

A Novel Stability Evaluation Technique for Clustering Algorithms in Vehicular Ad Hoc Networks

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A novel stability evaluation technique for clustering algorithms in vehicular ad hoc networks

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Abstract: The development of the technology and connected devices such as internet of things (IoT), internet of vehicles (IoV), and 5G motivate the researchers to give more attention in the field. Clustering is a key factor in vehicular ad-hoc network (VANET) where a number of vehicles join to form a group based on common characteristics. Vehicles are distinguished by their high mobility in ad hoc vehicle networks. Changes frequently occur in the topology of VANET, causing continuous failures in network communication. In such a dynamic environment, the creation and maintenance of a stable cluster are significant challenges. The evaluation of stability in VANET clustering is an important part to evaluate the clustering approaches. In this paper, a mathematical technique (based on the birth-death process) is created to evaluate the clusters stability based on the number of leaving and joining vehicles to each cluster after its creation. The stability of the created clusters is tested by checking the number of vehicles in each cluster at different successive times. These tests indicate the joining and leaving vehicles to each cluster and their effects on the cluster stability. When the results of the technique show that the standard deviation is small for each cluster, it can be concluded that the proposed clustering algorithm is able to achieve stability in cluster maintaining phase.

Keyword: Vehicular ad hoc networks, Clustering, Intelligent transport systems, Stability evaluation, Internet of things, Cluster maintenance, Center base clustering.

1. Introduction

Intelligent Transportation Systems (ITS) and internet of things (IoT) technologies have been built dramatically in recent years. Various models have been proposed and implemented in support of this technology [1]. This varies from the level of network elements such as the routing, clustering, reliability analysis, congestion solutions, Internet of vehicles (IoV) [2]. Wireless access in vehicular environments (WAVE) is used on dedicated short-range communications (DSRC) [3] frequency bands by IEEE802.11P for vehicular ad hoc networks (VANET) wireless communication. DSRC is currently used to meet the requirement of a low latency for vehicle to vehicle communication (V2V) control messages, and safety, also long term

evolution (LTE) [4] is used for vehicle to infrastructure communication (V2I). Each vehicle actions as a mobile router, and it used available sensor in each vehicle called on-board unit (OBU) to communicate with the nearby vehicles, and roadside units within a coverage [5]. The mobile ad hoc network (MANET) methods have been adopted by several VANET approaches, as there are some similar features [6]. However, VANET has its own distinctive characteristics, such as high mobility of vehicles. In different applications, clustering in VANETs is fundamental. It has been used by some researchers to build a data-dissemination method to avoid flooding in the network based on different approaches. Figure 1 illustrates the clustering in VANET.

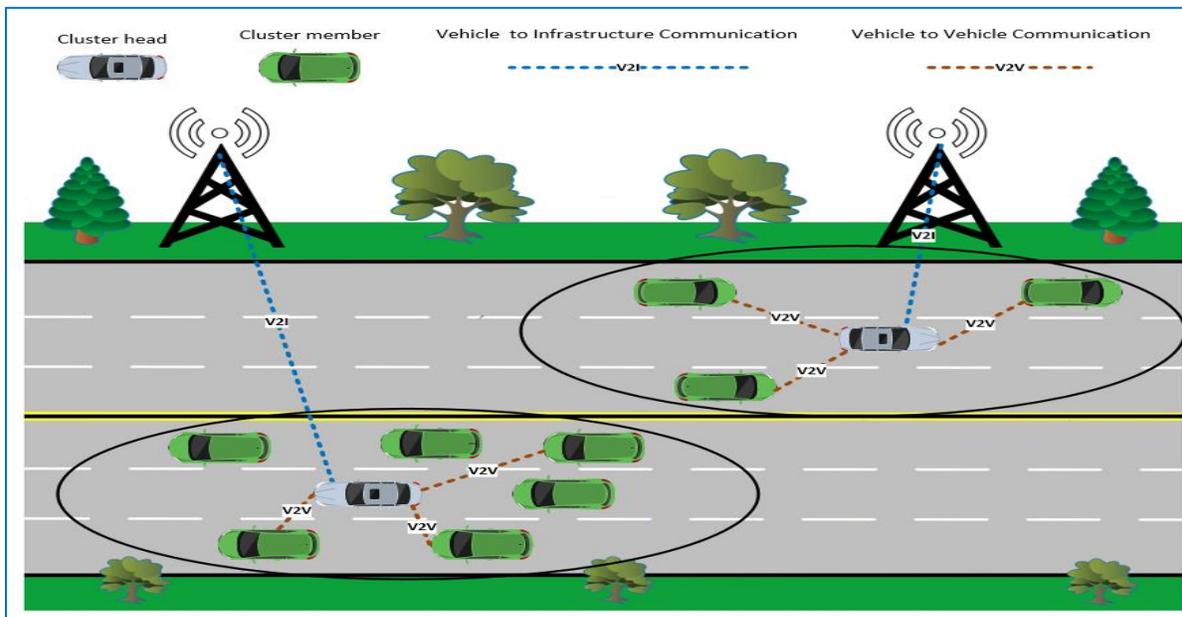


Figure 1: Clustering in vehicular ad hoc networks

VANET clustering is considered to be a critical method for boosting a network performance. More than one aspect is associated with it. Stable clustering, for example, is reflected in good MAC scheduling performance, efficient routing, and a reliable and stable network as a result. Clustering has many categories and types in VANET, such as topology single-hop and multi-hop [7]. The clustering contains of three phases, the first phase is creating creation, the second phase is cluster head selection, and the third phase is cluster maintenance.

Many approaches have been proposed for VANET clustering. However, most of them focused on the cluster head selection and give less attention to the other phases. The high dynamic of the VANET environment making the creation and maintenance of stable clusters is a big challenge issue. The stability of clusters is a key factor in VANET clustering. Several approaches have

been proposed to develop the clustering algorithms for increasing the stability [8]. This article aims to tackle the complexity of the stability evaluation in VANETs clustering. More specifically, this paper focused on utilize the calculation of leaving and joining vehicles from/to cluster during the maintenance phase to evaluate the stability of the clustering, to solve certain challenging issues in stability evaluation in VANET clustering such as the complex calculations of the performance metrics, and applying these metrics to other algorithms to comparing the algorithms and then show the superiority. This paper proposed a novel VANET clustering stability evaluation technique by exploiting the model of the birth-death process based on the leaving and joining vehicles in the maintenance phase. The contributions of this article can be summarized as follows:

- This article proposed a novel technique to evaluate cluster stability.
- It has developed the birth-death process model for the cluster maintenance phase.
- This article employs a mathematical aspect to utilize in the dynamic environment and different generated scenarios using different parameters including vehicle density and high mobility of vehicles on the highway.
- It extensively evaluates based on the joining and leaving vehicles to/from each cluster.

The article is organized as follows. The literature is provided in section 2. Next, the methodology of the proposed technique is presented in section 3. After that, experimental results and discussion are presented in section 4. Finally, the conclusion with the future work is given in section 5.

2. Related works

The evaluation of VANETs clustering approaches concentrates on the stability of the generated clusters. More specifically, the further prolonged state of the vehicle in terms of cluster head (CH) or cluster member (CM) can be used as clustering performance metrics; these are known as cluster head lifetime and cluster member lifetime, respectively. Another aspect of performance is the clustering efficiency. This metrics provide the effectiveness of the clustering approach. Connecting these metrics to other performance aspects, such as the number of clusters, which need to be reduced, can present a broader view of stability and effectiveness [9] [10] [11] [12]. The evaluation of the clustering stability is based on performance metrics such as efficiency, average cluster head duration (CHD), average cluster member duration (CMD), average cluster head change rate (CHCR), and number of clusters which need complex computations. Moreover,

these metrics need to compare the presented approaches with other relevant approaches to show the superiority. Figure 2 shows the performance metrics of clustering in vehicular ad hoc networks.

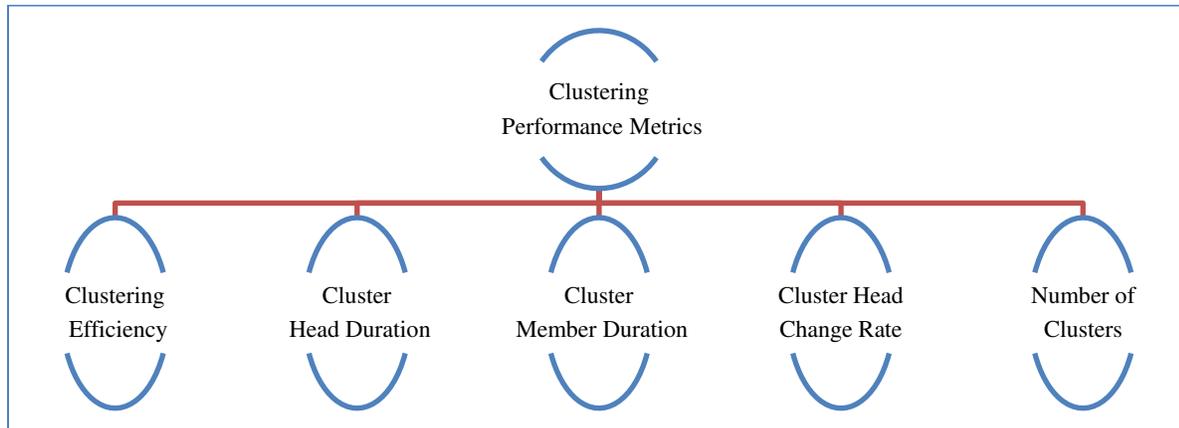


Figure 2: Performance metrics of clustering stability

Clustering efficiency: The percentage of vehicles entering the clustering phase in the simulation is the metric of clustering efficiency. Dividing the number of vehicles that were part of the cluster (cluster member or cluster head) into the total number of vehicles is determined.

Average cluster head duration: The time from changing the state of a vehicle as cluster head to a time when this vehicle leaves this state is called cluster head duration. The average CH duration (ACHD) is estimated by dividing the total cluster head duration periods to the number of state changes. The average length of the cluster head shows the average duration of being in the state of the cluster head. The longer CH lifetime is an indicator of the high stability of the clustering approach.

Average cluster member duration: Vehicle cluster member duration represents the time interval from joining the cluster as a cluster member to leaving this cluster by changing its state. A measure of the stability in the clustering approach is the average cluster member lifetime or duration (ACMD). It refers to the average time in a CM's state of being. Thus, for each conversion to a member of the cluster, the ACMD is dividing the total time durations over the total number of changes to a cluster member state. This study goal is to maximize the cluster member duration (lifetime).

Average cluster head change rate: Cluster head change rate represents a metric to demonstrate the cluster stability. It is defined as the number of changes from a CH state to another state

within a time unit. The average cluster head change rate (ACHCR) is calculated by dividing the total number of changes over the total simulation time.

Number of clusters: During the entire life of the network, the average number of clusters determines how many clusters have been derived from the clustering algorithm. Each simulation experiment resulted certain number of clusters. The average number of clusters is estimated by dividing the total number of the generated clusters in all the experiments by the total number of the simulation experiments. The aim is to reduce the number of clusters. Table 1: Analysis for the most related VANET’s clustering approaches.

Table 1: Analysis of clustering approaches

Clustering Approach	Proposed for	Single hop	Multi-hop	Simulation	Scenario	Performance metric	Reference
ALM	VANETs	---	---	SUMO / SMURPH	Random	Cluster lifetime, Status changes	[13]
GDMAC	MANETs	yes	no	NS2	Random	Cluster lifetime, residence time, status changes	[14]
UFLCS	VANETs	no	yes	iTETRIS, Octave	Random	Cluster head lifetime, Cluster head stability, no. of clusters	[15]
MBDF	VANETs	---	---	NS3 & SUMO	Random	Stability, ACMD	[16]
MC-DRIVE	VANETs	---	---	NCTUns	Urban	Overhead, no. of Cluster head, accuracy	[17]
LBC	VANETs	yes	No	NS3	Urban	Cluster head changes	[18]
DBC	VANETs	---	---	JiST/ SWANS& VanetMobiSim	Urban	AC size, A no. of C, ACH, A no. of CHCh, efficiency	[19]
CA	VANETs	no	yes	---	Urban	Lifetime, throughput, overhead	[20]
MDMAC	VANETs	no	yes	Jist/SWANS++	Urban	Overhead, no. of clusters	[21]
DMSC	VANETs	yes	no	ns-2 & SUMO	Urban	CHD, CMD, CHCR, no. of clusters	[12]
AMACAD	VANETs	yes	no	Java JDeveloper	Urban	CHD, CMD, no. of clusters, re-affiliation rate	[22]

Clustering Approach	Proposed for	Single hop	Multi-hop	Simulation	Scenario	Performance metric	Reference
				10G			
VWCA	VANETs	---	---	MATLAB	Highway	ACHD, ACMD	[23]
CCA	VANETs	no	yes	SUMO	high mobility	Lifetime, no. of clusters, ACHCR, ACMCR	[24]
SBCA	VANETs	yes	no	ns-2	Highway	AC lifetime, overhead, PDR	[25]
TBC	VANETs	yes	yes	C++	Highway	Cluster stability, AC lifetime, no. of clusters	[26]
Sp-CI	VANETs	yes	yes	---	Highway	Cluster stability, no. of clusters, Cluster lifetime	[27]
FLBA	VANETs	yes	no	ns-2, MOVE, SUMO	Highway	CHD, CMD, AC size	[28]
APROVE	VANETs	yes	no	ns-2	Highway	ACHD, ACMD, ACHCR, A no. of clusters	[9]
MCTC MDC	VANETs	yes	no	MATLAB	Highway	AC lifetime, AC size A no. of CHs	[29]
DMCNF	VANETs	no	yes	ns-2/ VanetMobiSim	High-mobility	CHD, CMD, CHCR, no. of clusters	[10]
VMaSC-LTE	VANETs	no	yes	NS3 & SUMO	Highway	CHD, CMD, CHCR, Overhead	[11]
CBSC	VANETs	---	---	OMNeT++ & SUMO	Highway	ACMD, A no. of re-affiliation, PLR	[30]
UFC	VANETs	yes	no	SUMO	Highway	CHD, CMD, no. of clusters, Efficiency	[31]
CBSC	VANETs	yes	no	Veins LTE	Highway	ACHD, ACMD, PLR	[32]
DBSCAN-FLC	VANETs	yes	no	MATLAB R2017b	Highway	ACD, vehicle status change, no. of clusters	[33]

3. Methodology

Usually, vehicles inside each cluster move at different speeds. The number of vehicles in each cluster may increase, decrease, or stay without change after a certain time interval. As the number of vehicles in a cluster remains without modification for a long-time-interval, this gives a good indication for improving cluster stability. The next system state will have decreased, increased, or stay without change during a very short interval. These processes are based on a

stochastic process (called the Birth-Death process). Each cluster can lose a vehicle (according to a leaving process) due to either it has a higher acceleration/speed, or it may have a very low acceleration/speed (the vehicles number in a cluster will be decreased; which is equivalent to a death process).

A cluster can get an additional vehicle (as a joining vehicle) that either has a very high speed to leave forward from a back cluster or it may have a very slow to lag from a forward (leading) cluster (the vehicles number in a cluster will be increased by one; which is equivalent to a birth process). All these cases can happen with certain probabilities based on the vehicle acceleration and speed. Figure 3 represents a schematic diagram to show these possible cases, while Figure 4 presents a developed flowchart to indicate the vehicles leaving and joining possibilities.

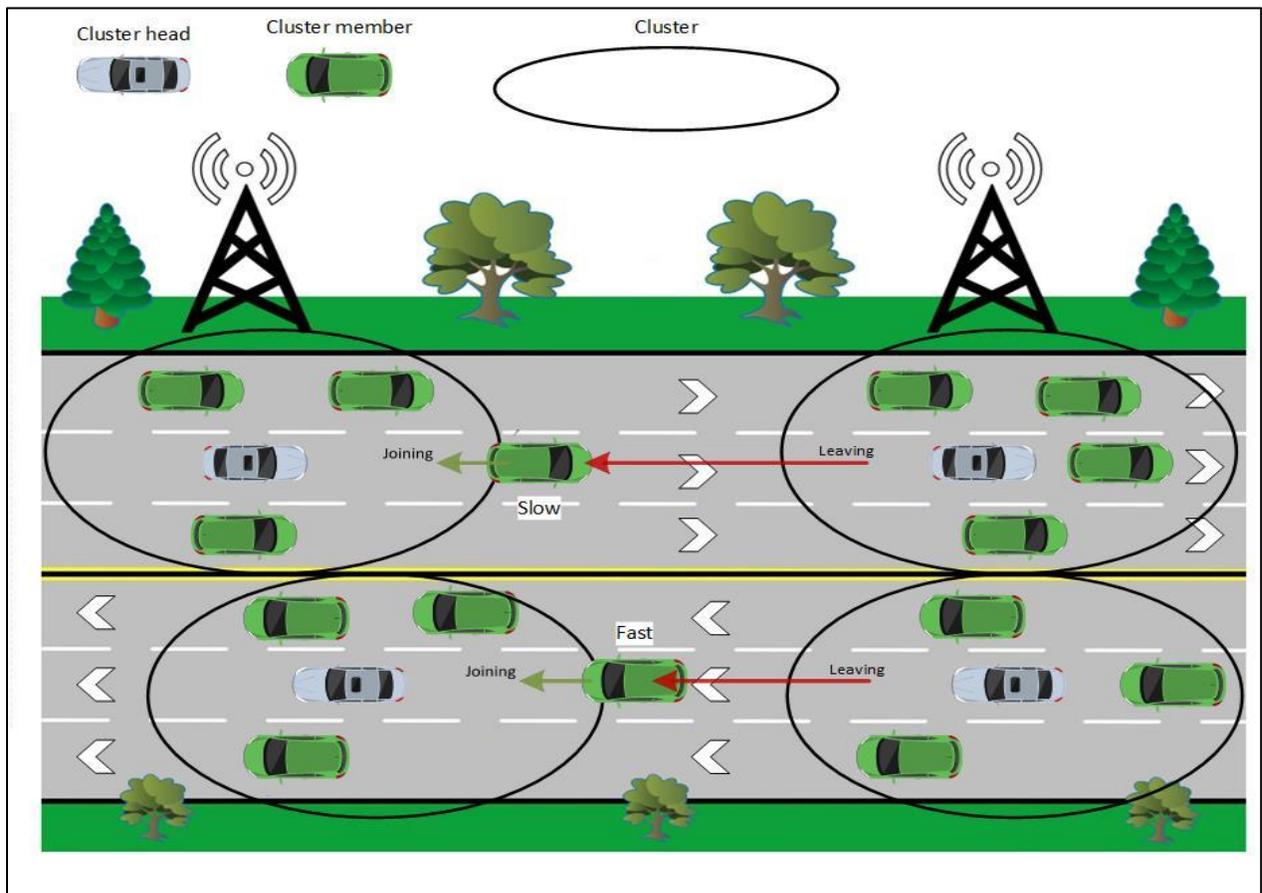


Figure 3: Vehicles leaving and joining representation

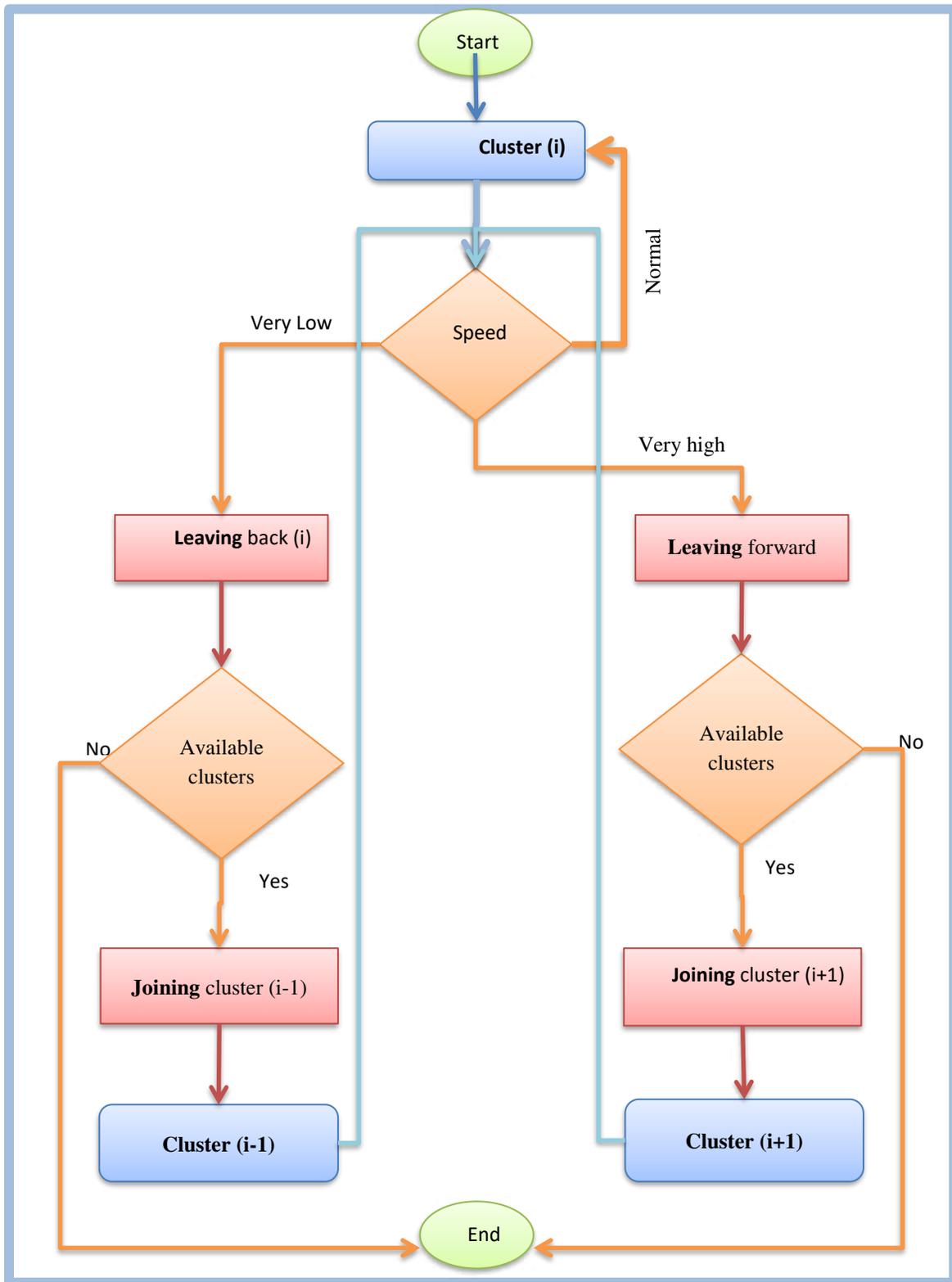


Figure 4: Flowchart for vehicles leaving and joining from/to a cluster

Based on Figure 3, the following assumptions can be suggested:

Δt : very short interval of time.

n : numbers of vehicles in the zone area at the time t .

L_f : leaving rate (vehicle leave its cluster forward; very fast; v. high speed).

L_b : leaving rate (vehicle leave its cluster backward; very slow; v. low speed).

J_f : joining rate (vehicle joining a cluster from forward; very slow; v. low speed).

J_b : joining rate (vehicle joining a cluster from backward; very fast; v. high speed).

S : vehicle staying in its cluster.

E_n : the system's state means (vehicles number in a cluster at a certain time).

$O(\Delta t)$: (order Δt) = 0.

t : is the current time.

$t + \Delta t$: is the next time or after a period of Δt .

$P_n(t)$ = probability that there are n vehicles in the cluster at time t .

$P_n(t, t + \Delta t)$ = probability that there are n vehicles in a cluster at time $(t + \Delta t)$.

Any joining process can be modelled as the birth process.

Any leaving process can be modelled as the death process.

The whole problem can be modelled as a complex birth-death process.

1. The probability that a vehicle leaves its cluster forward in an interval of time $(t, t + \Delta t)$; thus

Δt is a very short interval of time, and the system having n vehicles (E_n) is:

Pr. one vehicle will leave forward in $(t, t + \Delta t)$, and the system is in state E_n

$$= L_f \Delta t + O(\Delta t) \quad (1)$$

2. The probability that a vehicle leaves its cluster backward in the interval of time $(t, t + \Delta t)$; thus Δt is a very short interval of time, and the system having n vehicles (E_n) is:

Pr. one vehicle will leave backward in: $t, t + \Delta t$ and the system is in state E_n :

$$= L_b \Delta t + O(\Delta t) \quad (2)$$

3. The probability that a vehicle joining a cluster from its head in the interval of time $(t, t + \Delta t)$; thus, Δt is a very short interval of time, and the system having n vehicles (E_n) is:

Pr. one vehicle will join from forward in: $t, t + \Delta t$ and the system is in state E_n

$$= J_f \Delta t + O(\Delta t) \quad (3)$$

4. The probability that a vehicle joining a cluster from back in the interval of time $(t, t + \Delta t)$; thus Δt is a very short interval of time, and the system having n vehicles (E_n) is:

Pr. one vehicle will join from back in: $t, t + \Delta t$ and the system is in state E_n

$$= J_b \Delta t + O(\Delta t) \quad (4)$$

5. The probability that no vehicle leaves or joins its cluster backward or forward in the interval of time $(t, t + \Delta t)$;

Pr. no vehicle leaves or joins its cluster backward or forward in: $t, t + \Delta t$ and the system is in state E_n :

$$= (1 - L_b \Delta t)(1 - L_f \Delta t)(1 - J_b \Delta t)(1 - J_f \Delta t) + O(\Delta t) \quad (5)$$

6. The forward leaving the state and backward leaving the state are independent of each other.

7. The probability of occurrence of more than one event in the interval of time $(t, t + \Delta t)$ is equal to zero, thus:

$$\text{Pr. more than one event in: } t, t + \Delta t = O(\Delta t) \quad (6)$$

This paper assumes that $p_n(t)$ is the probability of being the system in state E_n (the expected vehicles number in the cluster is n) at time t , or the probability of being the number of vehicles equal to (n) at time t .

Also, $p_n(t, t + \Delta t)$ is the probability of being the system in state E_n at the time $(t, t + \Delta t)$.

Hence, the possible states at the time $(t, t + \Delta t)$ are as follows:

Table 2 summarizes all the expected states at time t and the possible states at time $t + \Delta t$ with all their probabilities and transition possibilities.

Table 2: Expected states at time t and $t + \Delta t$ with all their transitions possibilities

An occurrence at a time $(t, t + \Delta t)$	The Probability	Transitions from state at time t to state at time $t + \Delta t$
No vehicle leaves or joins its cluster	$(1 - L_b \Delta t)(1 - L_f \Delta t)(1 - J_b \Delta t)(1 - J_f \Delta t) + O(\Delta t)$	$E_n \longrightarrow E_n$
Only one vehicle will leave forward	$L_f \Delta t (1 - L_b \Delta t)(1 - J_b \Delta t)(1 - J_f \Delta t) + O(\Delta t)$	$E_{n+1} \longrightarrow E_n$
Only one vehicle will leave backward	$L_b \Delta t (1 - L_f \Delta t)(1 - J_b \Delta t)(1 - J_f \Delta t) + O(\Delta t)$	$E_{n+1} \longrightarrow E_n$
Only one vehicle will join from forward	$J_f \Delta t (1 - L_b \Delta t) (1 - L_f \Delta t) (1 - J_b \Delta t) + O(\Delta t)$	$E_{n-1} \longrightarrow E_n$
Only one vehicle will join from backward	$J_b \Delta t (1 - L_b \Delta t) (1 - L_f \Delta t) (1 - J_f \Delta t) + O(\Delta t)$	$E_{n-1} \longrightarrow E_n$
More than one occurrence	$O(\Delta t)$	

Equation (3.24) can be derived by collecting Equations (3.18) to (3.23) with Table 3.10.

$$\begin{aligned}
 P_n(t, t + \Delta t) = & P_n(t) (1 - L_b \Delta t)(1 - L_f \Delta t)(1 - J_b \Delta t)(1 - J_f \Delta t) + P_{n+1}(t) L_f \Delta t (1 - L_b \Delta t)(1 - J_b \Delta t)(1 - \\
 & J_f \Delta t) + P_{n+1}(t) L_b \Delta t (1 - L_f \Delta t)(1 - J_b \Delta t)(1 - J_f \Delta t) + P_{n-1}(t) J_f \Delta t (1 - L_b \Delta t) (1 - L_f \Delta t) (1 - J_b \\
 & \Delta t) + P_{n-1}(t) J_b \Delta t (1 - L_b \Delta t) (1 - L_f \Delta t) (1 - J_f \Delta t) + O(\Delta t) \quad (7)
 \end{aligned}$$

Equation (7) can be used in expecting the number of vehicles in each cluster at any time. Also, this expectation can be utilized to compare the number of vehicles in any successive times to indicate the increase or reduction. Figure 5 represents the state diagram for vehicles leaving and joining process [34].

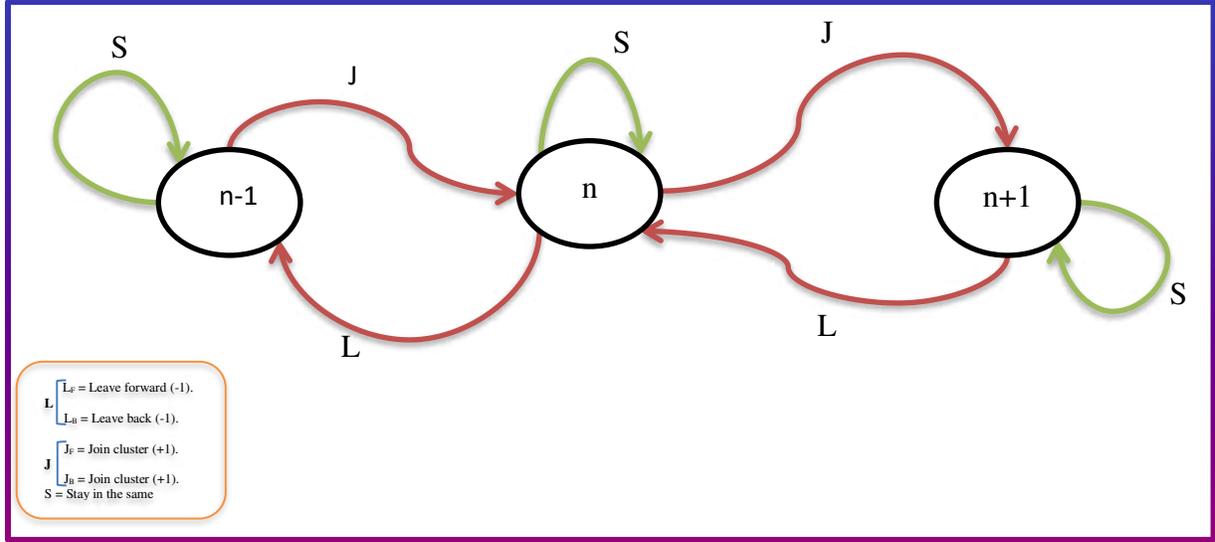


Figure 5: State diagram for vehicles leaving and joining process

Simulation parameters

The simulation parameters is provided in Table 3.

Table 3: The simulation parameters of the performed experiments

Parameter	Value
Number of Lanes	4, 6, 8
Experiment Duration	300 s
Max-Velocity	30 m/s
Min-Velocity	10 m/s
Transmission Range (TR)	300 m
Number of Vehicles	120, 200, 300
Length of Environment	10 km

4. Results and discussions

The leaving and joining vehicles to each cluster after its establishment can be expected and observed. In this paper, the concept of this developed technique is implemented to test the stability of the cluster. This technique is used to test the cluster stability by observing the number of vehicles in each cluster at different successive times. All the generated clusters in the proposed approach called CEC-GP [35] are tested at their starting time to indicate the initial number of vehicles. Also, these clusters are tested at different successive times to observe the leaving or the joining vehicles. Five clusters observations are selected randomly from each traffic level and presented as a sample. Figure 6 presents the average number of

the generated clusters in each traffic level. The number of leaving or joining vehicles to a cluster is observed after each very short time interval Δt . These times are; $t + \Delta t$, $t + 2\Delta t$, $t + 3\Delta t$, and so on). In each of these times, the number of vehicles in a cluster is observed and compared with the previously observed number to indicate any joining or leaving vehicle.

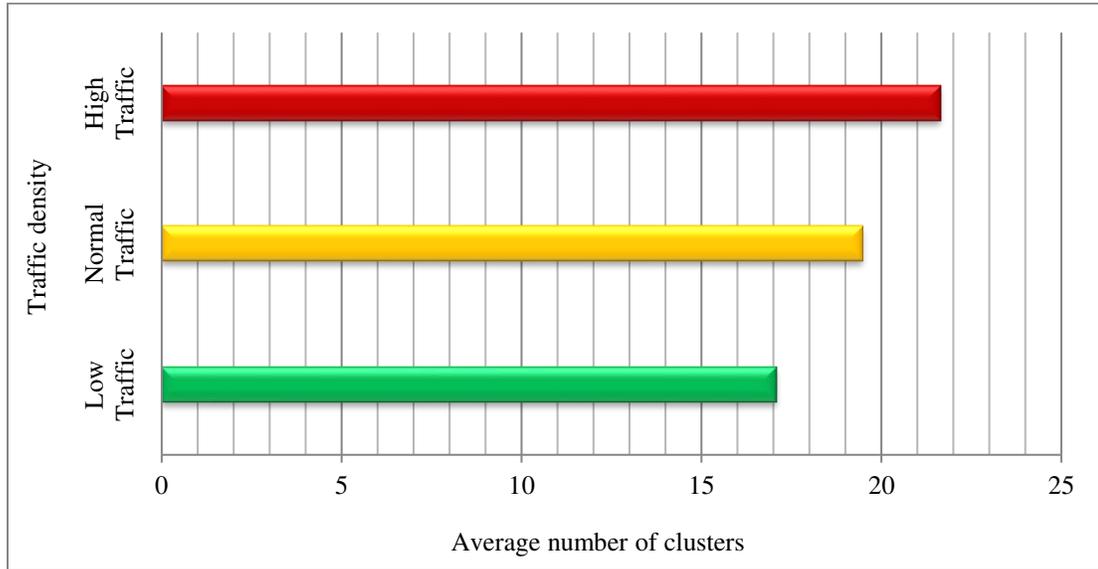


Figure 6: The average number of clusters in CEC-GP

Three possible outcomes can be observed; if the current number is greater than the previous number (there is a joining vehicle to a cluster), if the current number is less than the previous number (there is a leaving vehicle from a cluster), and if the current number is the same with the previous number (there is no joining nor leaving vehicle). The cluster stability is achieved if the cluster size is changed slightly along a certain time.

The cluster is stable when the number of vehicles at each time is close with the average number of vehicles in a cluster. The range measure is used to indicate the difference between the extreme values in each cluster. Keeping these extreme points close will result in a stable cluster. Mean, and standard deviation are also used as statistical indications to measure the central tendency and the spread. This test is implemented in low, medium, and high traffic levels. Table 4 shows the observed number of vehicles in each cluster of CEC-GP on a low traffic level. It presents the observed number of vehicles in each cluster at each time interval Δt during the time t to time $(t+9\Delta t)$. A little variation in the number of vehicles in each cluster is observed from the values of the mean, standard deviation, and the range for each cluster.

Table 4: Number of vehicles in each cluster at each time interval in low traffic level

Low Traffic					
Time/ Cluster number	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
t	11	20	3	7	17
t+ Δt	12	20	3	8	17
t+2 Δt	12	21	3	8	17
t+3 Δt	12	21	2	8	18
t+4 Δt	12	21	2	8	18
t+5 Δt	12	21	2	8	18
t+6 Δt	12	21	2	8	18
t+7 Δt	12	21	2	8	17
t+8 Δt	12	21	2	8	17
t+9 Δt	11	22	2	7	16
average	11.8 \approx 12	20.9 \approx 21	2.3 \approx 2	7.8 \approx 8	17.3 \approx 17
Standard deviation	0.4	0.5	0.4	0.4	0.6
Range	1	2	1	1	2

Figure 7 shows the observed number of vehicles in each cluster from t to t+9 Δt . It gives a graphical representation to observe the leaving and joining vehicles to each cluster during each Δt .

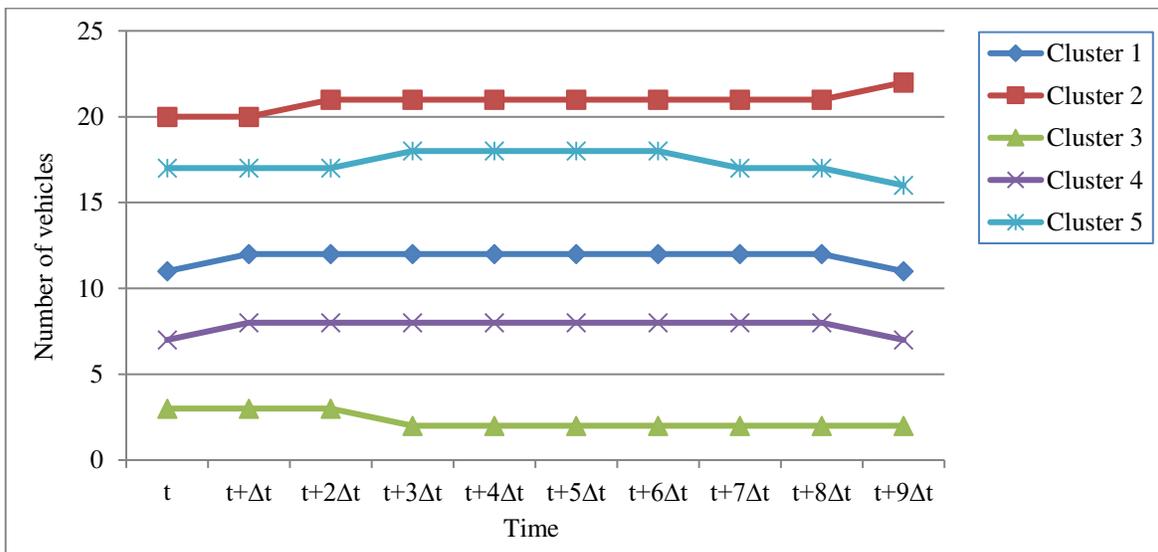


Figure 7: Number of vehicles in each cluster at each time interval for the low traffic level

Table 5 shows the observed number of vehicles in each cluster in a normal traffic level during the time t to time $(t+9\Delta t)$. The central tendency values show high stability in the dispersion around the average. Figure 8 shows the observed number of vehicles in each cluster at each time interval (Δt) in a normal traffic level. It gives a graphical representation to observe each cluster's stability in addition to the leaving or joining vehicles to each cluster during each successive Δt .

Table 5: Number of vehicles in each cluster at each time interval in normal traffic level

<i>Time/ Cluster number</i>	Normal Traffic				
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
t	8	13	16	19	27
t+Δt	8	13	16	19	28
t+2Δt	8	13	15	19	28
t+3Δt	8	13	15	20	29
t+4Δt	9	14	15	20	28
t+5Δt	10	14	15	20	28
t+6Δt	10	14	15	20	29
t+7Δt	10	14	15	20	29
t+8Δt	10	14	16	19	29
t+9Δt	10	14	16	19	29
Average	9.1 \approx 9	13.6 \approx 14	15.4 \approx 15	19.5 \approx 20	28.4 \approx 28
Standard Deviation	0.9	0.5	0.5	0.5	0.6
Range	2	1	1	1	2

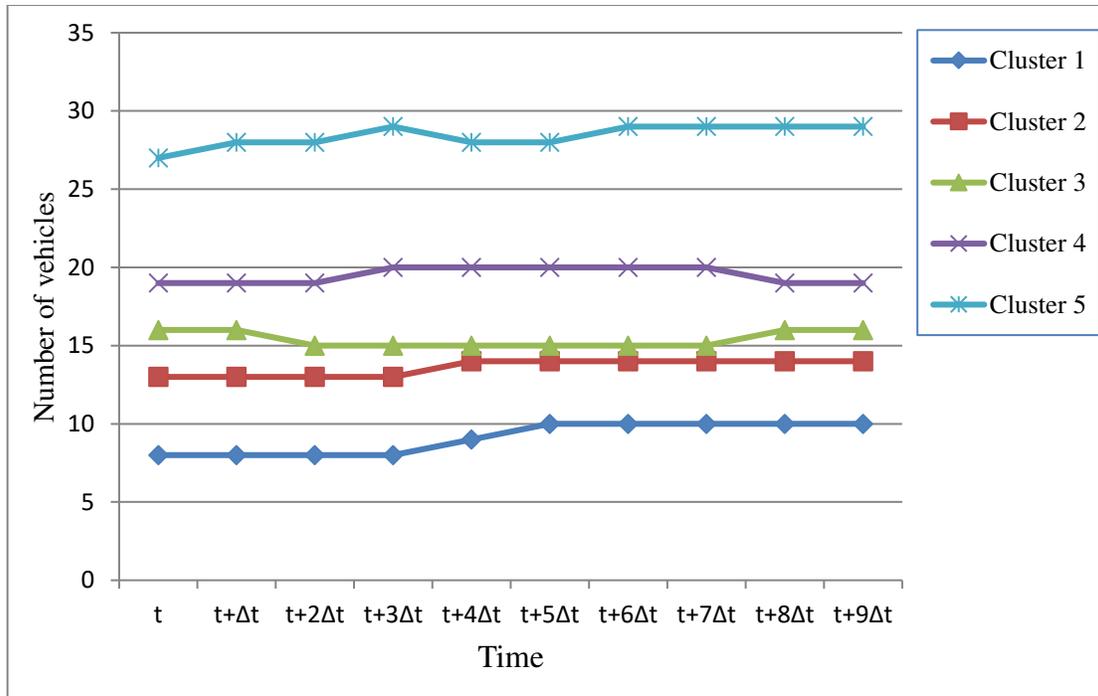


Figure 8: Number of vehicles in each cluster at each time interval for normal traffic level

Table 6 shows the observed number of vehicles in each cluster in a high traffic level during the time t to time $(t+9\Delta t)$. The central tendency measure values show high stability in the dispersion around the average for all clusters. Figure 9 shows a graphical representation to observe each cluster's stability and the leaving or joining vehicles to each cluster during each Δt . The results in this traffic level present the effect of high mobility concerning the other two levels. These results are observed through the range and the standard deviation values, although it keeps a high level of stability.

Table 6: Number of vehicles in each cluster at each time interval in high traffic level

Time/ Cluster number	High Traffic				
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
t	43	31	7	11	35
t+Δt	42	31	8	12	34
t+2Δt	42	31	9	12	34
t+3Δt	42	32	9	12	33
t+4Δt	41	32	8	12	33
t+5Δt	41	33	8	11	32

t+6Δt	42	34	8	12	31
t+7Δt	43	35	8	12	31
t+8Δt	43	35	8	12	31
t+9Δt	43	35	8	12	31
Average	42.2≈ 42	32.9≈ 33	8.1≈ 8	11.8≈ 12	32.5≈ 33
Standard Deviation	0.7	1.7	0.5	0.4	1.5
Range	2	4	1	1	4

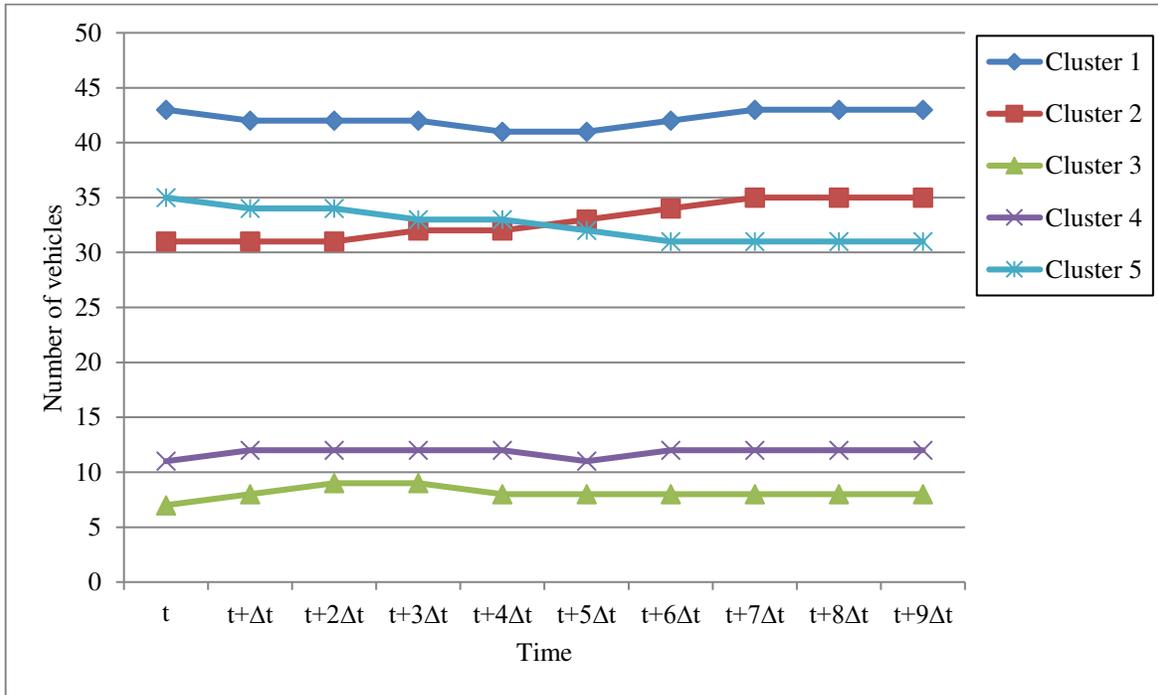


Figure 9: Number of vehicles in each cluster at each time interval for high traffic level

5. Conclusions

VANET represents one of the essential parts of ITS. Clustering was considered a critical part of the hierarchy of intelligent transportation systems. VANET clustering is the process of joining the neighboring moving vehicles on the road in one group according to specific properties. The critical aim of collecting the vehicles into groups (clusters) is to achieve higher connectivity, reducing the possible interruptions due to vehicles' random speeds. VANET clustering is to change the vehicle's network representation into sets of connected vehicles. A stable cluster is essential to support the routing and data dissemination process in a VANET. This study

developed a mathematical technique (based on the birth-death process) to evaluate the clusters stability based on the number of leaving and joining vehicles to each cluster after its creation. The leaving and joining vehicles to each cluster after its establishment can be observed. In this study, the concept of this developed technique is implemented to test the stability of the cluster. This technique is used to test the cluster stability by observing the number of vehicles in each cluster at different successive times. In clustering approaches the leaving and joining vehicles to each cluster after its establishment can be expected without the completion of the environment experiment will be the future work.

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Declarations

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*Code availability (software application or custom code): 'Not applicable'.

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Figures

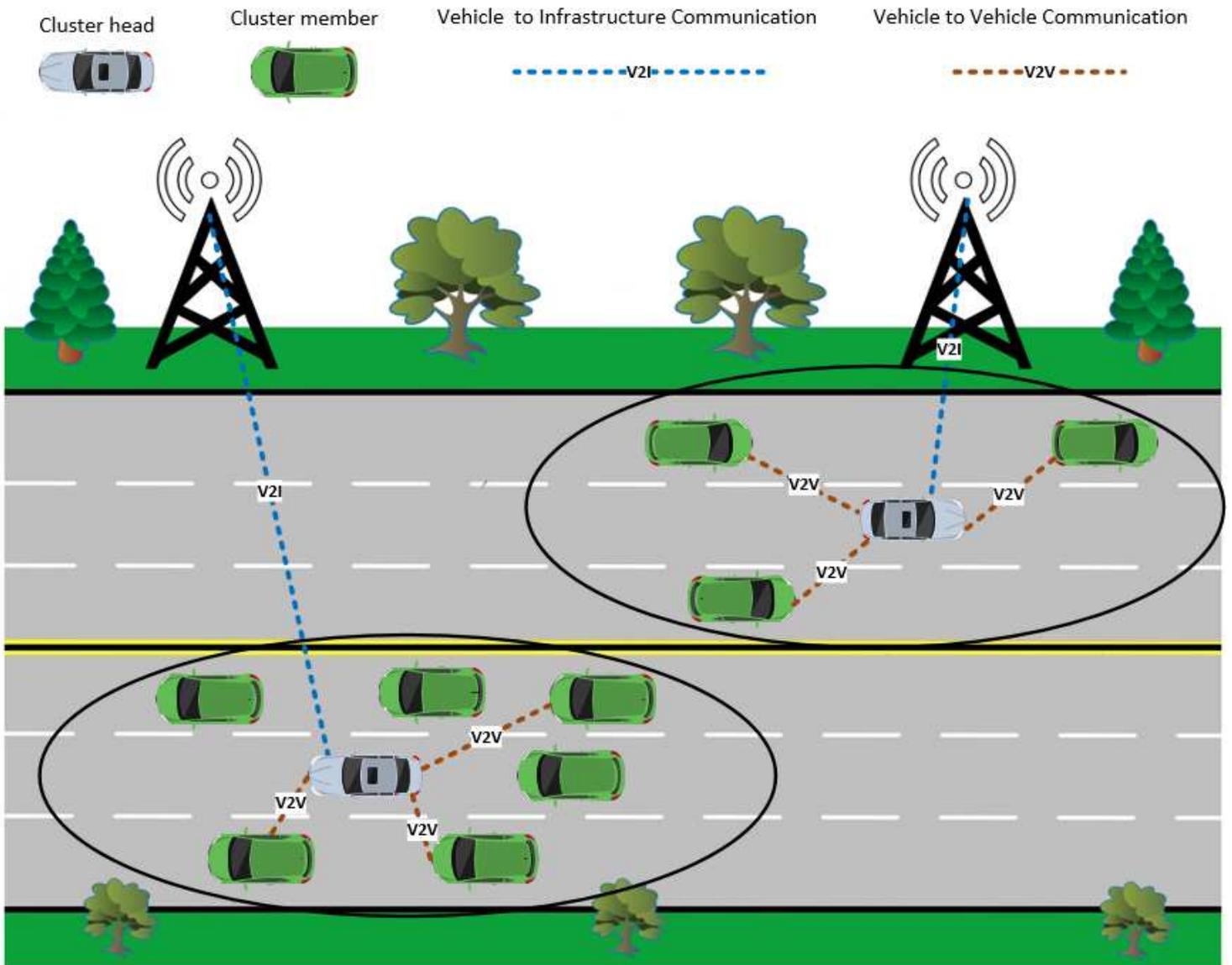


Figure 1

Clustering in vehicular ad hoc networks

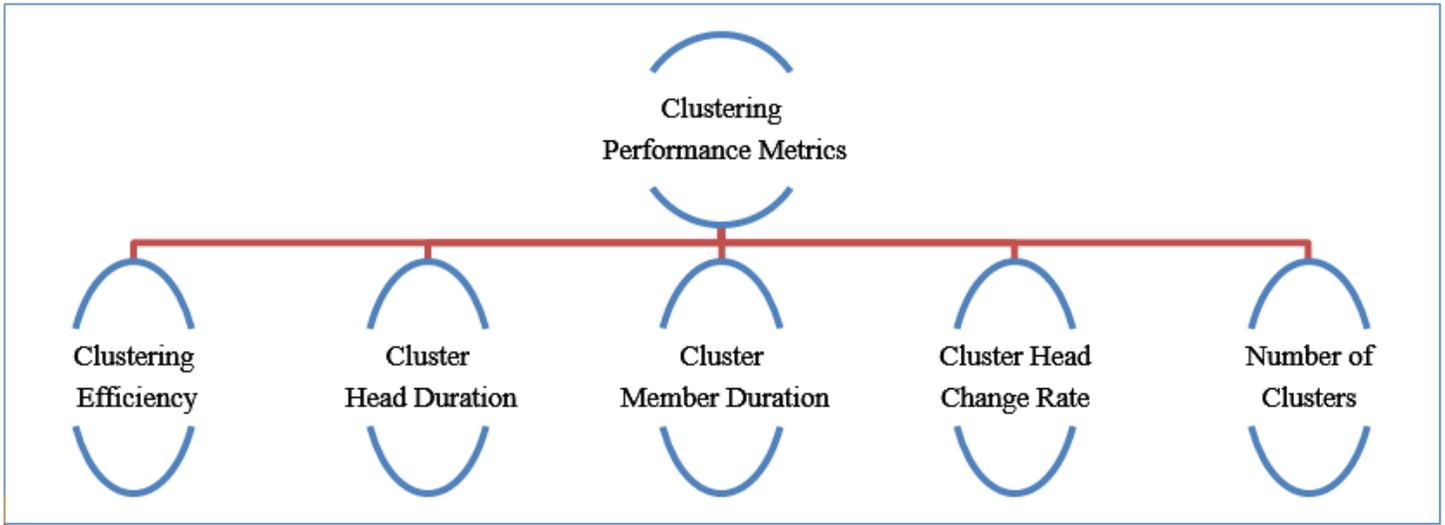


Figure 2

Performance metrics of clustering stability

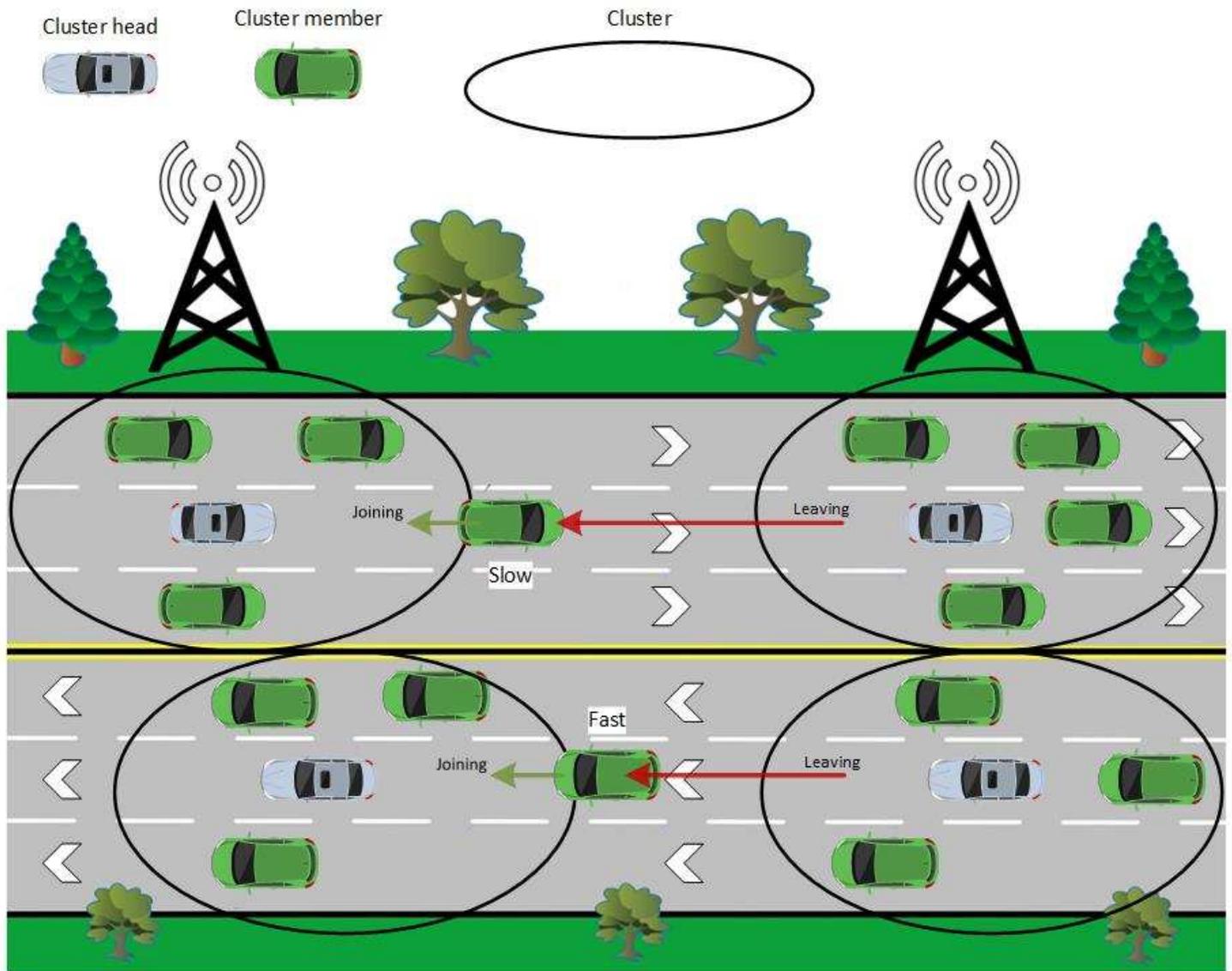


Figure 3

Vehicles leaving and joining representation

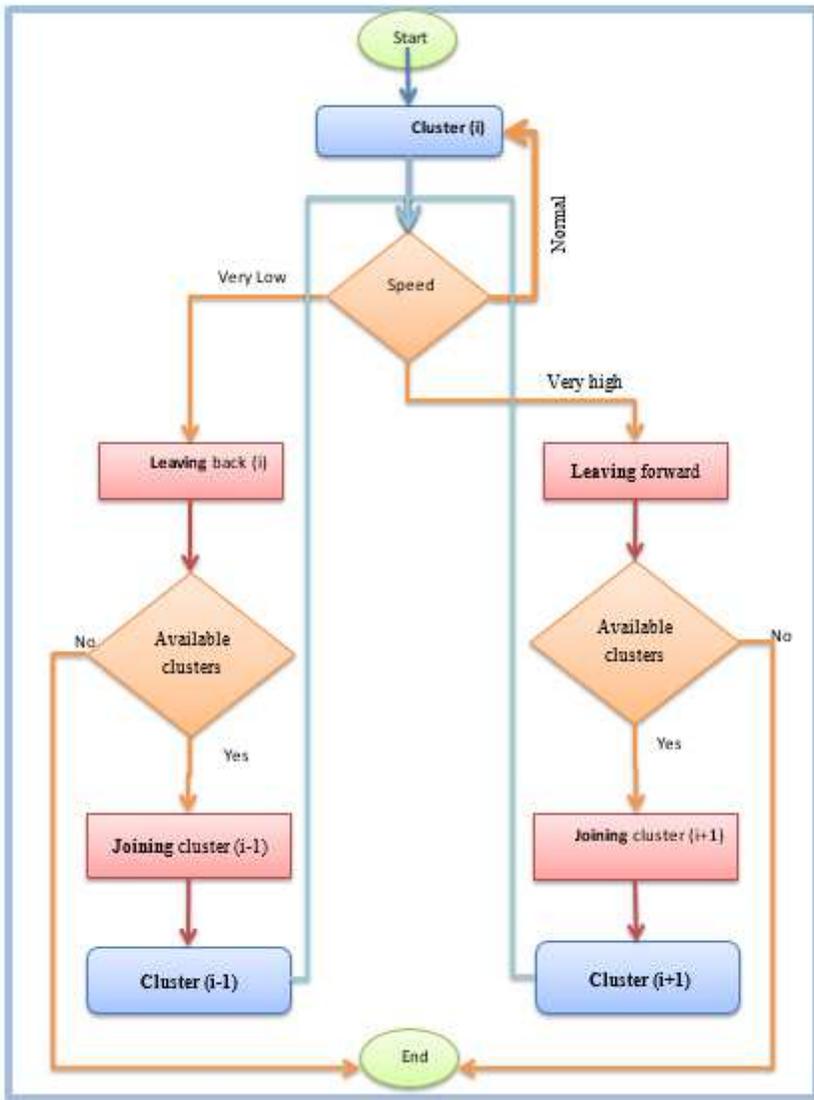


Figure 4

Flowchart for vehicles leaving and joining from/to a cluster

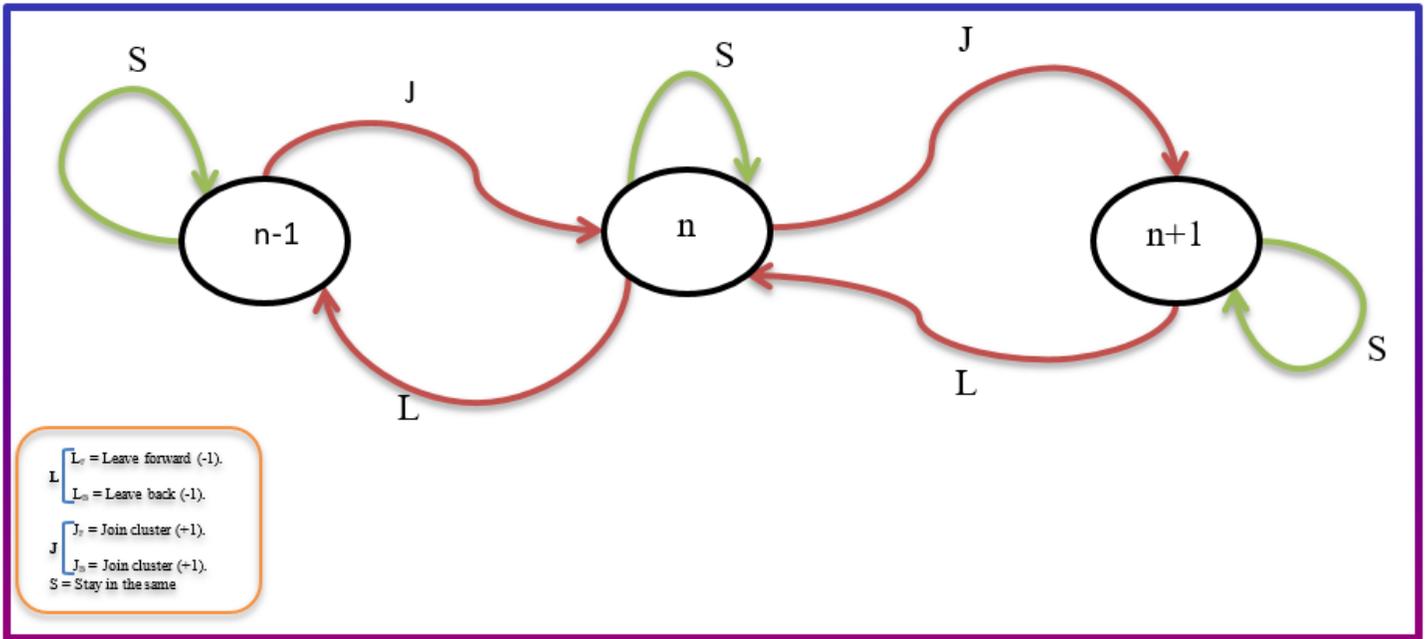


Figure 5

State diagram for vehicles leaving and joining process

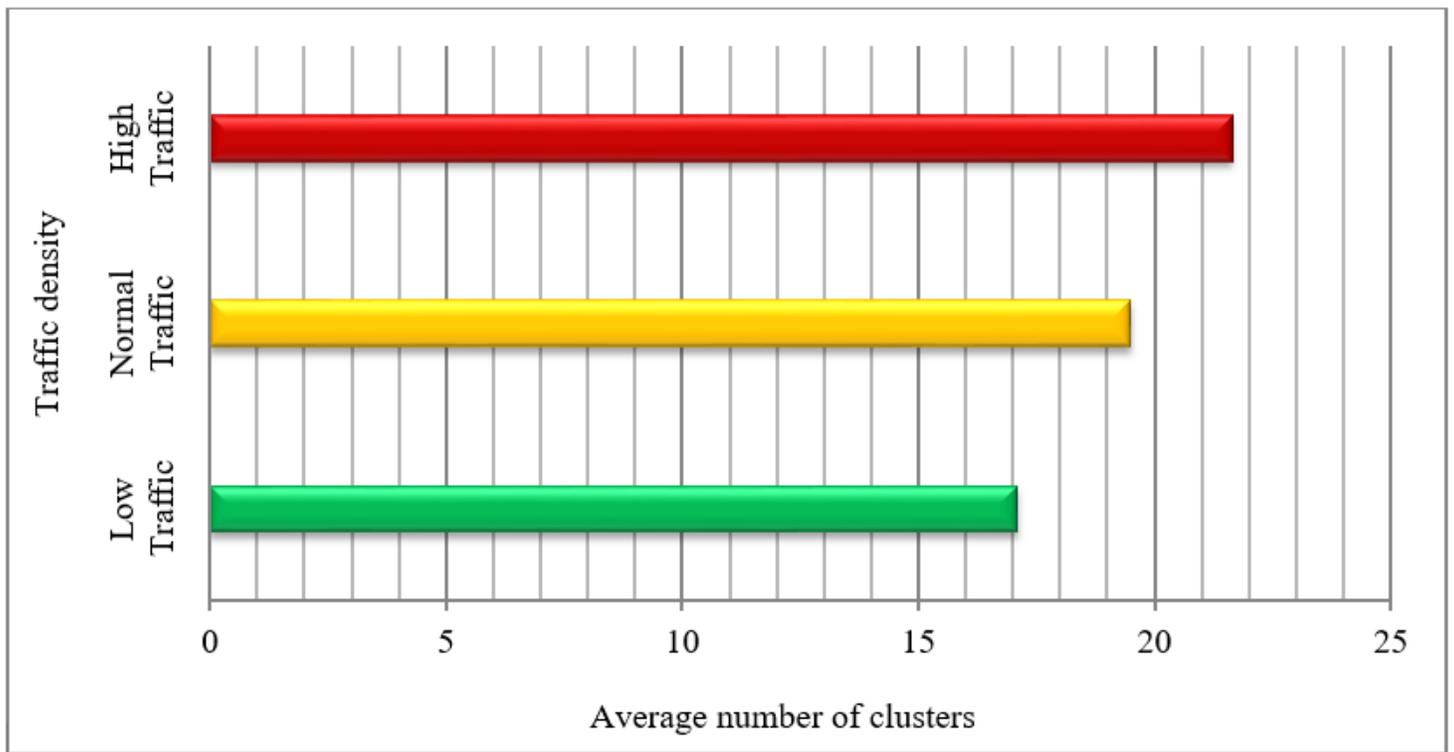


Figure 6

The average number of clusters in CEC-GP

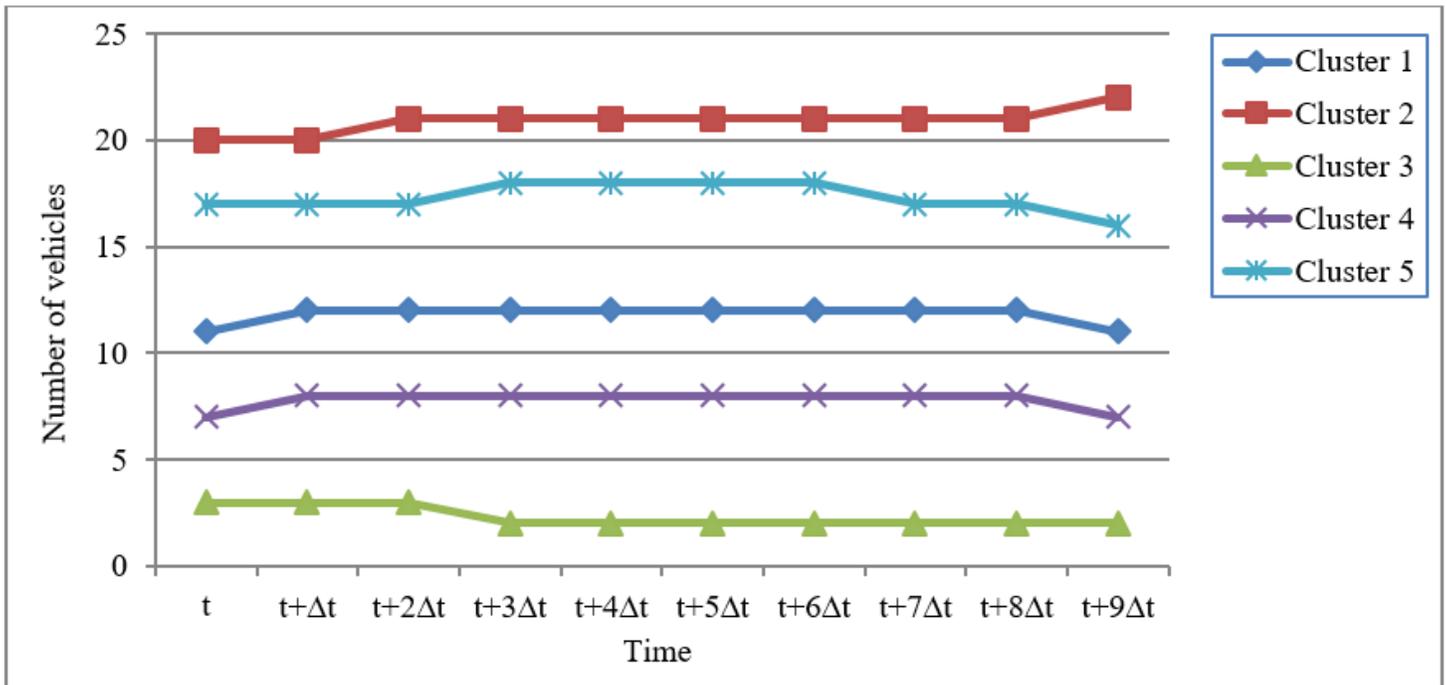


Figure 7

Number of vehicles in each cluster at each time interval for the low traffic level

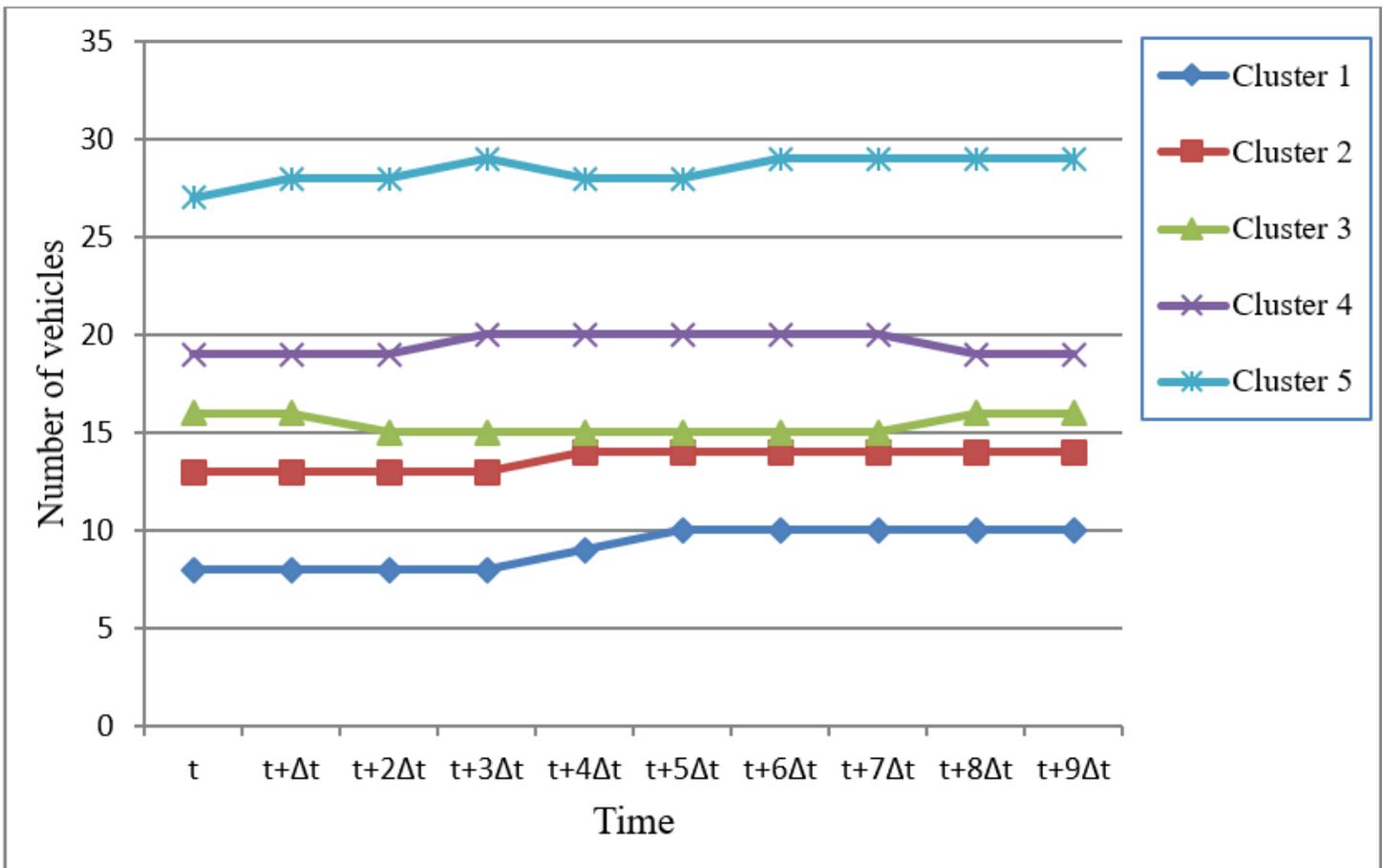


Figure 8

Number of vehicles in each cluster at each time interval for normal traffic level