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Multiagent driven dynamic clustering of vehicles in VANETs

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ABSTRACT

Cluster formation in vehicular ad hoc networks (VANETs) is a challenging problem due to rapidly changing network topology and frequent network disconnections of vehicles. Dynamic clustering is a technique to form grouping of vehicles on the fly. We propose a multiagent driven dynamic clustering scheme for VANETS on a lane between two intersections by considering vehicle speed, direction, connectivity degree to other vehicles and mobility pattern. The scheme comprises of heavy-weight static and light-weight mobile agents. Initially, cluster members are identified based on vehicle's relative speed and direction for dynamic clustering. Cluster head is selected among the cluster members based on stability metric derived from connectivity degree, average speed and time to leave the road intersection. Cluster head predicts future association of cluster members based on mobility patterns. The announcement of cluster mobility pattern to all cluster members is made by cluster head. The cluster members with similar mobility pattern can reconnect with cluster head after passing an intersection of the lane. We have evaluated the performance and effectiveness of proposed scheme by comparing with an existing clustering scheme. It is observed that proposed scheme performs better than existing stable clustering scheme in terms of cluster formation time, cluster member selection time, cluster head selection time and control overheads.

1. Introduction

Vehicular ad hoc networks (VANETs) vision include applications such as route planning, road safety, e-commerce, entertainment, cooperative driver assistance, sharing traffic and road conditions, user interactions, information services, etc. (Caliskan et al., 2005; Fubler et al., 2005; Schnaufer et al., 2006; Balon and Guo, 2006; Manvi et al., 2006, 2009). Major driving factor for the investigation and deployment of the VANETs is safety. Safety applications coexist with non-safety applications such as traffic information systems, commercial and entertainment services and less critical safety related messaging (beaconing).

The cluster formation plays a key role in VANETs for information gathering, aggregation and dissemination. Dynamic clustering is a technique to form grouping of vehicles on the fly that does not have physical connections. Clustering can be used in VANETs to partition the network into smaller groups of moving vehicles embedded with computing and networked devices. This has several benefits including efficient usage of bandwidth, distribution of resources and scalability (Goonewardene et al., 2009). The clustering in VANETs has to consider the following unique features of network: vehicle movement constrained by roads; Road Side Units (RSUs) such as signs and traffic lights that lead vehicles to follow traffic patterns; vehicles are equipped with Global Positioning Systems (GPS) devices providing knowledge about geographical position; distributed operation; and topology variations due to mobility pattern.

Traditional clustering method in VANETs is as follows: each fixed base station situated at strategic point along the road defines a cluster and vehicles belong to that cluster according to proximity of base station. A dynamic cluster removes the concept of base stations altogether. The dynamic cluster physically moves on the length of the road and vehicles join or leave clusters according to their speed and proximity to identified cluster-heads.

The issues to be considered for clustering in VANETs are vehicle mobility, direction, relative speed of node and mobility pattern. Following have to be addressed while designing dynamic clustering: moving cluster formation in minimum time, maintenance of moving cluster with reduced overheads and cluster reconfiguration due to cluster head change because of mobility. This paper proposes a dynamic cluster formation scheme for vehicles in VANET which group the vehicles showing similar mobility pattern, direction and velocity.

1.1. Related works

Several works have been reported in VANETs dealing with mobility pattern of vehicles and formation of clusters. The study

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of VANET characteristics and different mobility patterns of vehicles are presented in Schoch et al. (2008). A car-following model using a neural network approach for mapping perceptions to actions is developed in Panwai and Dia (2007). The model has a formulation to the desired spacing models that does not consider reaction time and attempt to explain the behavioral aspects of the following car. An inter vehicle information dissemination protocol called received message-dependent protocol (RMDP) that propagates the preceding traffic information to the following vehicles is discussed in Saito et al. (2007). RMDP protocol autonomously changes the dissemination interval depending on the number of reception messages and detected reception errors in order to avoid message collision among vehicles. Using RMDP, many vehicles can acquire preceding traffic information within short periods under light and heavy traffic conditions.

Social cluster-based point-to-point framework that estimates similarity and connection condition among mobile peers to provide efficient resource discovery and retrieval is proposed in Lin et al. (2009). Mobile peer's preference and its connectivity such as the lifetime and bandwidth of a wireless link are considered. Mobility-based stable clustering scheme for VANETs which utilizes the affinity propagation algorithm in a distributed manner is presented in Shea et al. (2009). Vehicular mobility during cluster formation is considered in affinity propagation algorithm. Each node in the network transmits the responsibility and availability messages to its neighbors and then makes an independent decision on clustering.

Localization technique that takes advantage of the emerging VANETs environment is considered in Drawil and Basir (2010). Communication among vehicles is utilized to compute relative vehicle location; the integration of which with motion information and GPS location estimate lead to accurate vehicle localization. Clustering of vehicle trajectories obtained by an automated vision system is proposed in Atev et al. (2010). A trajectory-similarity measure is performed based on the Hausdorff distance with modifications to improve its robustness and account for the fact that trajectories are ordered collections of points.

A beacon-based clustering algorithm aimed at prolonging the cluster lifetime in VANETs is discussed in Souza et al. (2010). A contention method is used to avoid triggering frequent re-organizations when two cluster heads encounter each other for a short period of time. Three passive clustering (PC) based techniques to determine the suitable vehicles to become the main participants in cluster structure formation is discussed in Wang and Lin (2010). PCs consider numerous metrics such as vehicle density, link quality and link sustainability. A clustering algorithm and a hierarchical routing protocol that work together to achieve the network stability is presented in Xu and Wang (2009). Three metrics for measuring network stability are presented: (1) the cluster lifetime, (2) the intercluster link lifetime, and (3) the end-to-end path lifetime.

Clustering scheme to improve the broadcasting performance for inter vehicle communication is presented in Fan (2007) which has been used for comparing with our proposed work. Each node announces itself as a cluster head by putting its own address and ID in the broadcast beacons. After receiving beacons from neighbors, a node has complete knowledge of its current neighbors and makes decision whether to change its current cluster status. The status change is bi-directional, either from cluster head to member node or from member node to cluster head. Decision to change status is done depending on three major factors: vehicle ID, current direction and leadership duration.

Vehicular clustering based on the weighted clustering algorithm (VWCA) is presented in Daeinabi et al. (2011). VWCA takes into consideration the number of neighbors based on dynamic transmission range, the direction of vehicles, the entropy, and the distrust value parameters. An adaptive allocation of transmission range technique is discussed to adaptively adjust the transmission range among the vehicles. Decentralized and adaptive approach for information dissemination in VANETs is discussed in Bakhouyaa et al. (2011). Adaptive approaches efficiency in information dissemination over statistical-based approaches is studied in this work.

Some of the above mentioned clustering algorithms mainly used either mobility or direction as design parameters. None of them addressed the dynamic clustering concept by considering mobility and direction of vehicles together. This paper provides a scheme on cluster formation by using multiagents, vehicle mobility, vehicle direction, and neighbors connectivity.

1.2. Our contributions

The proposed multiagent driven dynamic clustering in VANETs is motivated by observing inherent drawbacks of existing clustering algorithms such as less robust to link failures, vehicle mobility, dynamic topology and lack of vehicle direction consideration. Proposed scheme consists of heavy-weight static and light-weight mobile agents that consider the parameters such as vehicle speed, direction, connectivity degree to other vehicles and mobility pattern. It operates in the following phases. (1) Identification of cluster members based on vehicle's relative speed and direction. (2) Cluster head selection among the cluster members based on stability metric derived from connectivity degree, average speed and time to leave the road intersection. (3) Prediction of future association of cluster members after an intersection of the lane based on mobility patterns by cluster head. (4) Announcement of cluster mobility pattern by cluster head to all cluster members while on the lane, and (5) the cluster members with similar mobility pattern can reconnect after passing an intersection of the lane.

Our contributions include the following. (1) Selection of cluster members based on relative speed and direction to provide stable clustering for VANETs, (2) consideration of vehicles traveling in the same direction on the lanes which provides the robust clustering. (3) Multiagent based approach for dynamic clustering to minimize cluster formation time, cluster head selection time and cluster overhead. (4) Stability metric of cluster members results in finding stable cluster head and (5) prediction of similar cluster members based on mobility pattern for future association of the cluster members after passing lane intersection.

The rest of the paper is organized as follows. Brief introduction of software agents is presented in Section 2. Section 3 contains detailed description of the proposed multiagent driven dynamic clustering in VANETs. Simulation model and the result analysis are presented in Section 4. Finally, Section 5 concludes the work and briefs future scope.

2. Software agents

The traditional programming paradigm uses functions, procedures, structures and objects to develop a software for performing a given task. This paradigm does not support development of flexible, intelligent and adaptable softwares and also does not facilitate all the requirements of Component Based Software Engineering (CBSE) (Castelfranchi and Lorini, 2003; Griss and Pour, 2001; Jennings, 2001). In recent developments, agent technology is making its way as a new paradigm in the areas of artificial intelligence and computing, which facilitates sophisticated software development with features like flexibility, scalability and CBSE requirements (Funfrocken and Mattern, 1999; Schmidt and Scott, 2000).

Agents are the autonomous programs which sense the environment and acts upon the environment using its knowledge to achieve their goals (Franklin and Graser, 1996; Jennings, 1997; Bradshaw, 2000; Russell and Norvig, 2001). The agent environment generally referred as a host system, network, a user via a graphical user interface, a collection of other agents, or perhaps all these combined. Agents are classified as single agent and multiagent systems (MAS). Single agent systems comprise of a single agent interacting with resources, humans and other processes to perform a dedicated task. MAS comprises of set of agents that interact, cooperate and coordinate with each other to perform a set of tasks or a dedicated tasks. Mobile agents are multiagent systems, which roam in the network to achieve their goals (Manvi and Venkataram, 2004).

Now we briefly provide comparison of mobile agent based approach with simple message passing, which could have been used for information dissemination. Message passing is a form of communication used in concurrent computing, parallel computing, object-oriented programming and interprocess communication. Mobile agent allows processes to migrate from computer to computer, for processes to split into multiple instances that execute on different machines and to return to their point of origin. Mobile agent computing, considered as a special case of message passing, attempts to move computations as close as possible to the data and makes efficient use of the bandwidth by considerably decreasing the number of messages exchanged between cooperating applications.

The advantages of using mobile agents as compared with the simple message passing approach are as follows:

- Mobile agents reduce the network load whereas simple message passing approach often uses more bandwidth.
- Mobile agents can operate directly on mobile nodes thus avoiding network latency while operating locally. This is most relevant in VANETs where network latency is a prime issue.
- Mobile agents interact with their environment and adapt themselves. This is required for intelligent and dynamic clustering in VANETs.
- Mobile agents can be embedded with intelligence in order to perform data filtering, aggregation and validation in VANETs.
- Mobile agents can execute in asynchronous and autonomous fashion. This autonomy along with platform and system independence make them ideal for building reliable and robust applications. Thus they can deal with the environment by reacting dynamically to changes in VANETs.
- The mobile agent code can encapsulate the protocol. When a protocol is upgraded, only the mobile agent has to be altered. A vehicle administrator can upgrade the protocol by adding some parameters and code based on required services.

3. Multiagent driven dynamic clustering

In this section, we describe network environment considered for the proposed work, description of the clustering agency components and dynamic clustering scheme using the agency.

3.1. Network environment

We consider a VANET in which a number of vehicles are separated by certain distance (between consecutive vehicles). The VANET is purely based on vehicle-to-vehicle (V2V) architecture. We assume that vehicles move in an urban road scenario as shown in Fig. 1. All vehicles are equipped with GPS, Inertial Navigation System (INS) and a VANET transceiver. Each vehicle is loaded with a location digital map and is concerned about road information ahead of it on its way to forward direction. Each vehicle is aware of its moving road lane segment length and communicates with other vehicle within its communication range. A lane segment ends at an intersection.

We assumed that original equipment manufacturer (OEM) of on-board devices provides an agent platform to support the proposed agency. Agency comprises of set of agents along with a knowledge base. Agents have protection from hosts on which they execute. Similarly, hosts have protection from agents that can communicate on available platform. The secured platform consists of protection from denial of execution, masquerading, eavesdropping, etc. Recently developed techniques for mobile agent security have techniques for protecting the agent platform (Jansen and Karygiannis, 1999; Jansen, 2000). These techniques include software-based fault isolation, safe code interpretation, signed code, authorization and attribute certificates, state appraisal, path histories and proof carrying code. Techniques for protecting mobile agent include partial result encapsulation, mutual itinerary recording, itinerary recording with replication

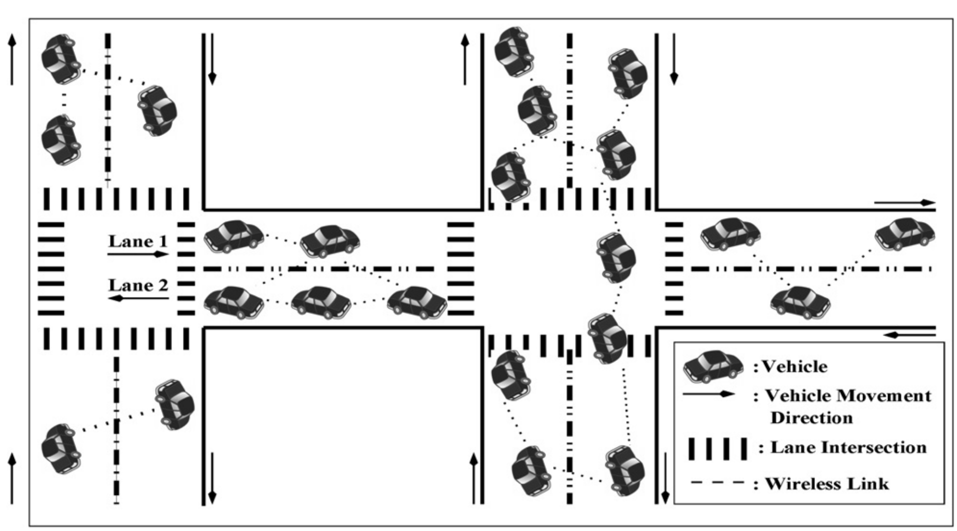

Fig. 1. Network environment.

and voting, execution tracing, environmental key generation, computing with encrypted functions and obfuscated code (Time Limited Black-box).

The mobile code considered is platform independent, so that, it can execute at any remote host in the heterogeneous network environment. They communicate and cooperate with other agents to achieve its goals. Agent can update its information base while interacting with other agents during its travel. Simple message passing technique may be used, if mobile agent is unable to transmit reports back to the parent node because of change in the relative positions of vehicles.

3.2. Definitions

This section presents some of the definitions used in proposed scheme. This will help in proper understanding of the scheme:

- *Time to leave*: It is defined as the time remaining for a vehicle to cross the lane intersection from its current location.
- *Connectivity degree*: It is the total number of neighboring vehicles connected to a vehicle.
- *Cluster mobility pattern*: It is defined as the collective pattern of vehicle movement in a cluster.
- *Intersection movement pattern*: It is a dispersing pattern of vehicles at lane intersection.

3.3. Dynamic clustering agency

This section describes the dynamic clustering agency located in a vehicle that is a part of VANET. Dynamic clustering agency takes the comprehensive decisions on selection of cluster members and cluster head. The components and interactions of the agency are depicted in Fig. 2. It consists of a set of static and mobile agents such as Cluster Manager Agent (CMA), Cluster Information Collection Agent (CICA), Cluster Information Dissemination Agent (CIDA). CMA is a static agent, whereas CICA and CIDA are mobile agents. The agency also consists of a knowledge base (KB) that works on the principle of blackboard architecture, which is used for inter-agent communication.

Knowledge base (*KB*): it comprises of information of itself and neighboring vehicles. The information about itself are as follows: moving lane segment length, status of the vehicle (cluster member or cluster head), available memory, movements made in recent interval, bandwidth utilized for clustering, memory utilized for clustering, mobility pattern and probability of vehicle direction after passing an intersection of a lane (intersection movement probability). The information about the neighbor comprises of the following: neighbor IDs and their status, connectivity status (up or down), mobility pattern and intersection movement probability. Intersection movement probability presents the future vehicle connectivity after vehicles pass a lane intersection. The knowledge base is read as well as updated by the agents.

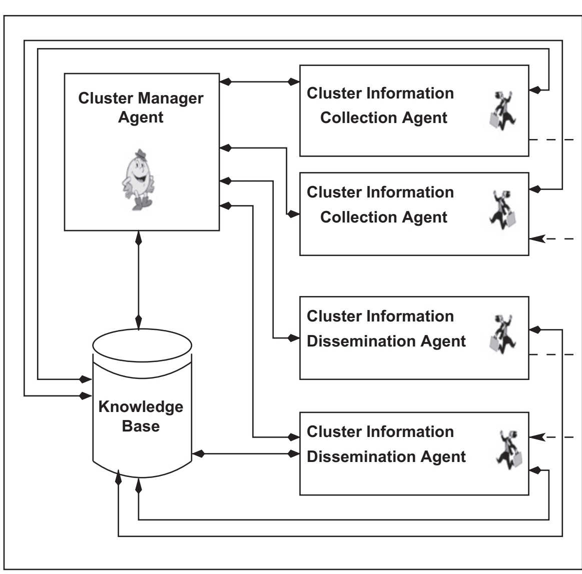

Fig. 2. Dynamic clustering agency.

Cluster manager agent (*CMA*): it is a static agent that runs on each vehicle, creates mobile agents and knowledge base, controls and coordinates the activities of agency. This agent triggers CICA and CIDA. CMA measures the speed of a vehicle, time to leave and intersection movement probability as follows.

CMA computes the speed of a vehicle (v) as a random variable following the normal distribution with mean (μ) and variance (σ^2). Normal distributions have many convenient properties, hence random variates with unknown distributions are often assumed to be normal. It computes the probability density function (pdf) of vehicle speed (v) as given in the following equation:

$$f_V(v) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(v-\mu)^2/2\sigma^2} \tag{1}$$

where μ is computed as given in Eq. (2). This equation provides the mean of observed speeds of a vehicle (like $v_1, v_2, \ldots, v_n$) in a time window

$$\mu = \frac{1}{n}\sum_{i=1}^{n} v_i \tag{2}$$

Variance σ^2 is as shown in the following equation:

$$\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}(v_i-\mu)^2 \tag{3}$$

CMA measures its location by using the position information embedded in the vehicle. Based on the vehicle present location (distance covered "d" by a vehicle with uniform speed on the lane segment of length "L"), CMA periodically computes the time to leave "T" (remaining time to cross the intersection) from the lane segment as shown in the following equation:

$$T = \frac{(L-d)}{d} t \tag{4}$$

where $t \rightarrow$ time taken by a vehicle to cover distance "d" on lane segment length "L".

CMA of a vehicle computes the intersection movement probability based on the history of vehicle mobility patterns, which are recorded at each lane intersection. Let ζ_t be the total number of movements stored in the history of mobility patterns at the lane intersection which include the following; ζ_l, ζ_r, ζ_s and ζ_u. Where ζ_l is the number of times vehicle moving towards left, ζ_r is the number of times vehicle moving towards right, ζ_s is the number of times vehicle moving straight and ζ_u is the number of times vehicle taking a U-turn. Thus, at the lane intersection, the probability of the vehicle moving in the same direction (P_s^t), taking U-turn (P_u^t), left direction (P_l^t) and right direction (P_r^t) are given by Eqs. (5)–(8) respectively. These probabilities depend on the vehicle mobility pattern, location of the vehicle on the lane and speed of the vehicle

$$P_s^t = \frac{\zeta_s}{\zeta_t} \tag{5}$$

$$P_u^t = \frac{\zeta_u}{\zeta_t} \quad (6)$$

$$P_l^t = \frac{\zeta_l}{\zeta_t} \quad (7)$$

$$P_r^t = \frac{\zeta_r}{\zeta_t} \quad (8)$$

Cluster information collection agent (*CICA*): It is a mobile agent which performs collection of speed and location from neighbor vehicles by using knowledge base. CICA is periodically generated by CMA. The period of generation depends on the speed of the vehicles. CICA moves from one vehicle to another in lane segment to collect the speed, time to leave and intersection movement probability of individual cluster member. This information is given to the CMA of the parent vehicle.

Cluster information dissemination agent (*CIDA*): It is a mobile agent which is used to form and maintain a dynamic cluster. It distributes the cluster member and cluster head status to all cluster members. As the cluster head approaches towards the intersection, CMA triggers CIDA to each cluster member and provides the cluster head time to leave the lane segment and intersection movement connectivity pattern (i.e., vehicles with similar mobility pattern) to all the cluster members.

3.4. Dynamic clustering

Functioning of the proposed multiagent driven dynamic clustering scheme for VANETs is explained in the following steps: (1) identification of cluster members, (2) dynamic cluster formation, (3) cluster head selection and (4) announcement of intersection mobility patterns.

Cluster member identification: The relative speed difference among neighboring vehicles is the prime parameter for identifying cluster members. Vehicles broadcast their speed to other vehicles within their communication range "*R*". Vehicles are said to be neighbors if the distance between them is less than "*R*". But all neighboring vehicles may not be suitable for becoming cluster members for a lane due to direction of movement and relative speed. For dynamic clustering, neighbor vehicles traveling in the same direction on a lane are considered by eliminating neighbor vehicles traveling in the opposite direction as well vehicles moving with high relative speed in the same direction.

It is assumed that CMA of a leading vehicle on the lane segment between the intersections called $V_{initiator}$ initiates the clustering process to identify cluster members.

CMA of the $V_{initiator}$ and its neighbors computes $f_V(\nu)$ as given in Eq. (1). Since the speed of the neighboring vehicles of $V_{initiator}$ follow the normal distribution, the speed difference $\Delta\nu$, between $V_{initiator}$ and its neighbor also follows normal distribution with pdf as given in the following equation:

$$f_{\Delta_\nu}(\Delta\nu) = \frac{1}{\sigma_{\Delta\nu}\sqrt{2\pi}} e^{-(\Delta\nu-\mu\Delta\nu)^2/2\sigma_{\Delta\nu}^2} \quad (9)$$

where

$$\Delta\nu = V_{initiator} - V_{neighbor}$$
$$\mu_{\Delta\nu} = \mu_{initiator} - \mu_{neighbor}$$
$$\sigma_{\Delta\nu}^2 = \sigma_{initiator}^2 + \sigma_{neighbor}^2$$

CMA of the $V_{initiator}$ compares the speed difference $\Delta\nu$ of all its neighbors with threshold ΔV_{th}. If the speed difference of corresponding neighbor of $V_{initiator}$ is less than the threshold (i.e., $\Delta\nu < \Delta V_{th}$), neighbor vehicle is considered as a cluster member. This comparison assists in assumption that vehicles moving with high speed in same direction and moving in opposite direction are eliminated from the cluster member selection process. This process is repeated throughout lane segment length to all the vehicles connected to the cluster members.

For cluster member identification process, consider an example as shown in Fig. 3. It comprises of vehicles (V1–V20) moving in different lanes. For simplicity, we consider only two lanes for explanation. Vehicles 1, 2, 3 and 4 are moving towards right in lane 1, whereas vehicles 5, 6, 7 and 8 are moving towards left in lane 2. V1 is the leading vehicle in the lane 1. Hence V1 is considered as the $V_{initiator}$. V1 initiates the cluster member identification process. V2 and V5 are the neighbor for V1. V1 compares the speed difference $\Delta\nu$ of V2 and V5 with its threshold ΔV_{th}. In this example, V2 has less speed difference; hence it is considered as a cluster member. But V5 moving in lane 2 has more speed difference with V1. Hence V5 is not considered as a cluster member.

After attaining the cluster member status, V2 repeats the above process for its neighbors. V3 is the only neighbor of V2 which is having less speed difference as compared to the threshold ΔV_{th} of V2. In this way, all the assigned cluster members repeat the above said process for their neighbors on the lanes L1 and L2. Finally, V1 identifies V2, V3 and V4 as its cluster members.

Dynamic cluster formation: CMA of the vehicle $V_{initiator}$ triggers CICA to its neighbor cluster members. CICA creates clones and selectively floods them through the neighbor cluster members. The agent cloning is a technique of creating an agent similar to that of parent, where cloned agent contains the code and

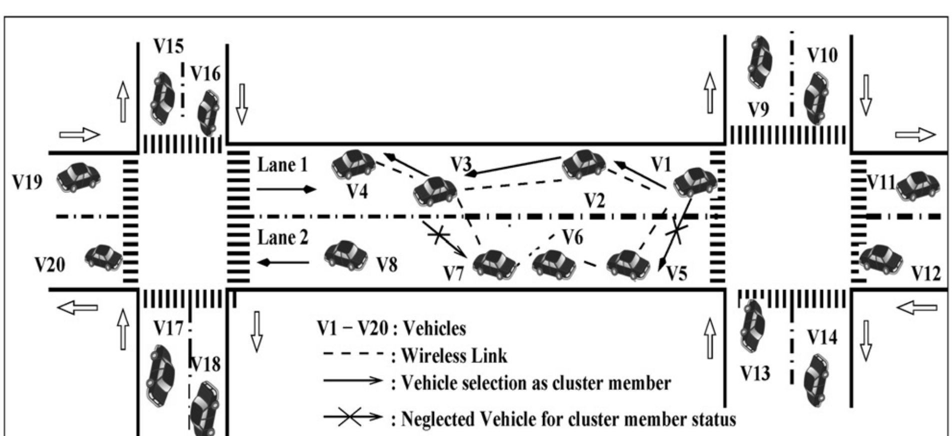

Fig. 3. Cluster member identification.

information of the parent agent (Pham and Karmouch, 1998). The cloning if done at multiple levels, cloned agent contains identification of parents at all its levels. A cloned agent can communicate either to any one of its parents who are within the range or to any of its parents at a given level. In our work, cloned agent has only one parent residing at each cluster member, hence cloned agent communicates to CMA of cluster member about traversed path.

CICA interacts with the CMA of each visited cluster member to confirm its connectivity to the cluster and collects details such as vehicle ID, location, average speed of the vehicle, connected vehicles, time to leave from the lane segment and intersection movement probability. CICA sends this information to parent CICA residing at each cluster member. CICA is programmed to move across lane segment up to the last cluster member. At vehicle $V_{initiator}$, parent CICA informs to its CMA. CMA uses the knowledge base to develop the cluster information table for identification of the cluster head. In this way, the dynamic cluster is formed.

Figure 4 shows an example scenario of dynamic clusters formation process, by considering three dynamic clusters. First dynamic cluster 1 is formed, then 2 and 3. Cluster members (vehicles) enter into the road at different instants of time. Hence these clusters (three dynamic clusters) are formed at different instants of time. Dynamic cluster 1 depicts six vehicles forming a dynamic cluster. Dynamic clusters 2 and 3 are formed similar to dynamic cluster 1. The details of the cluster 1 formation is as follows. CMA of $V_{initiator}$ triggers the CICA to confirm its cluster connectivity and to collect cluster member's details. CICA creates clones and floods to the cluster members. In this example, CICA clone visits to V1 and V2. From V1, CICA clone moves to next cluster member V5. CMA of V2 does not trigger CICA clone to V3, because V3 is not cluster member of cluster 1.

In similar manner, CICA clone informs to all the cluster members on the lane segment 1 (i.e., lane 1) about the cluster connectivity and collects the necessary clustering information. Once the CICA reaches to the boundary vehicle of the lane (in this case V8 on lane 1), traces back to its parent CICA. CICA presents the information to the CMA of the $V_{initiator}$. Thus dynamic cluster is formed on lane 1. CMA uses the knowledge base to develop the cluster information table as shown in Table 1 for identification of the cluster head.

Cluster head selection: CMA of the $V_{initiator}$ uses the stability metric (Γ) to determine the eligibility as a cluster head. The criteria of vehicle's suitability are defined to increase the stability of the cluster structure and maximize lifetime. Hence, an elected cluster head is expected to stay connected with its members for the longest period of time. Therefore, vehicles having higher connectivity degree (C_d) i.e., connected with more vehicles, less average speed (ΔS) and more time to leave (T) from the lane segment are more qualified for winning the cluster head status. CMA of the $V_{initiator}$ computes Γ for all the cluster members as given in the following equation:

$$\Gamma = \alpha * (C_d) + \beta * (T) - \gamma * \log(\Delta S) \quad (10)$$

where α, β and γ are the constants varying in the range of 0 to 1 such that $\alpha+\beta+\gamma=1$ as decided by the CMA of the $V_{initiator}$. These constants facilitate the weightage to the parameters. The value of Γ is a function of initial values of the parameters T, C_d and ΔS. By taking 'log' function for average speed ΔS, we can measure average speed (ΔS) more precisely. Once the cluster head is elected, CMA of the $V_{initiator}$ declares the cluster head information to all the cluster members by triggering CIDA.

CMA of the $V_{initiator}$ compares the stability metric (Γ) of all cluster members. The cluster member with highest stability metric (Γ) is considered as the cluster head. This information is broadcasted to all cluster members by CIDA of the $V_{initiator}$. Cluster head manages and coordinates the dynamic cluster on the lane segment.

Let us consider the scenario as shown in Fig. 4 to explain the cluster head selection process. Assume CMA of the $V_{initiator}$ computes the stability metric (Γ) value of cluster members $V_{initiator}$, $V1$, $V2$, $V5$, $V6$, $V8$ as 0.6, 0.4, 0.2, 0.1, 0.8, and 0.3, respectively. $V_{initiator}$ declares $V6$ as a cluster head to all cluster members ($V1$, $V2$, $V5$, $V6$ and $V8$) since its stability metric (Γ) value is higher as compared to other cluster members.

Table 1
Cluster information table in $V_{initiator}$.

Vehicle ID	Speed (km/h)	Connected cluster members	Time to leave	Intersection movement probability
$V_{initiator}$	S_i	V_1, V_2	T_i	$P_s^t=0.7$, $P_u^t=0.1$, $P_l^t=0.1$, $P_r^t=0.1$
$V1$	S_1	$V5$	T_1	$P_s^t=0.7$, $P_u^t=0.1$, $P_l^t=0.1$, $P_r^t=0.1$
$V2$	S_2	–	T_2	$P_s^t=0.4$, $P_u^t=0.1$, $P_l^t=0.3$, $P_r^t=0.2$
$V5$	S_5	$V6$	T_5	$P_s^t=0.3$, $P_u^t=0.3$, $P_l^t=0.2$, $P_r^t=0.2$
$V6$	S_6	$V8$	T_6	$P_s^t=0.3$, $P_u^t=0.3$, $P_l^t=0.3$, $P_r^t=0.1$
$V8$	S_8	–	T_8	$P_s^t=0.2$, $P_u^t=0.1$, $P_l^t=0.6$, $P_r^t=0.1$

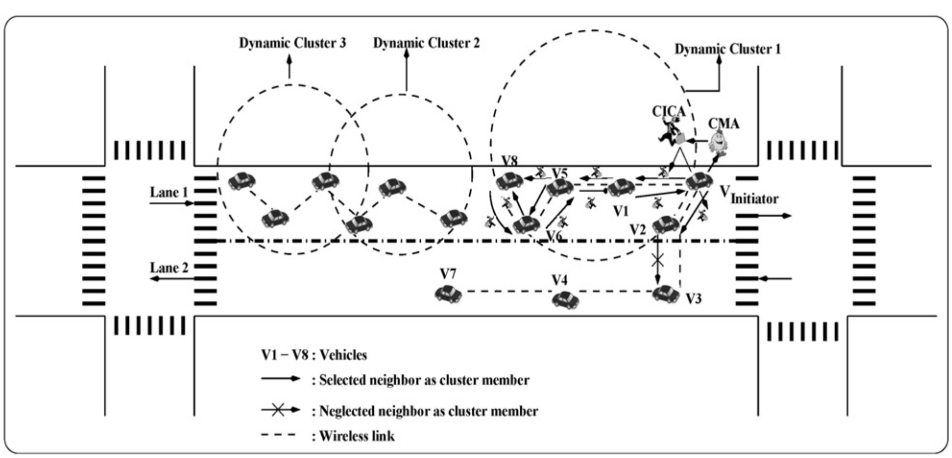

Fig. 4. Dynamic cluster formation.

Announcement of intersection movement pattern: Cluster head executes the responsibility of announcing intersection movement pattern. This is helpful for all cluster members to predict future connectivity among themselves after crossing an intersection. CMA of the cluster head computes the intersection movement pattern based on cluster member's intersection movement probability as follows:

- CMA triggers CICA to individual cluster member to collect the time to leave (T) parameter on the lane segment and intersection movement probabilities P_s^t, P_u^t, P_l^t, P_r^t.
- CICA collects all these parameters from cluster members and traces back to the CMA of the cluster head.
- Initially CMA segregates the stable vehicles which are having more time to leave "T" on the road segment out of the total cluster members. If $T_{CM} > T_{CH}$, then that cluster member is treated as the stable vehicle. Where T_{CM} is the cluster member time to leave from the lane segment and T_{CH} is the cluster head time to leave from the lane segment.
- Out of these cluster members, CMA computes the intersection movement pattern of cluster members (i.e., connectivity of the cluster members after passing the intersection). This is computed by grouping the similar and near value of cluster members intersection movement probability (P_s^t, P_u^t, P_l^t, P_r^t).
- CMA triggers CIDA with T_{CH} and intersection movement pattern to all the cluster members. T_{CH} helps cluster members to know the time to leave of the cluster head on the lane segment.

Consider an example to illustrate the concept. As shown in Fig. 4, vehicles $V_{initiator}$, $V1$, $V2$, $V5$, $V6$, $V8$ have the time to leave values as T_i=3 min, T_1=9 min, T_2=4 min, T_5=6 min, T_6=5 min and T_8=8 min, respectively. Among these vehicles, CMA of $V6$ (cluster head) segregates stable vehicles as {$V1$, $V5$, $V8$}.

The intersection probability P_{ζ_t} for V1, V5, V8 are as follows: V1 → P_s^t=0.7, P_u^t=0.1, P_l^t=0.1, P_r^t=0.1; V5 → P_s^t=0.3, P_u^t=0.3, P_l^t=0.2, P_r^t=0.2; V8 → P_s^t=0.2, P_u^t=0.1, P_l^t=0.6, P_r^t=0.1. Based on these values, CMA of V6 computes intersection movement pattern by grouping the similar and near values of intersection probability P_{ζ_t}. In this case, V5 and V8 are associated after an intersection. CMA of V6 triggers CIDA to V1, V5 and V8 to inform about the future association members.

3.5. Limitations of the proposed work

Some of the limitations of the proposed dynamic clustering scheme using multiagent system are as follows. (1) The model assumes all vehicles to be smart, i.e., smart vehicle has relatively strong computational resources, typically access to on-board devices of cars and executes a number of applications. (2) It is assumed that all the vehicles have capability of authenticating and validation of vehicles during dynamic clustering process, and (3) urban scenario with less sparse network connectivity is not favorable for the proposed scheme; however, fixed base stations can be placed at strategic points where vehicle density is very low.

4. Simulation

The proposed scheme has been simulated in various network scenarios by using "C" programming language with a confidence interval of 95%. In this section, we discuss network model, traffic model, mobility model, channel model and simulation procedure which are used in simulation.

Network model: We consider n number of vehicles moving in a fixed region of length A km and breadth B km. We consider vehicles to move in L lanes. Communication coverage area for each vehicle is considered as a V_{com} meters.

Traffic model: Constant bit rate model is used to transmit certain number of fixed size packets, P_{pkts}. Coverage area around each vehicle has a bandwidth BW shared among neighbors. Arrival rate of vehicles on the road follows Poisson distribution with mean λ. Reason to use Poisson process is that it is an efficient method for arrival process of events to a queuing system.

Mobility model: At the beginning of the simulation, vehicles are uniformly distributed in lanes. We do not account for congestion that may arise in roads. It is assumed that all vehicles are equipped with a communication device and knows start position, start time of vehicle, route that it selects, and speed at which it travels. It is assumed that the cars following the leading one automatically adapt the behavior of leading car.

Manhattan mobility model is used for generation of roads and intersection topology (Bai et al., 2003). Manhattan is generated-map-based model, introduced to simulate an urban environment. Before starting a simulation, a map containing vertical and horizontal roads is generated. Each of these later includes two lanes, allowing the motion in the two directions. Lane changing for the vehicles is not considered. At the beginning of a simulation, vehicles are randomly put on the roads. They move continuously according to history-based speeds. When reaching crossroads, the vehicle randomly chooses a direction to follow. That is, continuing straightforward, turning left, or turning right, etc.

Safety distance of R_s meters is maintained from preceding vehicle for a certain tolerance time and then change lane if possible. Changing lane allows vehicle to move to an adjacent lane if there is space (safety distance) in that lane. At every intersection, we assume that each vehicle can choose to make either a left or right (if not a one-way road) or no turn. Mobility factor for each node is in between the range of I and J km/h. Border effect of bounded simulation region on vehicle mobility is accounted by making vehicle reappear in the region.

Channel model: The channel model used between vehicles for communication is based on the Gilbert model (Laurence and Wilhelmsson, 1999), where probability of channel being good is 'p_g' and channel being bad is given by '$1-p_g$'. Vehicles use CSMA/CA for media access (Xiuchao and Ananda, 2004).

4.1. Simulation procedure

The simulation input parameters are summarized in Table 2. Simulation procedure for the proposed scheme is as follows:

1. Generate VANET in given road length by placing vehicles uniformly. Each vehicle maintains a data structure to store information as specified by scheme.
2. Generate the agency (agents are implemented as objects).
3. Apply mobility to vehicles.
4. Randomly generate the clustering parameters at each vehicle and select cluster members using the agency. Create dynamic cluster.
5. Use agency to identify cluster head and announce the intersection mobility pattern.
6. Compute the performance of system.

4.2. Performance metrics

Some of the performance metrics evaluated are cluster member status assignment time, cluster formation time, cluster head

Table 2
Simulation parameters.

Sl. no.	Parameters	Specifications
1.	Simulation time	600 s
2.	Length of road	5000 m
3.	Breadth of road	30 m
4.	Breadth of lane	5 m
5.	Number of vehicles	10–100
6.	Transmission range	250 m, 500 m
7.	Speed (minimum)	10 km/h
8.	Speed (maximum)	40 km/h, 60 km/h, 80 km/h
9.	Data type	Constant bit rate
10.	Data packet size	256 bytes, 512 bytes
11.	Mobility model	Manhattan model
12.	Channel type	Wireless channel
13.	Antenna model	Omnidirectional
14.	Number of lanes in a road	2
15.	Total number of roads	10
16.	Number of intersections	5, 10
17.	Length between intersections	500–1000 m
18.	Available bandwidth	5000 Mbps
19.	Safety distance between vehicles	4 m

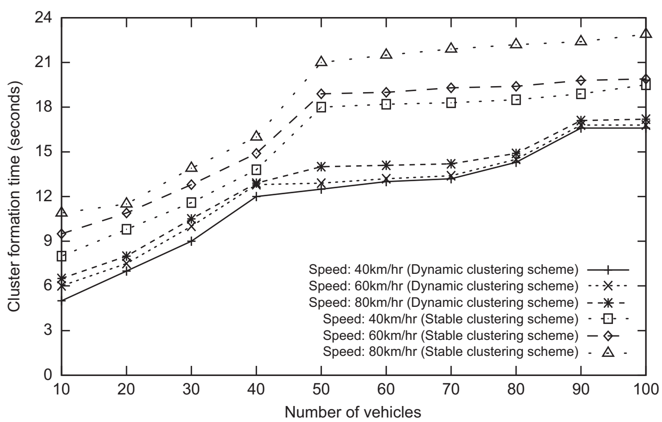

Fig. 5. Cluster formation time vs. number of vehicles (comm. range = 250 m).

selection time, cluster life time, number of vehicles per cluster, number of clusters formed, cluster head existence time and control overhead.

Cluster formation time: It is defined as the time taken by all cluster members to form a dynamic cluster. It is expressed in terms of seconds.

Cluster member selection time: It is the time taken by a vehicle to get the cluster member status. It is expressed in terms of seconds.

Cluster head selection time: The total time taken by all cluster members to elect the cluster head. It is expressed in terms of seconds.

Cluster life time: The total time of dynamic cluster existence on the road is known as cluster life time. It is also expressed in terms of seconds.

Control overhead: It is defined as the ratio of the total number of control messages or agents to the total number of packets generated to perform clustering.

4.3. Result analysis

Figure 5 depicts the comparison of cluster formation time of the proposed dynamic clustering scheme with existing stable clustering scheme presented in Fan (2007). For the communication range of a vehicle equal to 250 m, as the speed of vehicles (from 40 to 80 km/h) and the number of vehicles increase, cluster formation time is increased. In dynamic clustering scheme, cluster formation time is initially low for lower number of vehicles (up to 30) and increases linearly as the number of vehicles increases. For more number of vehicles (i.e., from 80 to 100) cluster formation time will remain almost constant. This behavior results from the network connectivity in the VANET. For all the mobility values, 40–80 km/h, the cluster formation time for the dynamic clustering scheme is less as compared to the stable clustering scheme.

Some of the reasons for dynamic clustering scheme performing better than stable clustering scheme are as follows: (1) selection of cluster members (out of the available neighboring vehicles) based on speed and direction of vehicle; results in less cluster formation time, and (2) selection of the cluster members by broadcasting technique in the stable clustering scheme yields high cluster formation time.

Furthermore, a set of simulations were conducted for the communication range of vehicle equal to 500 m, as shown in Fig. 6. For different mobility values like 40, 60, and 80 km/h; as the number of vehicles increase, the performance of the dynamic clustering scheme is better than stable clustering scheme. For a speed of 40 km/h, cluster formation time is low as compared to the mobility values 60 and 80 km/h. For less number of vehicles with low mobility, cluster member selection time and cluster head selection time are low. Hence the cluster formation time is less as compared the higher mobility values.

Figures 7 and 8 explain the cluster member selection time of the proposed dynamic clustering scheme in comparison with

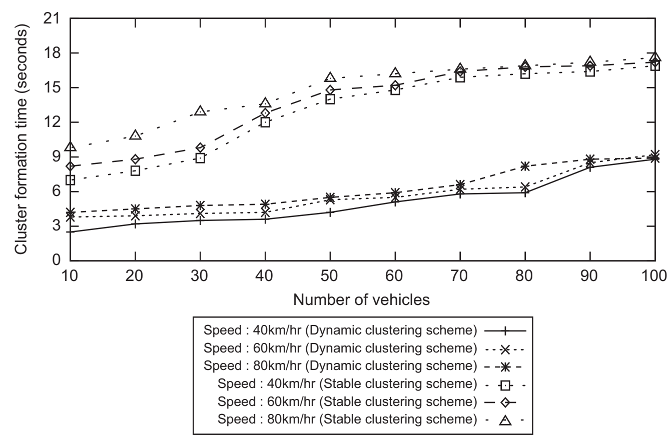

Fig. 6. Cluster formation time vs. number of vehicles (comm. range = 500 m).

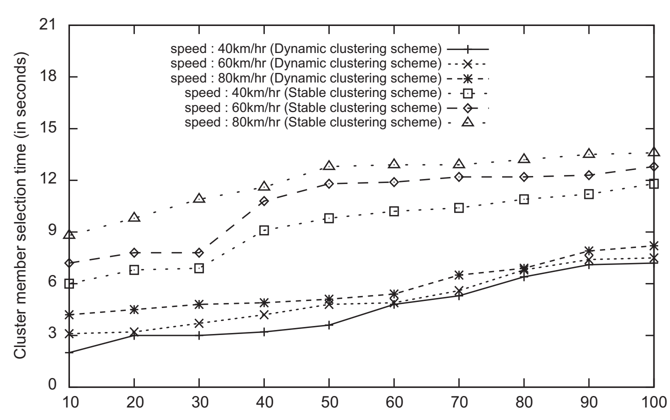

Fig. 7. Cluster member selection time vs. number of vehicles (comm. range = 250 m).

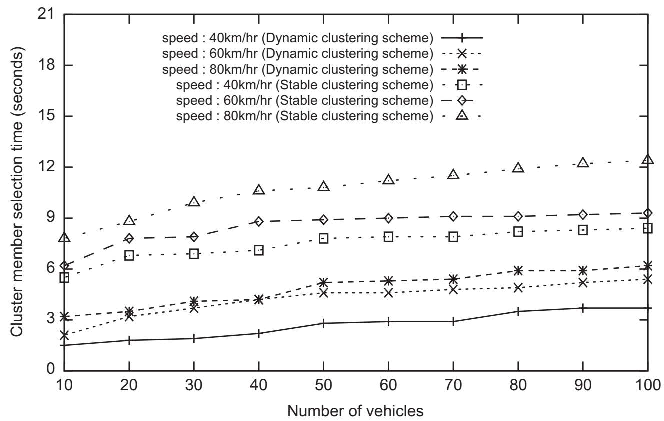

Fig. 8. Cluster member selection time vs. number of vehicles (comm. range=500 m).

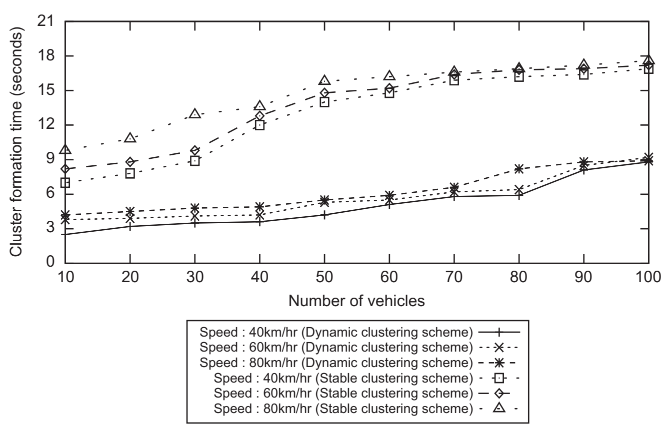

Fig. 9. Cluster head selection time vs. number of vehicles (comm. range=250 m).

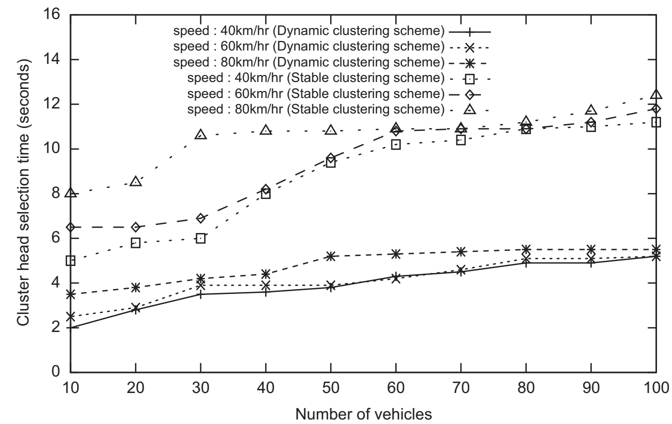

Fig. 10. Cluster head selection time vs. number of vehicles (comm. range=500 m).

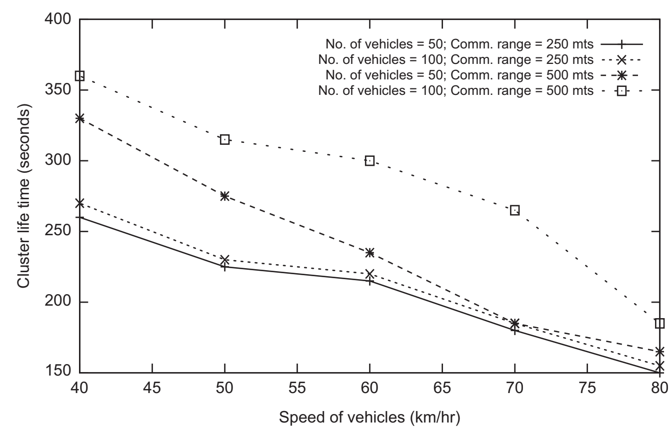

Fig. 11. Cluster life time vs. speed of vehicles (in km/h).

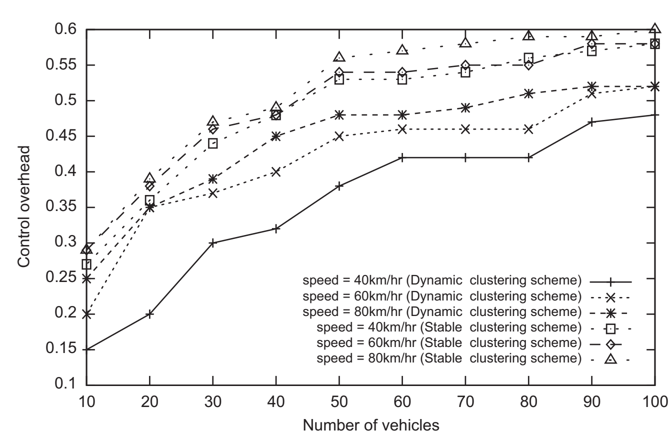

Fig. 12. Control overhead vs. number of vehicles (comm. range=500 m).

stable clustering scheme for vehicle communication range of 250 m and 500 m, respectively. The speed of the vehicle is varied as 40, 60, and 80 km/h. For a less number of vehicles, cluster member selection time is initially low and as the number of vehicles increases the cluster member selection time increases. Compared to the stable clustering scheme, for any number of vehicles, cluster member selection time of the proposed scheme is low. This is because of the limitations of the stable clustering scheme like broadcasting and buffering of the data packets to neighbor vehicles for selection of cluster members.

The comparison of cluster head selection time for different numbers of vehicles under varying speed conditions and communication range is shown in Figs. 9 and 10. As the number of vehicles increases, cluster head selection time increases gradually. Cluster head selection time is less as compared to stable clustering scheme. The selection of appropriate (or cooperative) vehicles as cluster members for proposed dynamic clustering scheme is the reason for minimum cluster head selection time. The stable clustering scheme with broadcast method requires more packet buffering while forwarding a packet; therefore, the cluster head selection time is increased.

Cluster life time for different speed values (40, 60 and 80 km/h) is illustrated in Fig. 11. Cluster life time decreases as the speed of vehicle increases. Cluster life time is relatively high for more number of vehicles with an increase in the communication range.

Figure 12 depicts the control overhead for dynamic clustering and stable clustering for vehicle communication range of 500 m, with a variation in speed from 40 to 80 km/h. For a few number of vehicles, initially the control overhead is less for both dynamic clustering and stable clustering schemes. But as the number of vehicles increases, control overhead is more for stable clustering scheme as compared with dynamic clustering scheme. This is due to the fact that stable clustering requires more control packets than the proposed scheme. In the stable clustering scheme, more control packets are used for the announcement of cluster head information in the form of broadcast beacons.

5. Conclusions

In this paper, we have developed a multiagent based dynamic clustering scheme for vehicles in VANETs. The scheme forms a moving dynamic cluster on a lane between two the intersections by considering parameters such as vehicle speed, direction, connectivity degree to other vehicles and mobility pattern. Multiagent based approach integrates mobile agents and static agents to deliver a rapid response for dynamic clustering. Simulation results showed that the proposed scheme performs better than existing stable clustering scheme in terms of cluster formation time, cluster member selection time and cluster head selection time. Multiagent systems should be regarded as an ‘‘add on’’ to existing service platforms, providing more flexibility, adaptability and personalization for realization of services within next generation VANET environments. Some of the additional research issues that can be considered for future extension of the work are as follows: (1) consideration of vehicles that belong to two or more clusters before they reach the intersection for the formation of dynamic clusters after crossing an intersection, (1) evaluation of the multiagent based model overheads including memory, computational and communication overhead, (2) consideration of a more number of lanes per road, (3) existence of non-smart vehicles, (4) evaluation of the re-clustering process after the vehicles pass lane intersection, (5) consideration of noisy environments, high vehicular mobility, traffic lights and signs at the intersections, etc.

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