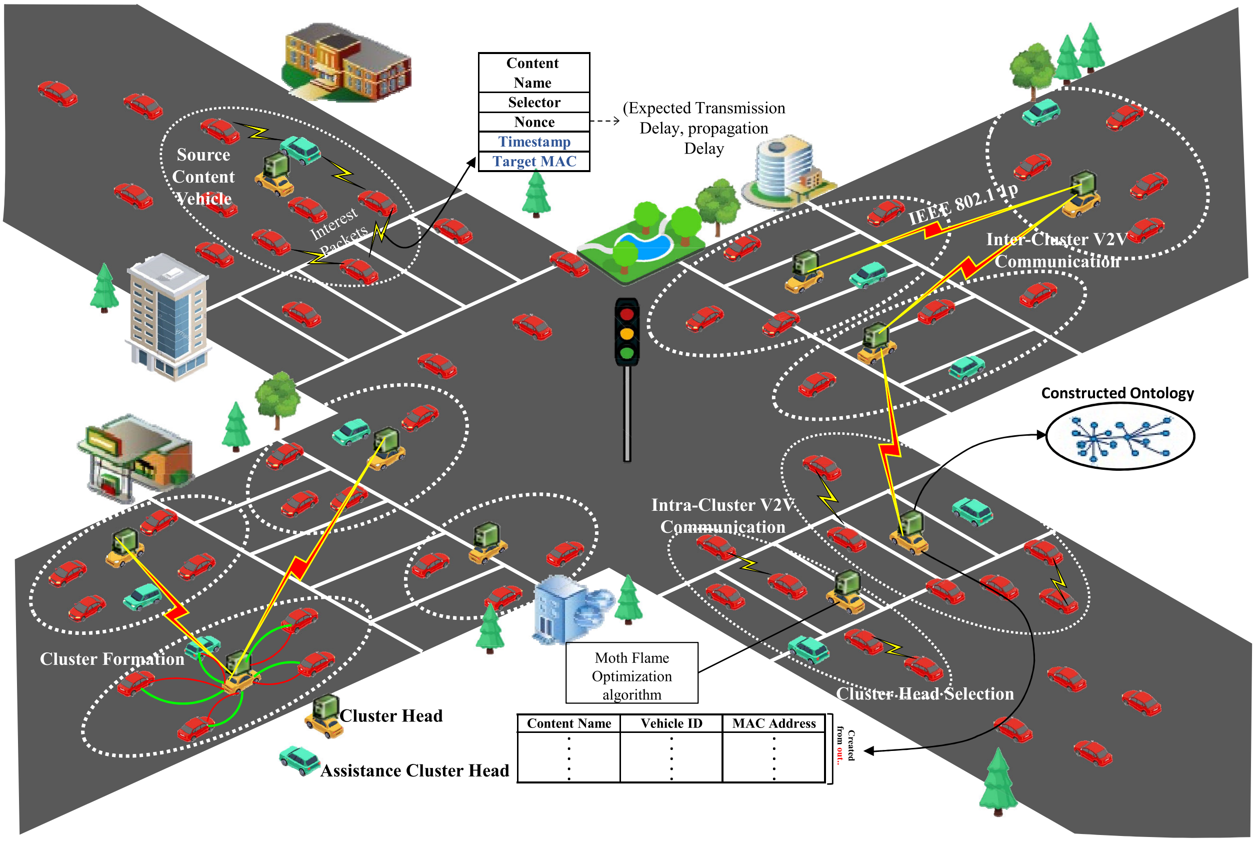


FIGURE 1. NDN-SDVN architecture.

The centrality factor of the i^{th} vehicle is C_i, and it is computed by summing the inward and outward links (C_i^{in} and C_i^{out} respectively) of the i^{th} vehicle. These links are determined from the total number of neighbors connected with vehicle i.

The inward and outward links are estimated from the adjacency matrix A_{ij}, where i and j are the connected vehicular nodes. They are mathematically computed as

$$C_i^{in} = \sum_{j \in n} A_{ij} \tag{2}$$

$$C_i^{out} = \sum_{j \in n} A_{ji} \tag{3}$$

Here, n denotes the number of neighboring vehicles, so it differs for each vehicle. After estimation of the centrality factor, the QoS is determined in terms of energy level, availability, and reliability. The energy level is the amount of energy retained by a particular vehicle, availability defines the number of successful transmissions relative to to the total number of transmitted packets, and reliability defines the capacity at which the packets are delivered to the other vehicles. The QoS metric is expressed as

$$Q_i = EL_i + AL_i + RL_i \tag{4}$$

The QoS of the i^{th} vehicle (Q_i) is determined by summing the three QoS parameters energy level, availability, and reliability (EL_i, AL_i and RL_i respectively). Reliability is based on the buffer size that is used to predict the capacity of the particular vehicle. The CH selection metrics are estimated from (1) and (4). The vehicle with a higher centrality factor and QoS values is appointed as the CH. Once the CH is selected, it is provided with the functionalities of an SDN controller and flow rules.

The first responsibility of a CH is to select an assistant CH from among the cluster members (CH). A cluster is formed by the CH, which exchanges request (RREQ) and response (RESP) packets between the CH vehicle and other neighboring vehicles. Cluster formation occurs within the back-off time. Back-off values of the vehicles are given based on the size of the contention window (CW). To construct stably increased clusters, flow rules are deployed by the CH.

The selected CH vehicle performs clustering and simultaneously aggregates the vehicles to act as an assistant CH in case an overwhelming failure problem occurs. The CH vehicle receives RREQ from a vehicle along with the back-off time, and the CW size is based on whether the vehicle is interested in becoming an assistant CH or not. The interested vehicles will have shorter waiting times that are estimated as back-off according to

$$B_O = \frac{CW_{\min}}{2} \tag{5}$$

TABLE 1. Contention window size.

Vehicle	CW_{min}	CW_{max}
I-CH	1	2
NI-CH	4	8

During the back-off time (B_O), the vehicle waits for the response, and then it sends RREQ packets to the CH again. Table 1 depicts the minimum and maximum CW size as CW_{min} and CW_{max}, respectively, and a vehicle interested in becoming an assistant CH is designated as I-CH, while a vehicle that is not interested is designated as NI-CH. The back-off time is determined based on a vehicle's interest. Hereby, flow rules for SDN-controllers are defined based on link stability, speed differences, and relative mobility. Based on these three constraints, the flow rules are defined, and the actions are performed. Link stability of a neighboring vehicle is determined from

$$LS_i = \kappa \times \frac{d_{ij}^T}{(R_i, R_j)_{min}} \tag{6}$$

where d_{ij}^T represents the distance between the i^{th} and j^{th} vehicles based on the packet received at time T. Let LS_i be the link stability computed for the i^{th} vehicle whose communication range is R_i, and the communication range of its neighbor is R_j. The distance is estimated using the Euclidean distance, expressed as follows:

$$d_{ij}^T = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{7}$$

The positional x and y coordinates of i^{th} and j^{th} vehicle are (x_i, y_i) and (x_j, y_j), which is less than the communication range of the vehicles. Let the i^{th} vehicle be the CH vehicle whose link stability includes a κ weighted constraint that defines the direction of the vehicle's motion. It is given as

$$k = \begin{cases} 1, & \text{same direction} \\ 0, & \text{otherwise} \end{cases} \tag{8}$$

To construct a stable cluster, a vehicle's direction is essential, because the link stability will be high only when the vehicles are moving in that direction. Therefore, this is one of the constraints used to determine link stability. Then, the difference in speed between the two vehicles is the second metric, and it is estimated from the acceleration of the vehicle. The speed difference and acceleration difference are given by

$$Sd_{ij} = |s_i - s_j| \tag{9}$$

$$a_{ij} = |a_i - a_j| \tag{10}$$

The speed difference Sd_{ij} and acceleration difference a_{ij} between the i^{th} and j^{th} vehicle are computed from (9) and (10), using the speed of the i^{th} vehicle s_i and j^{th} vehicle s_j. A similar process is repeated to find the acceleration difference. Then, the relative mobility between the CH and the neighboring vehicle is expressed as,

$$RM = \alpha \frac{d_{ij}^T}{\max\left\{d_{ij}^T\right\}} + \beta \frac{Sd_{ij}}{\max\left\{Sd_{ij}\right\}} + \gamma \frac{a_{ij}}{\max\left\{a_{ij}\right\}} \tag{11}$$

Flow rules in CH as SDN-controller is employed based on the three significant metrics. Based on the computed values, actions are made as per the defined flow rules. The above pseudo code depicts the procedure for stable cluster formation in NDN-SDVN.

Table 2 shows the actions that are taken based on the constraints to create stable clusters by the CH. The threshold values for link stability, speed difference, and relative mobility are specified as LT_h, ST_h and RT_h based on which actions are performed by the CH. A vehicle with a higher link stability and smaller speed difference and relative mobility will be included in the cluster. Meanwhile, the CH separates the vehicles RREQ that are I-CH, which is required to pick an assistant CH. The assistant CH is also enabled with the functionalities of an SDN-controller, but it is activated only if there is a failure. From the I-CH vehicles, an optimal assistant CH is chosen using an MFO algorithm.

TABLE 2. SDN-controller flow rules.

Flow Constraints			Action
Link Stability	Speed Difference	Relative Mobility	
$\geq LT_h$	$\geq ST_h$	$\geq RT_h$	Disagree to add as member
$\leq LT_h$	$\leq ST_h$	$\leq RT_h$	Agree to add as member

The MFO is a naturally inspired algorithm that is used in the optimal selection of an assistant CH. The selection of an assistant CH also assists with the stability of cluster, because the failure of a CH is mitigated by the assistant CH. The moths have a transverse orientation, in which they follow a path that moves towards the light. If the light is closer to the moths, they will move in a spiral path around the light. Initially, the population of the MFO algorithm is initialized in a matrix composed of individual moths, i.e. vehicles in this study. The population is represented as,

$$P = \begin{bmatrix} v_{1,1} & v_{1,2} & \cdots & \cdots & v_{1,d} \\ v_{2,1} & v_{2,2} & \cdots & \cdots & v_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ v_{N,1} & v_{N,2} & \cdots & \cdots & v_{N,d} \end{bmatrix} \tag{12}$$

The population P is defined for N numbers of vehicles that are present in the i^{th} cluster having d variables. It is initialized using the vehicle's direction and velocity, and the resultant fitness values of each vehicle member are stored in an array format. The fitness values are defined as the combination of the vehicle's speed, distance, and delivery ratio. The speed is calculated based on the current movement of the vehicle and the delivery ratio is estimated using the history of the vehicle. The delivery ratio is defined as the number of successful content packets delivered previously relative to the number of requests received. Let the fitness array be represented as follows:

$$F = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_N \end{bmatrix} \tag{13}$$

where an individual fitness $\{f_1, f_2, \ldots f_N\}$ for N vehicles will be composed with their current speeds $\{sp_1, sp_2 \ldots, sp_N\}$, distances, and delivery ratios $\{dl_1, dl_2, \ldots, dl_N\}$. Then, the flame, i.e. the CH, which is essential in MFO, is defined in

```
1. begin
2. initialize v_n  // n = 1,2,3,.....N
3. compute C_i and Q_i  // From (1) and (4)
4. for (n=1; n<N;n++)
   {
     If (C_n, Q_n = True)
       {
        select as CH and goto step 5
     else
        vehicle remains normal
       }
     end if
   }
   end for
5. CH → RREQ(x)  // x be total number of vehicle within R of elected CH
6. initialize v_x ,// x = 1,2,3,....X
7. RESP → (B_o, LS_x, Sd_xy, RM)  // response from vehicle x
8. if (B_o > 0)
   {
     Go to Step 8
   else
     Discard RREQ
   }
   end if
9. for (x=1;x<X;x++)
   {
     if (LS_x ≥ LT_h, Sd_xy ≥ ST_h, RM ≥ RT_h = True)  //  From SDN-flow rules
       {
        add vehicle as member
     else
        ignore RESP from v_x
       }
     end if
   }
   end for
10. end
```

FIGURE 2. Stable cluster construction pseudo-code.

matrix format as

$$F_l = \begin{bmatrix} F_{1,1} & F_{1,2} & \ldots & \ldots & F_{1,d} \\ F_{2,1} & F_{2,2} & \ldots & \ldots & F_{2,d} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ F_{N,1} & F_{N,2} & \ldots & \ldots & F_{N,d} \end{bmatrix} \tag{14}$$

Similarly, the fitness values are determined for the flame and the global optimum is estimated based on the three functions $\{I, SS, T\}$, where $I : \emptyset \rightarrow \{P, F\}$, $SS : P \rightarrow P$, and T is the termination, i.e. $\{T : P \rightarrow (0, 1)\}$. The iteration is repeated until the termination '0' is attained. Here, I denotes the randomly distributed moths that are present within the search space, SS defines the function by which the moths move in a spiral, and T is either true or false based on the termination condition. The position of the moths with respect to the flame is updated with each iteration, the fitness of the vehicles is sorted, and the vehicle with the best fitness is selected as an assistant CH in the stable cluster.

A spiral fly path-based distance estimation is performed from the location of each member to that of the CH. The initial position of the moth will be the farthest position of a vehicle at the edge of the CH's communication range. Here, we consider a spiral path based on moving vehicles, as shown in Figure 3.The logarithmic formulation for the spiral is defined as

$$SR_{il} = d_i e^{bt} \cos(2\pi t) + F_l \tag{15}$$

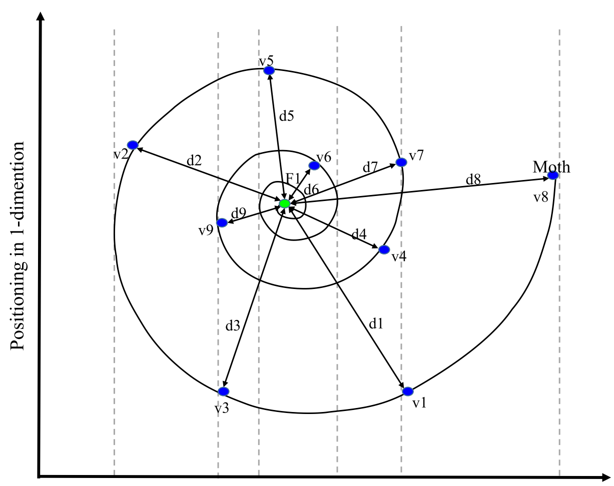


FIGURE 3. Spiral fly path.

If the spiral path SR_{il} goes between the member at the edge to the CH l at the center, then d_i is the distance from i^{th} vehicle to the CH, b is defined as a constant used for constructing the spiral shape, t is a random number in the range of $[-1, 1]$, and F_l denotes the central CH. The construction of stable clusters in NDN-SDVN is accomplished using flow rules and failure control. By considering the significant characteristics in the flow rules, stable clusters are created. Moreover, the CH, acting as an SDN-controller, has the potential to fail from continuous data processing. The failure of the CH as an SDN-controller will require re-clustering, which is resolved by prior selection of an optimal assistant CH. This prevents failure and maintains the cluster lifetime.

The clustering complexity is determined as $O(m.n^2)$, in which n denotes the data points (i.e., the vehicles), and m is the dimensional space.

C. CONTENT RETRIEVAL

In general, packets are initiated in NDN towards all the 1-hop neighbors for content retrieval. This type of broadcasting of interest packets creates a broadcast storm, which is a problem. Broadcasting was considered to be essential because the destination was unknown. In the proposed NDN-SDVN system, however, the CHs with SDN-controllers are equipped with knowledge of the contents that are carried by the members. In this proposed NDN-SDVN system model, content retrieval is incorporated into V2V communication. In order to mitigate the broadcast storm problem, a set of 1-hop neighbor vehicles are determined using KF-NN.

The vehicle that needs content initially sends a request for content information to the CH. Then, the CH, acting as an SDN-controller, searches for the requested content in the pre-stored ontology, which is an unstructured construction of the relationships between entities in accordance with their similarities and differences. The main purpose of ontology in NDN-SDVN is to retrieve exact content from the appropriate vehicle in a short amount of time. A limited number of 1-hop neighbors are selected by determining the residual lifetime, satisfactory rate, and forwarding score of each potential neighbor. These three parameters are significant for forwarding the packets towards the next hop neighbors. The residual lifetime defines the sustainability of the connection between the two vehicles. This residual lifetime is estimated using KF based on the vehicle's location and relative speed.

KF is a linear quadratic estimation that predicts state variable recursively at each step [32]. Let i be the vehicle moving on the road lane whose location is x_{k+1} during time $k+1$ and x_k during time k; similarly, the relative mobilities during times k and $k+1$ are $V_{RM(k)}$ and $V_{RM(k+1)}$, respectively . Relative mobility between vehicles is determined from (11). The residual lifetime in a Kalman filter is determined by measuring the covariance matrix. Then, the residual lifetime is expressed as follows [32]

$$RL^{i}_{(k+1)} = \frac{R_{eff\,(i)} - s\hat{x}_{k+1}}{\left|\hat{v}_{RM\,(k+1)}\right|} \tag{16}$$

The residual lifetime for time $k+1$ is given as $RL^{i}_{(k+1)}$ for the i^{th} vehicle, and it is computed using $R_{\text{eff}(i)}$, which represents the effective communication range. The relative position and speed of vehicle i are denoted as $\hat{x}_{k+1}$ and $\text{V}_{\text{RM(k+1)}}$, respectively. The residual lifetime of the i^{th} vehicle is estimated with respect to the neighboring vehicle j. The term s is given by

$$s = \begin{cases} -1, & if\ v_{RM\,(k+1)} > 0 \\ 1, & if\ v_{RM\,(k+1)} < 0 \end{cases} \tag{17}$$

Along with residual lifetime, the forwarding score and satisfactory rate are estimated for a particular vehicle. A higher forwarding score value ensures successful packet delivery, so this metric is one of the three used in the selection of the 1-hop neighbors. Let FP_i be the forwarding score of the i^{th} vehicle that is expressed as

$$FP_i = \alpha.\frac{vl_i}{v_{max}} + \beta\frac{d^T_{ij}}{R} \tag{18}$$

where α and β are the weighted constants, vl_i is the velocity of vehicle i, d_{ij} is the distance between the two vehicles at time T, and R is the transmission range. The proposed NDN-SDVN system concentrates on content retrieval, which takes into account the satisfactory rate that defines the number of successful content deliveries made to vehicles. This satisfactory rate is formulated as

$$SR_i = \frac{S_{cn(i)}}{Rq_{cn(i)}} \tag{19}$$

The satisfactory rate SR_i of the i^{th} vehicle is calculated using $S_{cn(i)}$ and $Sq_{cn(i)}$, which denote the number of satisfied contents and requested contents, respectively. The SR_i of each vehicle is periodically updated in accordance to the transmissions of each individual vehicle.

The three constraints of the i^{th} vehicle are ($RL^{i}_{(k+1)}$, FP_i, SR_i), which is fed into a neural network to select the number of neighbors that can be used for spreading interest packets.

Figure 4 depicts the KF-NN, in which the input layer is composed of the total number of neighboring vehicles, followed by extraction of the three constraints for each vehicle, and then categorization of the vehicles into class A or B. Class A includes vehicles that can be selected as 1-hop neighbors, and class B includes the 1-hop neighbors that can be ignored for receiving interest packets. Initially, the NN is trained using a set of 1000 input samples from 200 vehicles based on their residual lifetime, forwarding

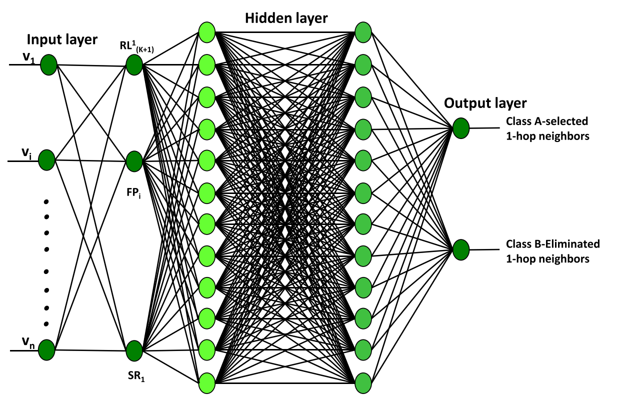
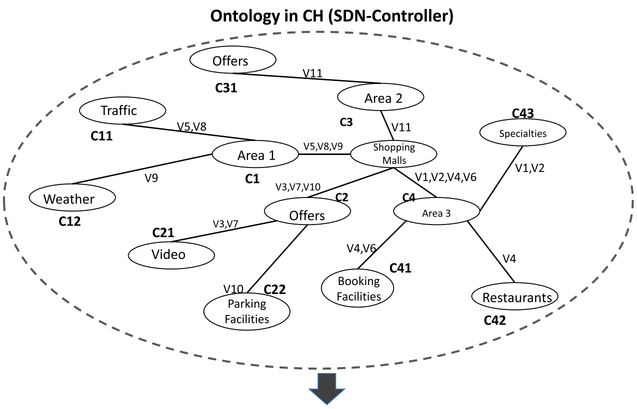


FIGURE 4. 1-Hop neighbor selection from KF-NN.

score, and satisfactory rate. In accordance with this trained measurement, the current process is handled by the selection of 1-hop neighbors. As per this NDN-SDVN, the requesting vehicle submits a request to the CH regarding the content. Figure 5 shows a sample ontology constructed by the CH, which is employed as an SDN-controller. An ontology is constructed based on semantic information such as vehicle information, passenger characteristics, or even environmental changes in the approaching location. From the ontology, a table of MAC addresses and contents holding vehicle identities is maintained. Let C1, C2, C3, and C4 be the contents that are present in vehicles: (V_5,V_8,V_9), (V_3,V_7,V_{10}), (V_{11}), and (V_1,V_2,V_4,V_6), respectively. The sub-categories of the contents are denoted as (C11,C12), (C21,C22), (C31), and (C41,C42,C43) that are associated with C11-V_5,V_8, C12-V_9, C21-V_3,V_7, C22-V_{10}, C31-V_{11}, C41-V_4,V_6, C42-V_4, and C43-V_1,V_2.



Content Name	Vehicle ID	MAC Address
C1	XX,YY,ZZ	FF:FF:FF:FF:FF:FF
C2	Ii,jj,kk	FF:FF:FF:FF:FF:FF
C3	mm	FF:FF:FF:FF:FF:FF
C4	ll,nn,pp,rr	FF:FF:FF:FF:FF:FF

FIGURE 5. Ontology managed in CH.

The requested member vehicle will reply with the target MAC address as *FF:FF:FF:FF:FF:FF*, which is necessary to retrieve content from the appropriate vehicle. After selection of a 1-hop vehicle, the interest packet is forwarded with the two additional fields of timestamp and target MAC address. The timestamp is not just a time within which the content must be retrieved but is defined by combining the transmission and propagation delays. Summation of the transmission and propagation delays is represented as a timestamp in the interest packets, which is expressed as

$$TS = Tr_d + Pr_d \tag{20}$$

The individual transmission delay Tr_d and propagation delay Pr_d for timestamp TS is formulated as follows

$$Tr_d = \frac{P_l}{TR} \tag{21}$$

$$Pr_d = \frac{d}{Tm_s} \tag{22}$$

where P_l is the length of the packet measured in bits, TR is the transmission rate of in terms of kbps, d is the distance between the vehicles, and Tm_s is the transmission speed in units of m/s. Tr_d is a type of delay which occurs due to the data-rates that exist in a particular link. This delay defines the time that is required to transmit the packet via the specified link. Similarly, Pr_d is also a time delay that illustrates the propagation of information between two vehicles. Therefore, in NDN-SDVN, the destination content holding vehicle is predicted by the CH, and a limited number of hops are selected. Because the target MAC address is known, the content is accurately retrieved from the appropriate vehicle. The content information is searched in the ontology of the CH, and then the content is collected from the corresponding vehicle. The time it takes for retrieval by the CH is $O(n)$, where n defines the size of the ontology. Then $O(1)$ represents the number of hops it takes to collect the content.

Consideration of significant link characteristics for clustering and content retrieval in NDN-SDVN achieves a higher efficiency than that reported in previous studies.

V. EXPERIMENTAL EVALUATION

In this section, the proposed NDN-SDVN architecture's performance is validated by measuring significant parameters from the implemented system. This section discusses the simulation environment and comparative analysis. In what follows, we describe the initial simulation setup followed by an evaluation of the NDN-SDVN network compared with previous research work. Furthermore, the reason for the achievements is highlighted.

A. SIMULATION ENVIRONMENT

The NDN-SDVN system model was developed in the Objective Modular Network Testbed in C++ (OMNeT++), which is a popular network simulation platform that can handle wireless networks. The INET framework is the base in OMNeT++ that is integrated with SUMO. OMNeT++4.6 with SUMO is installed in a Windows 7 operating system to deploy the proposed NDN-SDVN system. The proposed NDN-SDVN was created in a vehicular network environment under urban and highway scenarios.

The NDN-SDVN system model was configured based on the parameters highlighted in Table 3. Other basic parameters were initialized as per the network environment. In this study, all vehicles were equipped with SDN functionalities that were only active when a vehicle is selected as CH. Approximately 20 clusters were created, and each cluster consisted of a CH and assistant CH. The proposed stable clustering procedure with optimized assistant CH selection and content retrieval was built based on the parameter settings specified above. The results were measured by executing the simulation under urban and highway scenarios. Our NDN-SDVN system was equipped with 200 vehicles, and half of the vehicles required content. Nearly 100 vehicles were supposed to request

TABLE 3. NDN-SDVN simulation parameter setting.

Parameters		Specifications/ Ranges
Simulation area		5000m×5000m
Number of Vehicles		200
Traffic lane		Two way
Vehicle Movement		Bidirectional
Moving speed	Minimum	5 m/s
	Maximum	35 m/s
Transmission rate		6 – 10Mbps
Communication range		200m
Physical layer		IEEE 802.11p
Propagation model		Two-ray ground model
Packet Interval time		10 s
Interest packet size		70 bytes
Simulation time		500 s

content from the target MAC address as indicated by the particular CH.

B. COMPARATIVE ANALYSIS

The proposed NDN-SDVN is incorporated as a combination of SDVN with NDN. A short comparison of previous studies and their primary focus is shown in Table 4. This illustrates that most research has involved the integration of an SDNV and an NDN-VANET. Hence, the NDN-SDVN proposed in this study represents a novel combination.

TABLE 4. Previous works and their network integration.

Reference	SDVN	NDN-VANET	NDN-SDVN	Scenario
[15]	✓	×	×	Urban
[16]	✓	×	×	Urban
[19]	×	✓	×	Urban and Highway
[20]	×	✓	×	Highway
[21]	×	✓	×	Urban
[24]	×	✓	×	Urban and Highway
[28]	✓	×	×	Urban
[29]	✓	×	×	Not mentioned
[30]	×	✓	×	Urban
[31]	×	✓	×	Not mentioned
Proposed	×	×	✓	Urban and Highway

Comparative analysis was used to compare the proposed NDN-SDVN with the dSDiVN model. Both the NDN-SDVN and dSDiVN system models are infrastructure-less and enabled within clusters moving on road lanes. The CH acts as an SDN-controller and manages the cluster members. In dSDiVN, the selection of a leader was based on partitioning, and due to the mobility of vehicles, leader selection occurred frequently. Leader selection was not performed based on any particular constraints, and this degrades the performance. For example, if a fast-moving vehicle or edge vehicle is chosen as the leader, the cluster stability breaks down. To measure the efficiency of the proposed NDN-SDVN, a set of performance metrics are measured such as CH lifetime, cluster lifetime, idle vehicle ratio, satisfaction rate, latency, and packet delivery ratio.

1) CH LIFE TIME

CH lifetime plays a vital role in evaluating the efficiency of the constructed cluster by measuring the lifetime of CHs. A stable clustering algorithm must be employed with an optimized CH selection strategy because the CH is concerned with maintaining a set of members. The preliminary functionalities of the CH are information gathering, traffic monitoring, and fulfilling the requirements of members. Clustering of fast moving vehicles is slightly complicated due to the speed of the vehicles. However, when clusters are constructed, it is essential to sustain the selected CH to improve the stability of the clusters. The lifetime of the CH is defined as the amount of time during which the CH is maintained in the same cluster as a head.

The CH lifetime is analyzed from the time period at which a selected CH is upheld with respect to the vehicle's velocity. Figure 6 depicts the comparative results of CH lifetime for both urban and highway scenarios. As the vehicle velocity increases, the CH lifetime gradually decreases owing to changes that occur in the topology. The proposed NDN-SDVN should have a higher CH lifetime when compared with the previous dSDiVN, due to the optimal selection of CH for stable clustering. In addition, CH failure is mitigated by the selection of an assistant CH, which enables the lifetime to be increased since even if failure occurs, the assistant CH will be immediately activated. In contrast, in dSDiVN, the SDN-controller deployed CH may be subject to failure that is eventually, but not immediately, resolved.

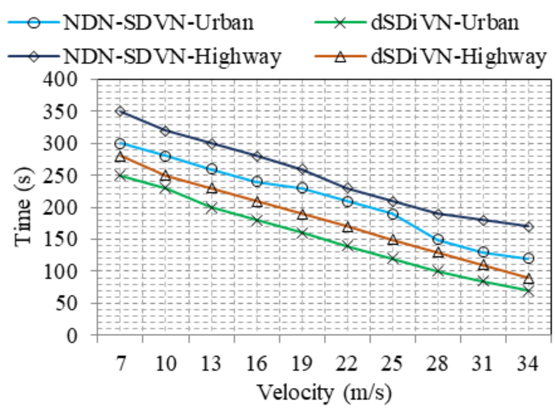


FIGURE 6. Effectiveness of CH lifetime.

The highway scenario shows a higher CH lifetime than the urban scenario because the mobility patterns of the vehicles have similar routes and speeds. In the proposed NDN-SDVN, for speeds of 7 m/s to 34 m/s, the sustained CH time is 300 s to 120 s drop and 250 s to 170 s for the urban and highway scenarios, respectively. On the other hand, in dSDiVN, the equivalent lifetime is 250s to 70s drop and 280s to 90s for the two different scenarios. In this comparison, the CH lifetime drop in dSDiVN is considerably higher than that in NDN-SDVN due to the selection of a random CH within the partition and delayed failure rectification.

2) CLUSTER LIFE TIME

Clustering is performed to join a set of entities into one group to facilitate efficient data transmission and management. The quality and stability of the clustering algorithm is measured by determining the lifetime of the clusters. Lifetime is a metric that measures the time period over which the created cluster maintains the stability of the cluster. An increased cluster lifetime in a network impacts its performance more than other parameters such as satisfaction rate and latency in data transmission. The proposed NDN-SDVN aims to construct a stable cluster, and its efficiency is evaluated using the cluster lifetime metric. Figure 7 is the graphical plot that shows the estimated cluster lifetimes of NDN-SDVN and dSDiVN.

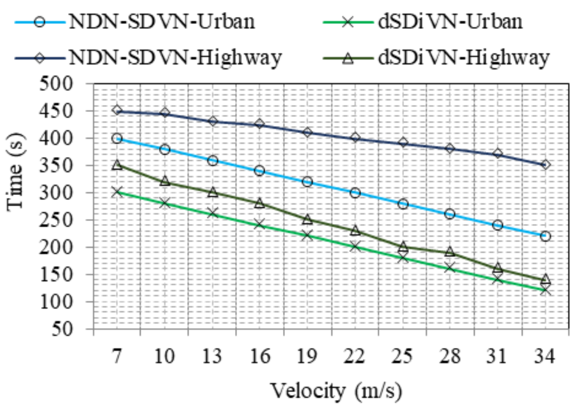


FIGURE 7. Effectiveness of cluster lifetime.

The cluster lifetime of the proposed NDN-SDVN in both urban and highway scenarios is higher than that of the dSDiVN in both cases. As the velocity gradually increases, the cluster lifetime drops. In an urban scenario, the lifetime drops from 400 s to 220 s in NDN-SDVN, whereas it drops from 300 s to 120 s in dSDiVN, which is comparatively less than the drop observed when proposed method was used. In highway scenario, NDN-SDVN achieves a drop from 450 s to 350 s, and dSDiVN drops from 350 s to 140 s. This cluster lifetime is evaluated with respect to increasing vehicle velocity, and as velocity increases, the number of clusters will also increase from 2 to 20. NDN-SDVN has a higher cluster lifetime because it considers link characteristics in the flow rules for clustering, which associates to create stable clusters. In addition, the selection of an optimal assistant CH helps to mitigate repeated CH selection, which may also scatter the cluster and requires the selection of a new head. Stable clustering in NDN-SDVN is ensured by the selection of a CH and deployment of flow rules in the CH.

3) IDLE VEHICLE RATIO

The idle vehicle ratio was used to predict the performance of the proposed clustering algorithm. Clustering is important to consider because it takes into account all the participating vehicles. Isolated vehicles in clusters tend to result in performance degradation. Such vehicles are called idle vehicles, and they cannot communicate with any other vehicle. Therefore, an increase in the number of idle vehicles means that the clustering algorithm is poorly constructed.

Figure 8 depicts the effectiveness of the idle vehicle ratio for measuring the number of vehicles that are left idle without joining a cluster. The comparative plot shows that the previous dSDiVN has larger number of idle vehicles due to inefficient management of clusters. The CH takes responsibility for constructing and managing clusters, so because the CH is selected randomly in dSDiVN, there are likely to be many idle vehicles. As the number of idle vehicles in the network increases, the idle vehicle ratio also increases. Comparatively, the highway scenario has a larger number of idle vehicles than the urban scenario. As the number of vehicles increases, the number of clusters also increases.

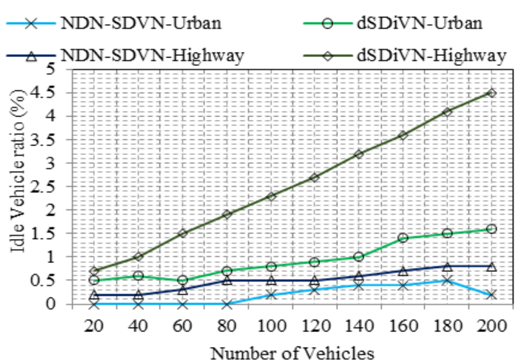


FIGURE 8. Effectiveness of idle vehicle ratio.

Compared with NDN-SDVN, the idle vehicle ratios are approximately 35% and 20% higher in the highway and urban scenarios, respectively, for dSDiVN. However, dSDiVN was not able to cluster vehicles in a highway scenario due to the higher mobility of the vehicles.

4) SATISFACTION RATE

The satisfaction rate is based on the rate at which a vehicle's interest is satisfied by the delivery of appropriate content. The satisfaction rate fluctuates with increases in vehicle participation and speed.

In NDN-SDVN, the interest packets are broadcast to a limited number of 1-hop neighbors, and here, the target MAC address is known to the CH. After receiving the target MAC from the CH, the contents are retrieved from the appropriate vehicle that is identified by the target MAC. Figure 9 illustrates that NDN-SVDN produced a maximum satisfaction

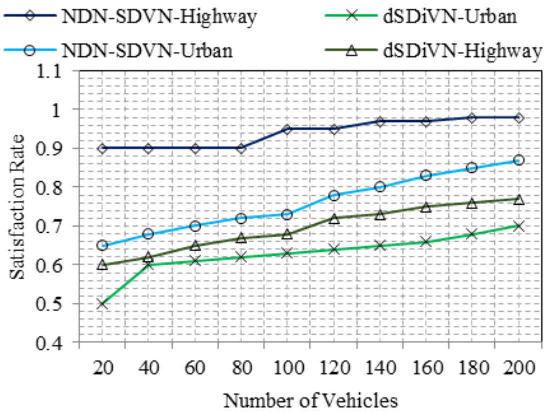


FIGURE 9. Effectiveness of satisfactory rate.

rate of 0.99 in the highway scenario, while the maximum satisfaction rate of dSDiVN was only 0.75. The satisfaction rate achieved by NDN-SDVN due to the detection of the target MAC was nearly 25% higher.

In the urban scenario, the satisfaction rates were 0.7 and 0.89 in the dSDiVN and NDN-SDVN, respectively, indicating that the rate is 20% higher for the proposed model.

5) LATENCY

Latency is defined as the time delay in retrieving the requested content from the destination vehicle. In the proposed NDN-SDVN, a special timestamp file is included in the interest packet. This timestamp is a combination of transmission and propagation delays. Including these two metrics in the timestamp ensures that contents will be retrieved with limited latency.

As the number of vehicles increases, the latency also gradually increases due to an increase in the number of interest packets. Figure 10 illustrates the latency metric for NDN-SDVN compared with dSDiVN, with respect to the number of vehicles. The highway scenario has a higher latency than the urban scenario since the mobility speeds of the vehicles are larger. However, in both urban and highway

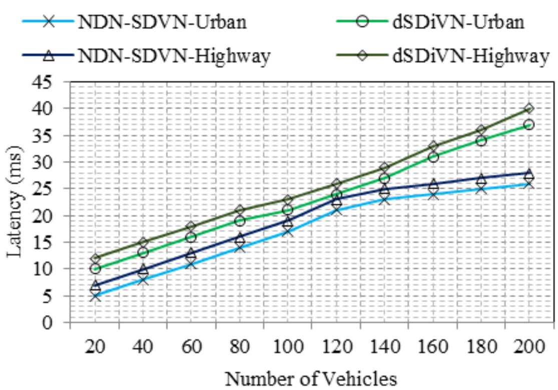


FIGURE 10. Effectiveness of latency.

scenarios, the latency in the proposed NDN-SDVN was less than that in the existing dSDiVN.

6) PACKET DELIVERY RATIO

The packet delivery ratio (PDR) plays a key role in evaluating the efficiency of the data transmission deployed in a network. The PDR is defined as the number of successful data transmissions made relative to the number of packets received at a given time. An increase in PDR is associated with a better network model design. Here, the PDR is validated based on forwarding of the received interest packets. PDR is measured with respect to the simulation time, and the resulting plot is shown in Fig. 11.

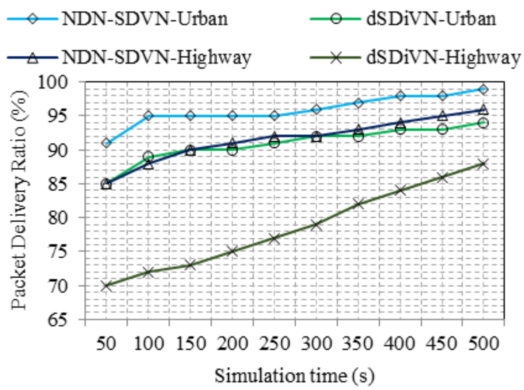


FIGURE 11. Effectiveness of PDR.

Increases in PDR demonstrate the improved performance of the proposed system model, and the proposed NDN-SDVN system model has a higher PDR than the existing dSDiVN. This increase in PDR is due to the accurate identification of the target, after which the interest packets are broadcast to 1-hop neighbors.

This comparative study shows that the proposed NDN-SDVN system model is more efficient in terms of the analyzed parameters. These achievements are assisted by stable clustering and content retrieval with appropriate procedures and algorithms.

VI. CONCLUSION

In this study, a combined NDN-SDVN system model was developed to provide stable clustering and content retrieval. Creating stable clusters and preventing a broadcast storm were the major challenging issues addressed by this research. Stable clusters were constructed by initially selecting a CH using centrality and QoS, and this is followed by the clustering process. The CHs are enabled with the functionalities of SDN-controllers, which are composed of flow rules for cluster construction within a given back-off time. After clusters are constructed, the head chooses an optimal assistant CH using the MFO algorithm. The presence of this assistant CH helps to prevent the CH from failing, and hence, it extends the performance of the network. Then, content retrieval is initiated when a vehicle makes a request to the CH. In the proposed NDN-SDVN, the CH acts as an SDN-controller that develops an ontology for the contents that are carried by member vehicles. From this ontology, the requesting vehicle is delivered with a target MAC address before the interest packets are broadcast. A broadcast storm is mitigated by selecting a 1-hop neighbor using a KF-NN based on link characteristics. Finally, two additional fields—the timestamp and target MAC address—are inserted into the interest packet. The proposed NDN-SDVN was implemented, and it demonstrated better performance than existing network models in both highway and urban scenarios.

In the future, we plan to extend this NDN-SDVN to include video content retrieval.

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