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Stability-Delay Efficient Cluster-based Routing Protocol for VANET

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Abstract

Vehicular Ad hoc Network (VANET) can be used in safety applications to transfer information about some events (e.g. accidents) with minimum time. Sending this information is achieved by using a routing algorithm. A large number of cluster-based routing schemes were presented for VANET. Unfortunately, the mobility of vehicles in unexpected directions negatively affects the performance of these schemes, destroys the network links, and decreases the routes' stability. This problem leads to repeat route discovery and maintenance operations and, as a result increases the overhead and delay. Thus, they are not an optimal selection for safety applications. Moreover, the cluster-based policies need efficient clustering approaches, but the previous ones fail to enhance the stability of links and cluster heads. Moreover, they did not focus on the stability of gateways. Therefore, a new clustering formation approach that focuses on the stability of cluster head and gateway is proposed. It gives priority to the parked and stopped vehicles to be cluster heads and gateways. Moreover, a new cluster-based routing protocol to build optimal paths with minimum delay and maximum stability called CRDS is suggested for safety applications. CRDS depends on the suggested clustering approach and computes the optimal routes depending on a novel suggested optimization model. Several simulation scenarios with various mobility speeds and numbers of stopped and parked vehicles have been run. The results showed that CRDS is better than LRCA, PASRP and CVoEG according to network overhead, average end to end delay, path stability, cluster head stability, and packet delivery ratio.

Keywords

VANET, Parked Vehicles, Cluster based Routing, Cluster Formation, Stability, Delay

1. Introduction

Vehicular ad hoc Network (VANET), or as it is named classic VANET, is an amazing network used to connect vehicles that are owned by citizens, fire stations, police (police patrol), hospitals (ambulances), etc. [1]. These vehicles may be moved at different speeds (inside the cities or on highways) or parked beside the highways, branch roads or parking lots [2]. Each vehicle talks with other vehicles using vehicle to vehicle (V2V) connection style. A new type of VANET, named hybrid VANET, is employed by connecting vehicles with each other using V2V and with the roadside unit using the vehicle to infrastructure (V2I) communication mode [3].

Generally, VANET depending on vehicles, can be used in various applications such as environmental applications (to reduce the CO2 generation), safety (to exchange information about accidents, weather, etc.) or convenience (to exchange information about oil stations, restaurants, etc.) or among drivers and passengers [4]. Moreover, it can be exploited in the military to exchange information between the vehicles and soldiers [5]. In the military, the soldiers and military vehicles have connectional devices and communication to exchange information about the topology, accidents, attacks, etc. Some of these vehicles are autonomous cars and connected and autonomous vehicles (CAV), which can reach dangerous locations and send information to the soldiers, which can help in saving the soldier's life.

It is right that VANET represents a significant class of mobile ad hoc network (MANET) [6]. However, it has a unique feature (i.e. energy availability in vehicles) that makes it an outstanding network and differs from MANET [7]. However, like the MANET, it suffers from some challenges such as un-stability of links, routing, lack of bandwidth, etc. [5]. Mobility of vehicles at high speed creates a high dynamic topology and makes VANET more challenging to deploy than MANET. Therefore, several of MANET's strategies are not suitable for VANET [8].

According to some parameters, computing the best route from source to destination is called the routing process [9]. With the mobility of vehicles, computing the best route is the most significant challenge in VANET. It can be done by different types of routing policies which are categorized into cluster-based and topology-based [10]. The former type is divided into proactive and reactive protocols [11]. The proactive protocols compute each node's route to all destinations frequently; even there is no need for that [12]. With the high mobility of vehicles, the overhead and bandwidth consumption of these protocols will be massive. Reactive ones are used only when there is a request to send data from a node to another. The time of computing this route increases the delay of delivering the data to the destination [12]. The latter type is used to organize the network as a set of clusters [13]. Each cluster's members communicate with each other to select one node to work as a leader called cluster head and some nodes to be as a bridge to connect with other neighbor clusters named gateways. The rest nodes are ordinary ones [14]. These protocols may increase network scalability. However, the mobility of vehicles destroys the clusters and the network link frequently [10].

The safety application is the important one of the VANET applications, which aims to send critical information about accidents, weather conditions, etc., to the passengers and drivers to save their life. Thus, sending this information must be quick without any delay, which can be done using a particular routing protocol focusing on the time. Several authors organized VANET using the clustering topology to enhance its performance. This topology type needs efficient clustering approaches at the first stage and then to the particular routing policies. Thus, on the one hand, many clustering techniques based on various parameters were suggested. Nevertheless, due to the vehicle's movement, they failed, and the stability of links and cluster heads was not high. Moreover, they did not focus on the stability of gateways. On the other hand, a large number of cluster-based routing schemes was presented for VANET. However, again, the frequent mobility of vehicles leads to disconnecting the network links and reducing the routes' stability. Therefore, these schemes' performance with the safety applications was not perfect in reducing the delay and increasing the total stability. Therefore, a cluster-based network's first problem is the need to re-build the clusters frequently, increasing overhead and delay. Moreover, this unfixed topology increases route failure and route maintenance cases, leading to high congestion and delay in transferring the data of safety applications to the target vehicles, leading to many disasters [5]. It makes the existed solutions are not an optimal selection for the safety applications. It is the motivation of this paper. It

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focuses on time and stability and produces an efficient solution for safety applications. This can be done by creating a new clustering technique and cluster-based routing scheme.

The contributions of this paper focus on the above problems as follow:

- Producing a new clustering strategy to build optimal clusters. It selects the suitable cluster head and gateways for each cluster and determines which member nodes should be connected to which cluster head. This strategy gives priority to the parked and stopped vehicles to work as cluster heads and gateway nodes to increase the stability and prevent the frequent re-selection operations of these nodes.
- Suggesting a new cluster-based routing protocol for the VANET's safety application to send the critical data quickly. This protocol selects the optimal routes with the help of the proposed optimization model, which gives priority to the links with high stability and minimum delay.
- Determining the priority of each link depending on its stability. Therefore, the link with the highest stability will take a bigger chance of being part of the optimal route to the destination.

The paper is divided into the following sections: Section 2 contains a set of the previous related works. Section 3 shows the suggested clustering mechanism. Section 4 explains the system model and problem definition. Section 5 illustrates the produced routing protocol. Section 6 displays the simulation. Finally, Section 7 shows the conclusion of this research work.

2. Related works

There is a large number of routing protocols suggested to enhance the routing operation in VANET. Some of them are topology-based (i.e. reactive and proactive), while others are cluster-based. The topology-based algorithms were studied in several surveys [12,15−19]. Therefore, this section focuses only on some of the clustering strategies and cluster-based routing protocols.

Set of researchers focused on producing cluster-based routing schemes to enhance stability. Ardakani [20] proposed a cluster-based routing approach to improve the total performance of VANET by assigning an address for each car according to its mobility and location. Moreover, they applied a clustering technique named hamming distance, which works in a distributed manner.

Hamedani et al. [21] produced a reliable two-level routing strategy to reduce the situations of the link broken. It selects the vital link in the first level while applies the greedy technique to find the optimal path. This strategy depends on the direction, distance and velocity in selecting the suitable links.

Benkerdagh et al. [22] designed a cluster-based routing strategy based on a real-time and rapid heuristic algorithm. Moreover, the authors produced a proposal to build stable clusters to enhance bandwidth consumption and time.

Zhang et al. [23] designed a multi-hop clustering scheme to increase the cluster's stability and coverage. The determining operation of the cluster head is done depending on the priority-based neighbor-following mechanism. Also, this mechanism chooses the best neighbors to connect to the same cluster.

Sophy et al. [24] built a cluster-based routing strategy to reduce broken links cases. They used the biogeography-based optimization model to select available network and ant colony optimization model to perform the vertical handover.

Azat et al. [25] proposed a clustering strategy that depends on the vehicle's location, direction, speed, destination and number of its interests. Besides, the authors suggested a routing algorithm that depends on the target vehicle to determine the forwarding vehicles in the path.

Another set of authors studied the lack of reliability problem in cluster-based VANET and produced many routing algorithms. Sachdev et al. [26] exploited the clustering technique and suggested a routing approach for VANET using the firefly strategy to perform reliable warning message transmission among the cars.

Ji et al. [27] suggested an algorithm named link reliability-based clustering approach (LRCA) to select cluster heads, format the clusters and maintain the destroyed clusters. Also, they proposed a link lifetime-based neighbor sampling method to determine the unstable neighbors. Then, they suggested a routing algorithm of LRCA to choose the routes depending on the network conditions. It assigns a weight for each road segment and computes the weight for each path.

Abbas et al. [28] produced a cluster head selection approach that depends on link reliability. Moreover, they exploited the ant colony algorithm to produce a new clustering-based multipath routing protocol. It chooses the optimal paths based on energy consumption, latency, throughput and reliability.

Khan et al. [29] proposed a new graph model named the cluster-based VANET oriented evolving graph (CVoEG) model to enhance communication reliability. It selects the cluster heads and members depending on the degree of link reliability. Moreover, it uses the Eigen gap heuristic method to integrate the vehicles in a suitable group of clusters. After that, the authors presented a reliable routing protocol depending on CVoEG model to build the most reliable route to the target.

Radhika et al. [30] designed a cluster-based routing algorithm based on bagging ensemble x-means. This algorithm divides the network into groups depending on the vehicles' density, velocities, directions, and distances to join each car to the nearest cluster.

Moreover, several researchers produced some cluster-based routing protocols to enhance the transmission time and network overhead. Abushour et al. [10] suggested a set of routing protocols to enhance the stability, throughput, and overhead in VANET. The first one is the cluster-based lifetime routing, which tries to enhance the average throughput and path stability. The second one is the intersection dynamic VANET routing technique which focuses on minimizing the delay and maximizing the throughput and path stability. The final one is the reduction protocol that was produced to mitigate the overhead of exchanged messages in the clusters.

Bhaumik et al. [31] suggested a novel clustering routing technique that divides the VANET into clusters of different sizes. It aims to calculate the path with the lowest time and reduce the total overhead.

Farooq et al. [32] designed a cluster election technique depends on the mobility speed and the cluster threshold value. It aims to reduce the number of cluster heads switch operations to reduce the overhead. Moreover, they suggested a multicast routing protocol to deal with the high dynamic feature in highway and urban environments.

Aravindhan et al. [33] combined the context and geographic clustering strategies to minimize the control traffic and overhead. They then proposed a routing algorithm that focuses on the destination and the vehicle's movement in determining the next forwarding vehicle in the path.

Liu et al. [34] suggested a protocol to send the safety data in VANET called parking area and spider-web routing protocol (PASRP). It uses a digital map and system to get the parking area's geographic information to apply a spider-web transmission model and select the route with the minimum delay. Using this route, the safety data is transferred depending on a greedy technique.

However, the limitations of the above previous cluster formation and routing schemes can be summarized by the following: First, most of them suffer from the frequent statuses of re-building of clusters and selecting cluster heads, leading to increased overhead control messages transmission. Second, the cluster heads' selection in a number of them is made depending on the number of neighbor vehicles, distance, etc., which leads to low stability. Third, most of them suffer from the lack of cluster heads, gateway nodes, and network links stability, increasing the route failure cases. These cases lead to re-calculating new routes or maintaining broken routes and as a result increasing the delay of sending the data to the targets. Thus, these schemes are not suitable for safety applications. Overcoming the above weaknesses is the paper's goal by presenting a new clustering strategy and delay efficient, stable routing protocol.

3. Suggested clustering technique

The clustering method is one of the essential factors in improving the performance of cluster-based routing schemes in VANET. It can help in increasing the stability of the network and reducing overhead and delay. This paper produces a clustering approach to select the cluster head and gateway nodes depending on the parked and stopped vehicles to increase the network stability. Therefore, we assume that there are three types of vehicles: parked, stopped and moving. The speed of stopped and parked vehicles is equal to 0 for a specified time period t (in this paper, we assumed that $0 < t \leq 3$ min) and a specified time period more than 3 min, respectively, while the speed of moving cars is more than 0.

The feasibility of dividing the vehicles into stopped and parked vehicles is as follows:

- The main goal of the proposal is to increase route stability. The route that contains the largest number of stable links is the best one. The stopped vehicles may stop beside the supermarket, restaurant, Oil station, etc. for a short time and move at any moment. The movement of these vehicles leads to break the links. Some of these broken links may be part(s) of the selected route(s) to the destination(s). Broking them before sending all data to the destination is one of the large problems in VANET. To solve this problem, these links must be maintained. However, the maintenance operations increase the delay. In contrast, the parked vehicles stop for long time. Thus, the probability of the broken links

Table I
Notations.

Symbol	Description
V, V_i	Set of vehicles, Vehicle i.
P	The number of HELLO messages with flag = 1. It represents the number of parked vehicles within a specific geographic area.
S	The number of HELLO messages with flag = 2. It represents the number of stopped vehicles within a specific geographic area.
H_i	The cluster head *i*.
Q	The number of selected cluster heads.
C_i	The number of vehicles with type CM within the domain of the cluster head *i*.
B	The set of neighbor parked vehicles.
A	The set of neighbor stopped vehicles.
μ_i	The set of members with type = CM within the domain of the cluster head *i*.
λ_i	The set of candidate members of vehicle *i*.
x_i, y_i	The coordinates of the vehicle *i*.
δ_i	The set of parked and stopped vehicles that sent the *INFO* message with flag = 1 and 2 respectively to cluster head *i*.
N_i	The number of CGs that belong to δ_i.
d_{ij}	The distance between vehicle *i* and *j*.
Υ_i	It is a Boolean variable. Its value is equal to true if $\delta_i = \varnothing$ and H_i received *HEAD* message with *ID_H* differs from its *ID_H*. Otherwise, its value will be false.
ID−H_i	The ID of cluster head that controls the vehicle *i*.
V_{i0}, V_{i1}, V_{i2}	Moving vehicle, parked vehicle, stopped vehicle.

before reaching all data to the targets is lower than that in the cases of stopped vehicles. If there are two links (one between the stopped vehicles and another between parked vehicles) and can be selected to be part of a route to a target, then the last one is the best and has high priority to be selected than the first one. Note: the priority of each link's type is explained in section 4.

- Moreover, we assumed that the parked vehicles have higher priority than the stopped vehicle to work as cluster heads or gateway nodes.

Thus, the stability of cluster heads, gateway nodes and network links will be increased. This is the purpose of dividing the vehicles into stopped and parked.

The type of each vehicle during the cluster formation operation can be candidate gateway (CG), candidate member (CM) or candidate cluster head (CH). After the cluster formation operation, these types are converted to the cluster head (H), member (M), gateway (G), or cluster head and gateway (HG). HG is the vehicle that can work as a cluster head and gateway simultaneously. Table I contains other notations that are used in this paper.

The cluster building in any cluster-based network is done by selecting the cluster heads, determining their members and selecting their gateway node(s). The next subsections will explain that as follows:

3.1. The cluster heads and members determining

In algorithm 1 (cluster heads selection), at the first stage, all vehicles broadcast HELLO message contains the vehicle ID, velocity, location, and flag. Each vehicle checks all the received HELLO messages. The values of acceleration and location are fetched from GPS, while the flag's value is determined based on the vehicle's type (moving vehicle's flag = 0, parked vehicle's flag = 1, and stopped vehicle's flag = 2). Each vehicle saves completed information about the neighbor vehicles in a table called n_table. Here, several cases that may be occurred as follows:

- If there is a received *HELLO* message with flag = 1 or 2 ($\beta \neq \varnothing \vee \alpha \neq \varnothing$), each moving vehicle changes its type to CM. In this status, the selection of cluster head is made as follows:
- If only one parked vehicle (let i) received HELLO messages with flag = 0 or 2, then it will change its type to H and send an ACK message to all other vehicles that change their type to M. See Fig. 1 (a).
- If there are more than one parked vehicles, each one will change its type to CH. Then, it sends a *CHECK* message contains completed information about the candidate members to the parked vehicle(s) (CHs) using multicast transmission mode. Then, each CH will compare its candidate members with the candidate members of each one of the

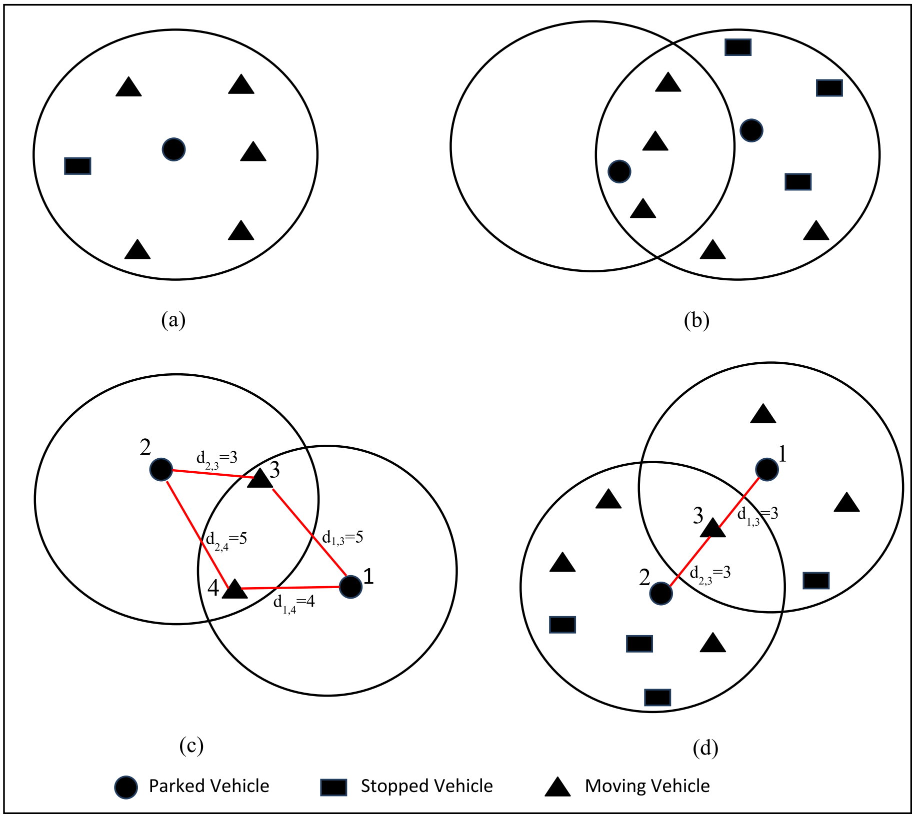

Fig. 1. The cases of cluster head selection.

other CHs. If ($\lambda_j \subseteq \lambda_i$), the parked vehicle *i* and *j* change their type to H and CM, respectively. The cluster head *i* will send *ACK* message to the CMs, which change the type to M (see Fig. 1 (b)). Otherwise (i.e. $\lambda_j \not\subseteq \lambda_i$), then the vehicle *i* and *j* will work as cluster head and their type will be H. Sometimes, there is a set of candidate members located within the coverage of more than one parked vehicles (i.e. $\mu_i \cap \mu_j \neq \emptyset$), then each cluster head will determine its members based on the distance using (1). For example, the candidate member *k* located at distances d_{ik} and d_{jk} from the cluster head *i* and *j*, respectively. Then, if $d_{ik} < d_{jk}$; then *k* will be as a member in the cluster of *i* (see Fig. 1 (c)). If $d_{ik} = d_{jk}$, then *k* will work as a member of the cluster that has the lowest number of members to reduce the overhead (see Fig. 1 (d)).

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}, \quad \forall i,j \in V \qquad (1)$$

Algorithm 1: Cluster Heads Selection
Input: V, P, S, β, α, St, Pa.
Output: Set of cluster heads.

Each V_i broadcasts *HELLO* message.
If ($\beta \neq \emptyset \vee \alpha \neq \emptyset$) **Then**
  Type (V_{i0}) ← CM
  If ($\beta \neq \emptyset$) **Then**
    If P = 1 **Then**
      Type (V_{i1}) ← H
      Call ***Cluster Formation (Algorithm* 2)**
    Else (i.e. P > 1)
      For each V_{i1}
        Type (V_{i1}) ← CH
          $V_{i,1}$ sends *CHECK* message
        End For
        For i = 1 to P
          If ($\lambda_i \subseteq \lambda_j$, $\forall j \in \beta$ |i) **Then**
            Type (V_i) ← CM
          Else
            Type (V_i) ← H
        End If
      End For
      Call ***Cluster Formation (Algorithm* 2)**
    End if
Else (i.e. $\alpha \neq \emptyset$)

(23) **If** S = 1 Then
(24) Type (V_{i2}) ←H
(25) Call ***Cluster Formation (Algorithm* 2)**
(26) **Else** (i.e. S > 1)
(27) For each V_{i2}
(28) Type (V_{i2}) ←CH
(29) V_{i2} sends *CHECK* message
(30) **End For**
(31) **For** i = 1 to S
(32) **If** ($\lambda_i \subseteq \lambda_j$, $\forall j \in \alpha$ |i) **Then**
(33) Type (V_i) ←CM
(34) **Else**
(35) Type (V_i) ← H
(36) **End If**
(37) **End For**
(38) Call ***Cluster Formation (Algorithm* 2)**
(39) **End If**
(40) **End If**
(41) **Else** (i.e. $\beta = \emptyset \wedge \alpha = \emptyset$) **Then**
(42) Determining V_i with lowest speed.
(43) Type (V_i) ←H
(44) Call ***Cluster Formation (Algorithm* 2)**
(45) **End If**

- If there is no parked vehicle (no flag = 1), then the stopped vehicles (flag = 2) are checked. If the is only one stopped vehicle, then it will work as a cluster head and change its type to H. Then, it will send an *ACK* message to all other vehicles which change their type to M. Otherwise,
- If there are more than one stopped vehicles, each one will change its type to CH and sends a *CHECK* message contains complete information about the candidate members to CHs using multicast transmission mode. If ($\lambda_j \subseteq \lambda_i$), then the stopped vehicle *i* and *j* change the type to H and CM, respectively. The cluster head *i* will send ACK message to the CMs which change the type to M. Otherwise (i.e. $\lambda_j \not\subseteq \lambda_i$), the vehicle *i* and *j* will work as cluster head and their type will be H. If ($\mu_i \cap \mu_j \neq \emptyset$), then each cluster head will determine its members based on the distance between it and each candidate member using (1).
- If there is no a received *HELLO* message with flag = 1 or 2 ($\beta = \emptyset \wedge \alpha = \emptyset$), then CH will be selected depending on the velocity. The vehicle with the lowest velocity will change its type to H and sends *ACK* message to all neighbor vehicles that change their type to M.

Algorithm 2: Cluster Formation
Input: Q, set(s) of candidate members.
Output: The members of each cluster head.
(1) **If** Q = 1 **Then**
(2) **Go to** Step 13
(3) **Else** (i.e. Q > 1)
(4) r = 1
(5) **While** r < Q **do**
(6) **For** i = r to Q
(7) **If** ($\mu_i \cap \mu_{i+1} \neq \emptyset$) **Then**
(8) Determining μ_i and μ_{i+1} using (1)
(9) **End For**
(10) r = r + 1
(11) **End While**
(12) **For** i = 1 to Q
(13) H_i sends ACK to each vehicle $\in \mu_i$
(14) **For** j = 1 to C_i
(15) Type (V_j) ←M
(16) **End For**
(17) **End If**

3.2. Gateway selection

After selecting a cluster head and determining its members, the cluster head and members (as shown in algorithm 3) broadcast a *HEAD* message containing its ID, velocity, location, flag, and *ID_H* (*ID_H* is the ID of its CH). If a member receives a *HEAD* message with *ID_H* that differs from its *ID_H*, it changes its type to CG and sends information about another cluster's vehicle(s) using *INFO* message to its cluster head. If there is one or more than one parked or stopped vehicles of CGs, the cluster head will store them as gateway vehicles and send *Notification* to all of them. After receiving this Notification, each of these vehicles will change its type to G. Using several gateways can increase the availability and capacity of links between the clusters and distributes the load of data transmitting among these gateways. However, the cluster head gives the first priority to the parked vehicles while the second priority is given for the stopped vehicles to be gateway (intermediate) nodes in the routing operation of data. **Note:** the cluster head may work as a gateway vehicle in addition to its work. It works as a gateway only if it receives a *HEAD* message(s) from the vehicles of the neighbor cluster(s) and there is no parked or stopped gateway vehicle. If the above cases are not available (i.e. no parked or stopped vehicle and cluster head cannot work as a gateway), it will select the vehicle with the lowest speed as a gateway vehicle.

Algorithm 3: Gateway Selection
Input: V, Q.
Output: Set of Gs
(1) Each vehicle broadcasts *HEAD* message
(2) **If** (ID−H_i ≠ ID-H_j, $\forall j \in V$| i) **Then**
(3) Type (V_i) ←CG
(4) V_i sends *INFO* message to its cluster head
(5) **End If**
(6) **For** i = 1 to Q

If ($\delta_i \neq \emptyset$) **Then**
  For j = 1 to N_i
    Type (V_j) ←G
  Else If (Υ_i = True) **Then**
    Type (H_i) ←HG
  Else
  Determining CG with lowest speed.
    Type (CG) ←G
  End If
End For

4. System model and problem definition

In this paper, we suggest that the used vehicular network is pure without any roadside unit. Some vehicles are stopped and parked while others are moving. Each vehicle has GPS to determine its location coordination. To send some data with size T from a vehicle to another, it is necessary to compute the optimal route according to several parameters and constraints. Routing operation of data in VANET is one of the largest challenges. Mobility of vehicles is the main reason for the routing problem because it leads to break the links. The correction operations of these links increase the overhead and data delivery time. On another side, some of the transmitted data between vehicles must be reached to the destination with minimum delay (e.g. police, emergency and firefight data). Therefore, delay and stability are essential factors in building operations of routes. Thus, to calculate the best route to the destination, a new routing protocol named CBSD is suggested depends on an optimization model. Determining the best route with minimum delay and maximum stability for VANET can be done by converting the whole network to a graph with a set of vertices and links. We assume that each link has a priority represents the stability degree. The objective function is minimum as shown in (3); therefore, we give the minimum priority value for the link with the highest stability. There are several types of links: parked to parked vehicle, parked to stopped vehicle, stopped to stopped vehicle, moving to parked vehicle, moving to stopped vehicle, moving to moving vehicle and vice versa (i.e. parked/stopped/moving to parked/stopped/moving vehicle) with priority value 0.1, 0.2, 0.4, 0.6, 0.8, and 1 respectively. As the objective function is minimum, the link from the parked to the parked vehicle takes the minimum priority. It has a bigger chance to be selected because it has the highest stability while the link from moving to moving vehicle takes the maximum priority.

To compute the route to the destination, the entire vehicular network is modeled as a graph with V and L represents the sets of vehicles and Links (edges), respectively. When the route is calculated, some links belong to L will be selected to be part of this route, while the rest will not be selected. Let x_{ij} is a variable to explain is the link from node i to j selected to be part of the calculated route or not. Let w_{ij} points to the priority of the link from i to j, d_{ij} refers to the delay of sending T bytes from i to j and b_{ij} is the remaining bandwidth in the link from i to j. The value of w_{ij} depends on the like's type, as it is explained above. Its value can be 0.1, 0.2, 0.4, 0.6, 0.8, or 1.

The value of d_{ij} is computed by dividing T by b_{ij}. The value of b_{ij} is calculated using (2).

$$b_{i,j} = BA_{i,j} - \sum_{z \in R} f^{z}_{i,j}, \ \forall i,j \in V, \tag{2}$$

where $BA_{i,j}$ is the total bandwidth of link from i to j and R is the set of the routes that use the link from i to j.

Moreover, suppose that f_{ij} is the size of data flow from i to j. The routing problem in this paper represents Mixed Integer Programming. It is as follows:

$$\text{Objective}: \ \min \ \sum_{i \in V} \sum_{j \in V} x_{ij} d_{ij} w_{ij}, \tag{3}$$

S.T.

$$f_{ij} \leq x_{ij} b_{ij}, \forall i,j \in V, \tag{4}$$

$$x_{ij} + x_{ji} \leq 1, \forall i,j \in V, \tag{5}$$

$$f_{ij} \geq 0, \forall i,j \in V, \tag{6}$$

$$x_{ij} \in \{0, 1\}, \tag{7}$$

$$0 < w_{ij} \leq 1, \forall i,j \in V, \tag{8}$$

According to (3), the selected route must contain links with minimum delay and maximum stability-however, choosing an optimal path to the destination subjects to several constraints. First (4), the volume of data that can pass using the link from node i to j should be less than or equal to the remaining bandwidth. Second (5), to avoid the loop in the selected route, the transmitted data from node i to j cannot be sent back from j to i. Third (6), the volume of transferring data from i to j must be more than or equal to zero. Fourth (7), the value of x_{ij} is determined in executing the mathematical model. Its value will be 0 if there is no data is transmitted from i to j. Else, its value is 1. Fifth (8), the priority of each link can be more than 0 and less than or equal to 1.

For example: let the network in Fig. 2 represents a simple VANET. Let the vehicle V1 likes to transfer data with volume 90 Bytes to the vehicle V1. In this

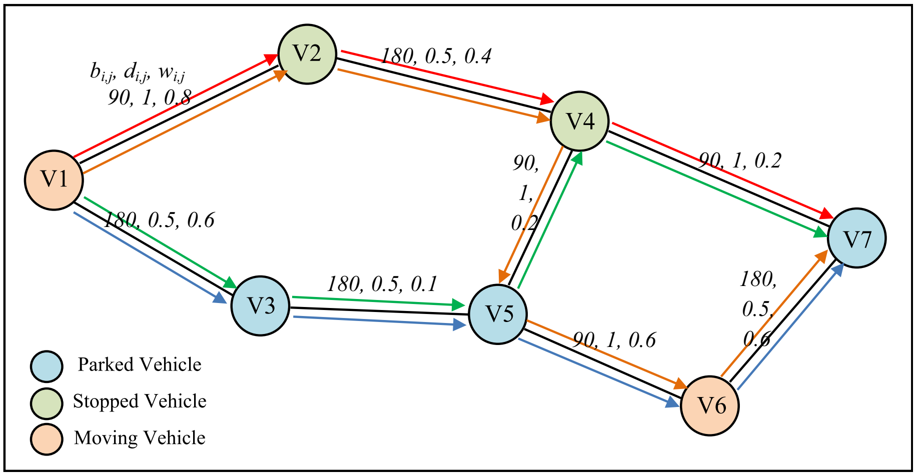

Fig. 2. Example.

figure, there is information about b_{ij}, d_{ij} *and* w_{ij} on each link. This network contains parked, stopped and moving vehicles. There are four paths (***path 1***: V1 → V2 → V4 → V7, ***path 2***: V1 → V3 → V5 → V6 → V7, ***path 3***: V1 → V2 → V4 → V5 → V6 → V7, and ***path 4***: V1 → V3 → V5 → V4 → V7) that can be used to send the data from V1 to V2. By applying the above mathematical model, the solution of path 1 = 1.2, path 2 = 1.25, path 3 = 2.1, and path 4 = 0.75. As the objective function is minimizing, then path 4 is the optimal one.

5. Suggested routing protocol

Before explaining how to compute the optimal routes to the destinations, we must explain that in the suggested routing protocol, each cluster head saves the information about its members, gateway(s) and connections with its neighbor clusters in a table named cluster_table. It sends the content of this table to other cluster heads, which save this information in an updatable table named neighbor_table. This table is updated when new information reached from other cluster heads. Moreover, each cluster head exchanges the content of its neighbor_table to the closest cluster heads. As a result, any one of the cluster heads will get a good view of the whole network.

To send data with volume T by one of the cluster's vehicles (i.e. members or gateway(s)) (let this vehicle is v1) to the target vehicle (let v9), v1 forwards a request contains the target vehicle ID (v9 in this example) to its cluster head. After receiving this request, the cluster head checks its cluster_table and if it finds v9 in this table, it sends the route to v1. Otherwise, it computes the route to v9 with minimum delay and best stability by modeling the information of neighbor_table as a graph. After that, it executes the proposed mathematical model (Section 4) on the resulted graph.

If one of the links of this route breaks, it is maintained locally by the cluster head that the broken link belongs to its coverage area. This procedure can reduce the delay of the correction operation of the failed links.

6. Simulation and results

The network simulator (NS) is used to simulate several types of networks (wireless or wired) and several types of protocols in different network layers [35]. The simulation of urban mobility (SUMO) is used

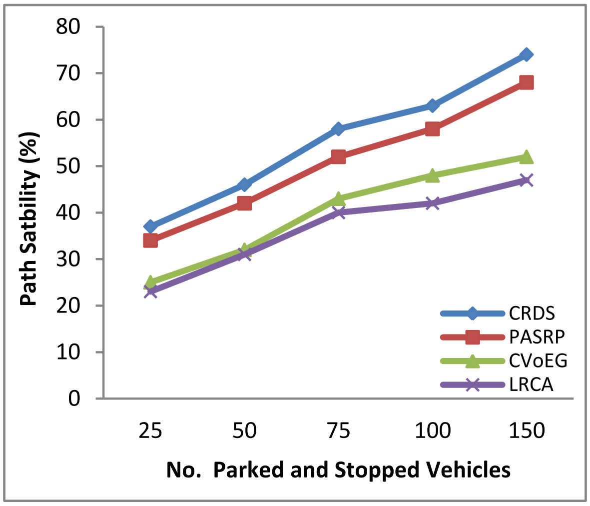

Fig. 3. Path stability.

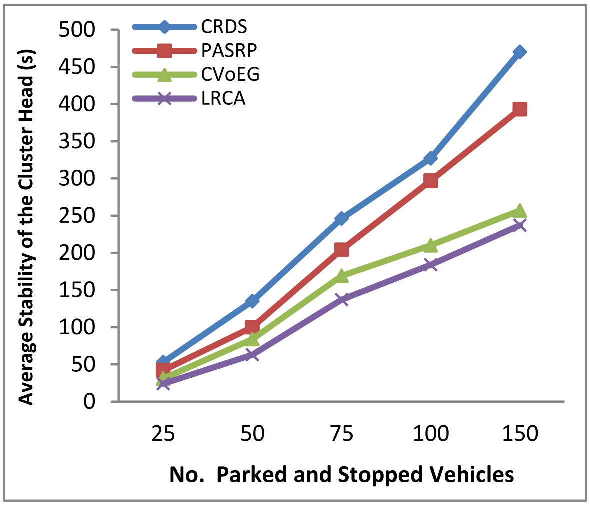

Fig. 4. Average stability of the cluster head.

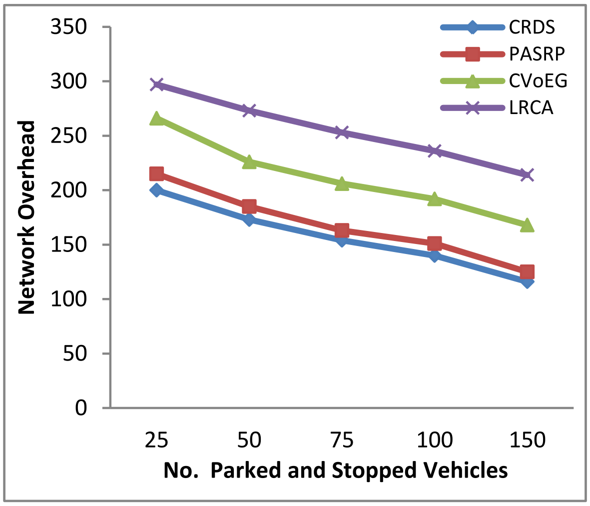

Fig. 5. Network overhead.

to model traffic system such as roads, vehicles, etc. [36]. To illustrate the behavior of the suggested clustering technique and routing protocol, NS version 35 and SUMO version 0.19.0 installed on the Linux operating system are used in this paper. C++ and OTCL programming languages are used to program the routing protocol and analyze its behavior, respectively. Two ray round, CBR, and uniformly distributed are propagation model, traffic generation and speed type that used in this simulation.

In the simulation environment, the total number of vehicles is 5000 vehicles widespread inside Baghdad city. CRDS is compared with LRCA [27], CVoEG [29] and PASRP [34] in various simulation scenarios with several numbers of parked and stopped vehicles and speeds. LRCA, PASRP and CVoEG were explained in the related works section of this paper. The Baghdad map (streets, fixed nodes and vehicles) has been imported from https://www.openstreetmap.org. The simulation time for each scenario is 600 s, and the execution is repeated 15 times. Then, the average value is computed for each performance metric to increase the accuracy. The performance metrics used in this paper are path stability (i.e. the total number of un-broken links in all paths divided by the total number of links in all paths), average stability of the cluster head, packet delivery ratio, average end to end delay and overhead. The simulation scenarios are as the following:

6.1. Scenario 1

This scenario studies the effect of a parked vehicle on the performance of LRCA, PASRP, CVoEG and CRDS. The numbers of parked and stopped vehicles are 25, 50, 75, 100 and 150 vehicles. The rest vehicles move at 15 m/s. Fig. 3 shows the path stability of LRCA, PASRP, CVoEG and CRDS with different numbers of parked and stopped vehicles. It is illustrated the path stability increases with maximizing the number of parked vehicles because the mobility reduces and as a result, the link broken situations will be reduced. However, CRDS is better than other routing protocols because it gives the highest priority to the links between the parked vehicles and stopped vehicles to work as parts of selected paths.

The cluster heads may be part of several paths to the target vehicles. Then their stability affects the path stability. The proposed cluster head cluster selection

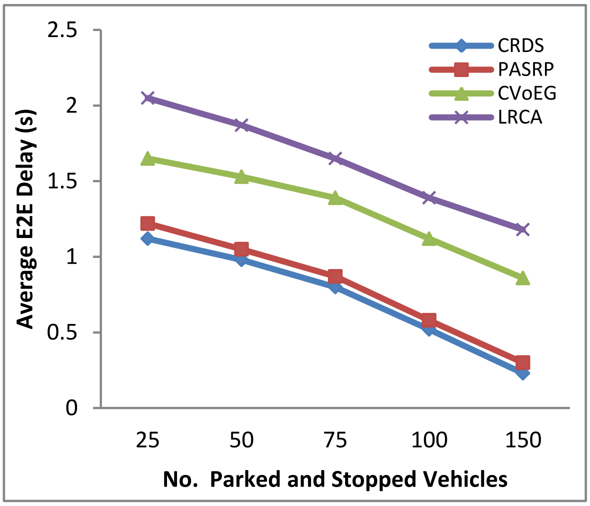

Fig. 6. Average E2E delay.

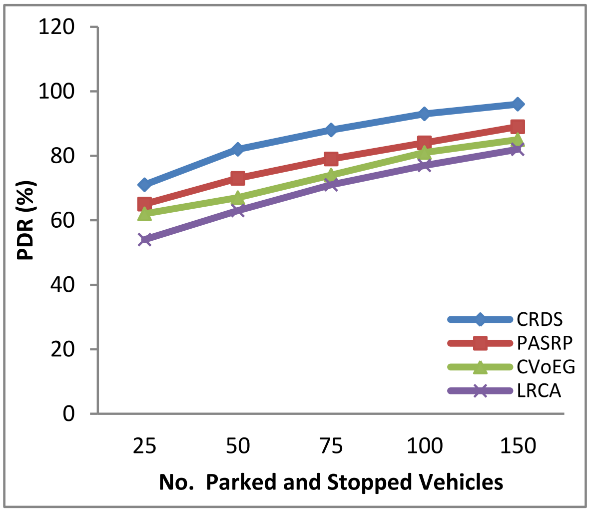

Fig. 7. PDR.

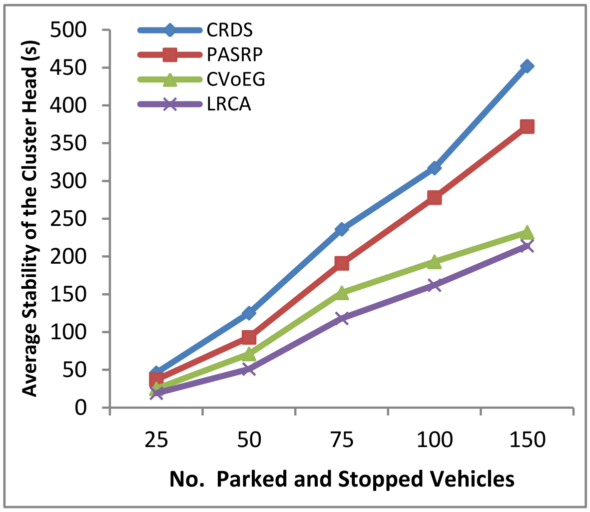

Fig. 9. Average stability of the cluster head.

approach plays a significant role in increasing path stability in Fig. 3.

Fig. 4 shows the average stability of the cluster head using LRCA, PASRP, CVoEG and CRDS with different numbers of parked and stopped vehicles. The continued time of working certain node as cluster head without change in its status to the gateway or normal node refers to the cluster head stability of that node. The average stability of a cluster head is computed by dividing the stability (the continuous-time) of all cluster heads by their number. This metric is used to study the strength of the cluster head selection and cluster formation algorithms. From Fig. 4, we can see that CRDS is better than other protocols since the proposed cluster head selection gives high priority to the stopped and parked vehicles to work as cluster heads. It can increase the stability of cluster heads, gateways and network links.

Fig. 5 explains the network overhead of applying CRDS, PASRP, LRCA and CVoEG with various numbers of parked vehicles. Mobility of the vehicles breaks the links frequently. Therefore, to maintain them, several routing packets are sent, which increase the overhead. Increasing the number of parked vehicles reduces the exchanging routing packets and as a result, the overhead will be reduced. However, CRDS

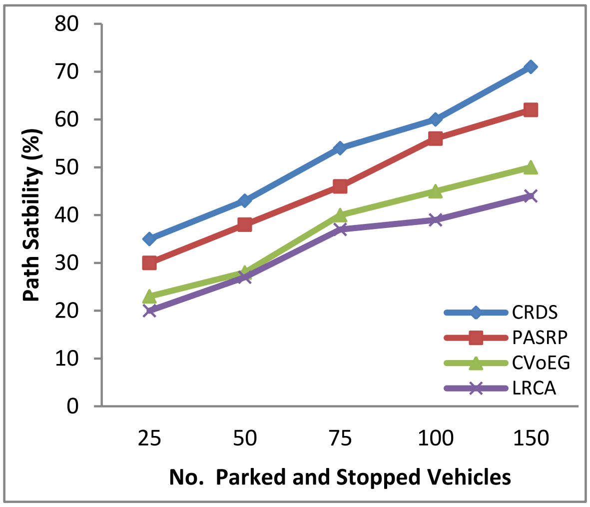

Fig. 8. Path stability.

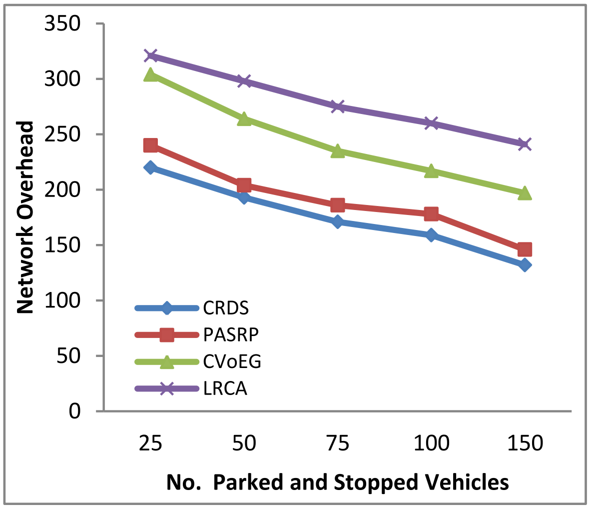

Fig. 10. Network overhead.

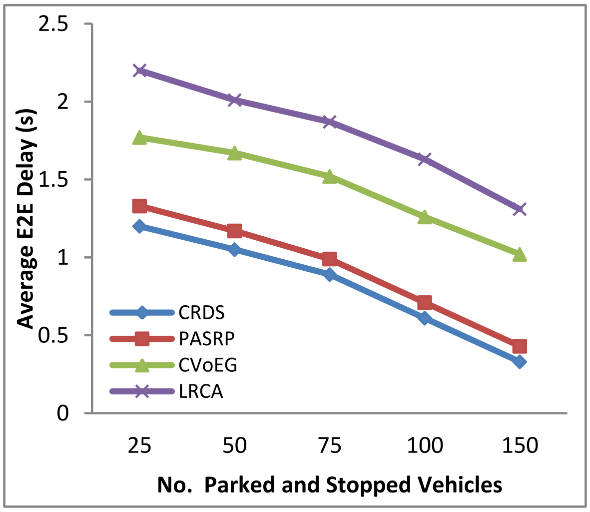

Fig. 11. Average E2E delay.

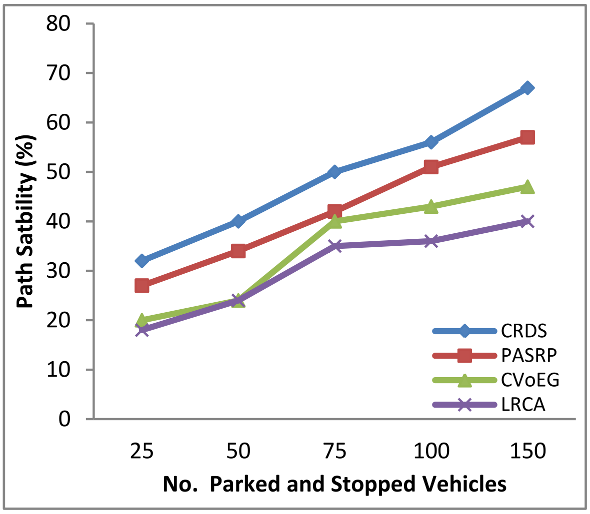

Fig. 13. Path stability.

minimizes the overhead to the lowest level because it exploits the links among the parked and stopped cars to construct the routes. It means that the broken links that belong to the selected paths are low using CRDS.

Fig. 6 illustrates the average E2E delay of applying CRDS, LRCA, PASRP and CVoEG with various numbers of parked vehicles. In VANET, the failure links need some time to be established again. This time increases the total E2E delay of delivering the data to the destinations. Typically, maximizing the number of parked vehicles reduces the situations of link failure, which minimizes the delay. Selecting the parked vehicles as cluster heads and gateways and using them as intermediate nodes in the built paths makes CRDS more suitable for VANET than other protocols.

Fig. 7 presents PDR of LRCA, PASRP, CVoEG and CRDS with several numbers of parked vehicles. Due to the mobility, the failed links increase the number of dropped packets. But by exploiting the parked and stopped vehicles by using CRDS, this number will be minimized.

6.2. Scenario 2

The effect of the parked vehicles on LRCA, PASRP, CVoEG and CRDS is studied in this scenario. The numbers of parked and stopped vehicles are 25, 50, 75,

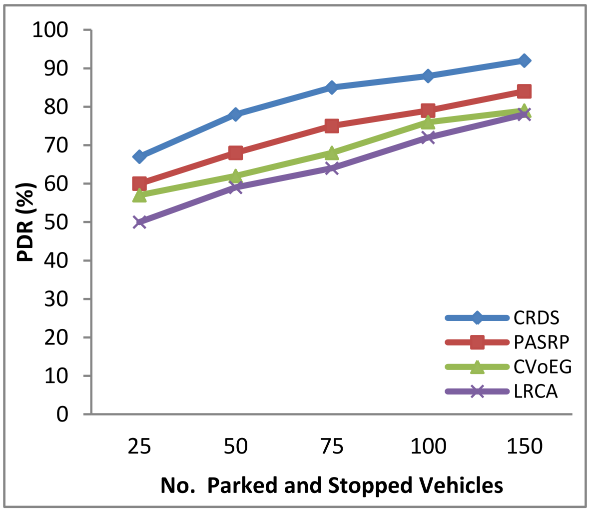

Fig. 12. PDR.

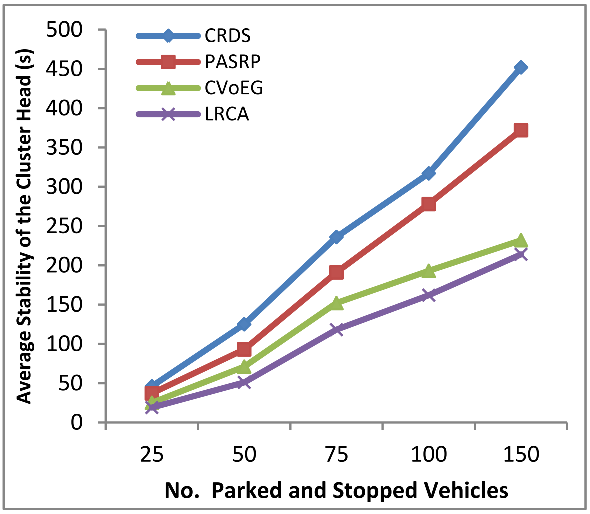

Fig. 14. Average stability of the cluster head.

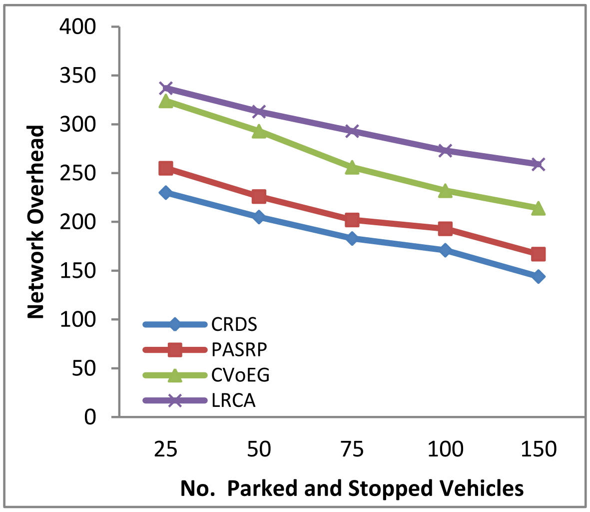

Fig. 15. Network overhead.

100 and 150 vehicles. The rest vehicles move at 20 m/s. Figs. 8–12 show the path stability, average stability of the cluster head, network overhead, average E2E delay and PDR of using CRDS, LRCA, PASRP and CVoEG with different numbers of parked and stopped vehicles.

6.3. Scenario 3

This scenario investigates the effect of the parked vehicles on the performance of LRCA, CVoEG, PASRP and CRDS. The numbers of parked and stopped vehicles are 25, 50, 75, 100 and 150 vehicles.

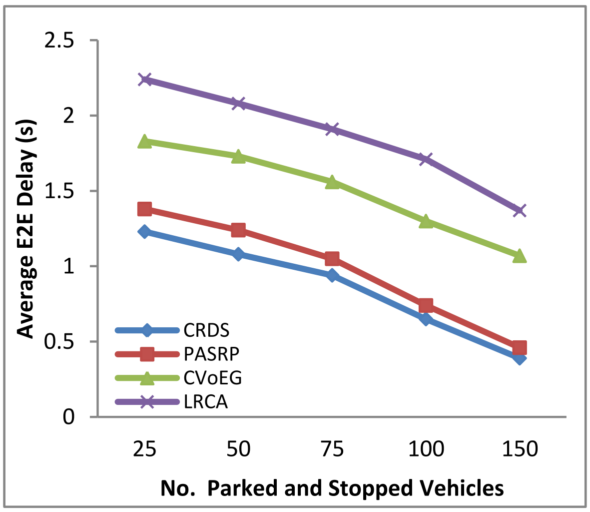

Fig. 16. Average E2E delay.

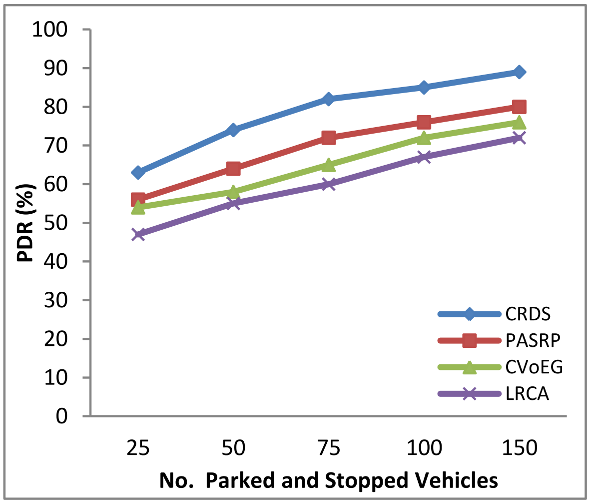

Fig. 17. PDR.

The rest vehicles move at 25 m/s. Figs. 13–17 show the path stability, network overhead, average E2E delay and PDR of using CRDS, LRCA, CVoEG and PASRP with different parked and stopped vehicles.

All the above scenarios study the effect of the number of parked and stopped vehicles with various mobility speeds. The results show that increasing the number of parked and stopped vehicles affects all the performance metrics positively. But, increasing the mobility speed in all these scenarios negatively affects the performance of all routing protocols. However, the performance of CRDS is better than the rest because it depends highly on the parked and stopped vehicles.

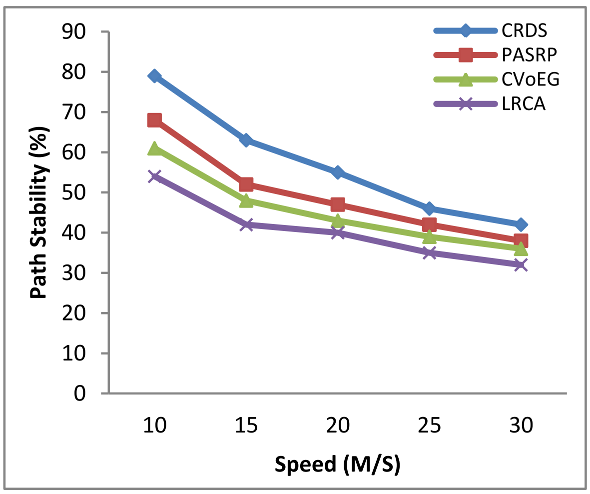

Fig. 18. Path stability.

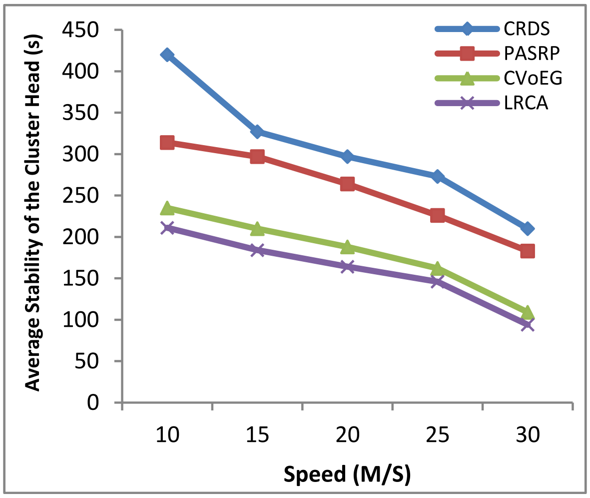

Fig. 19. Average stability of the cluster head.

6.4. Scenario 4

The effect of the moving speed of vehicles on the behavior of CRDS, LRCA, PASRP and CVoEG is investigated here. The number of parked and stopped vehicles is 100. The rest vehicles move at average speed 10, 15, 20, 25, and 30 m/s.

Figs. 18–22 display the path stability, average stability of the cluster head, network overhead, average E2E delay and PDR using CRDS, LRCA, CVoEG and PASRP with different average mobility speeds of vehicles. As shown, increasing the moving speed negatively affects the efficiency and performance of all routing strategies. The broken links reduce the path stability, average stability of the cluster head, and PDR as shown in Figs. 18, 19 and 22, while they increase the overhead due to the need to exchange additional routing packets to correct them (see Fig. 20). Moreover, they maximize the average E2E delay due to the time to fix these links (see Fig. 21). However, CRDS achieves better results than other routing protocols because it depends on the links with high stability (i.e. the links among parked and stopped vehicles) in building the paths. Thus, the mobility of other vehicles (i.e. moving vehicles) will not affect the selected path significantly compared to other protocols.

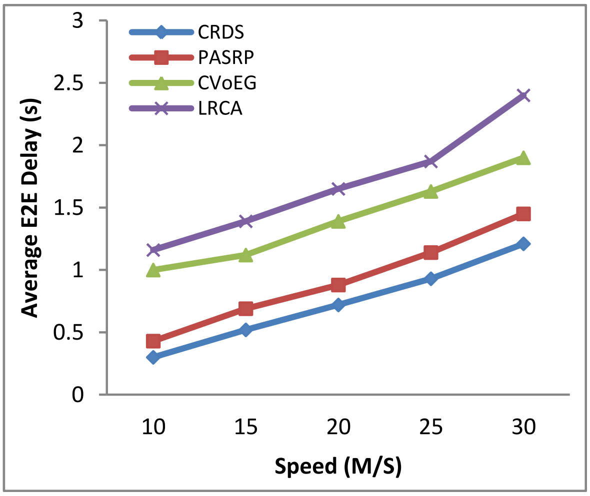

Fig. 21. Average E2E delay.

6.5. Scenario 5

This scenario investigates the effect of the moving speed of vehicles on the behavior of CRDS, LRCA,

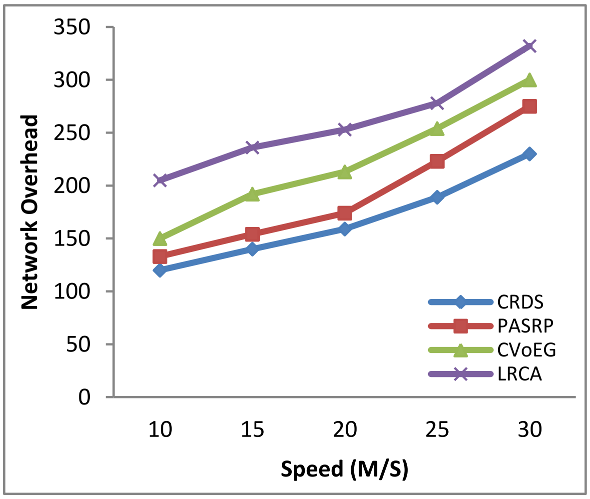

Fig. 20. Network overhead.

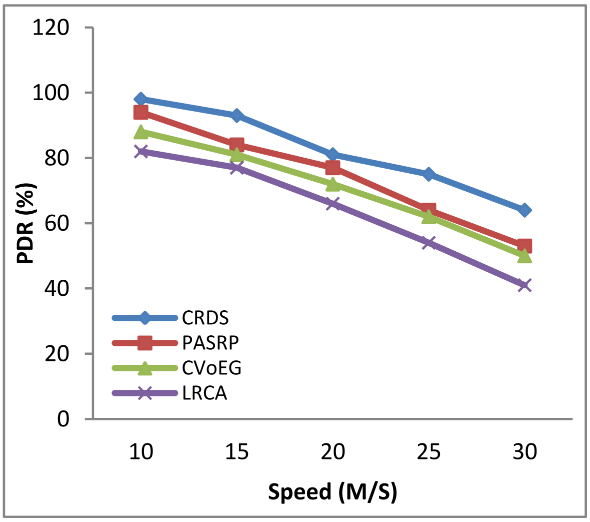

Fig. 22. PDR.

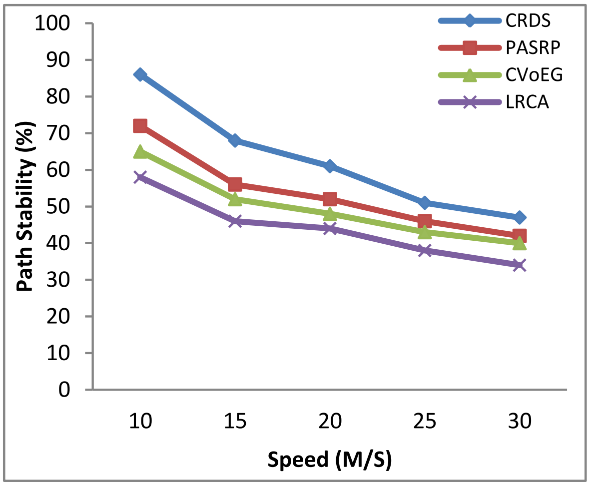

Fig. 23. Path stability.

PASRP and CVoEG. The number of parked and stopped vehicles is 150. The rest vehicles move at average speed 10, 15, 20, 25, and 30 m/s. Figs. 23–27 display the path stability, average stability of the cluster head, network overhead, average E2E delay and PDR using CRDS, PASRP, LRCA and CVoEG with different average mobility speeds of vehicles.

6.6. Scenario 6

The effect of the moving speed of vehicles on the behavior of CRDS, PASRP, LRCA and CVoEG is studied in this scenario. The number of parked and stopped vehicles is 200. The rest vehicles move at average speed 10, 15, 20, 25, and 30 m/s. Figs. 28–32 display the path stability, average stability of the cluster head, network overhead, average E2E delay and PDR of using CRDS, LRCA, PASRP and CVoEG with different average mobility speeds of vehicles.

Scenarios 4, 5 and 6 investigate the effect of movement speed on the performance metrics but with various numbers of parked and stopped vehicles. The results illustrate that increasing mobility speed negatively affects all the performance metrics. But, increasing the number of parked and stopped vehicles in these scenarios can enhance all these performance metrics. However, the performance of CRDS is better than the rest because it depends highly on the parked and stopped vehicles.

In dynamic networks like VANET, the topology changed frequently. This change leads to several challenges, such as route disjoint. Exploiting the fixed

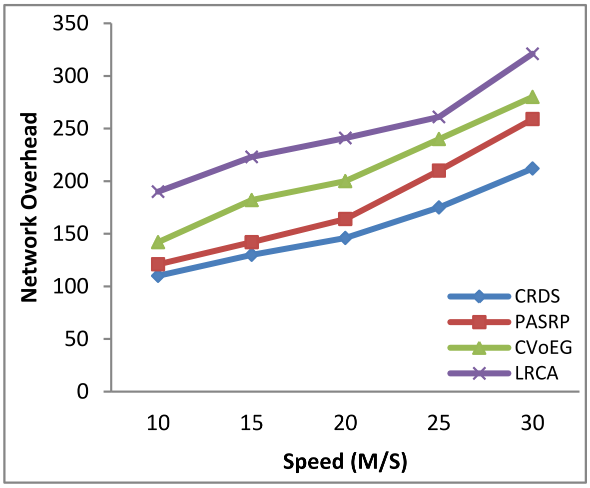

Fig. 25. Network overhead.

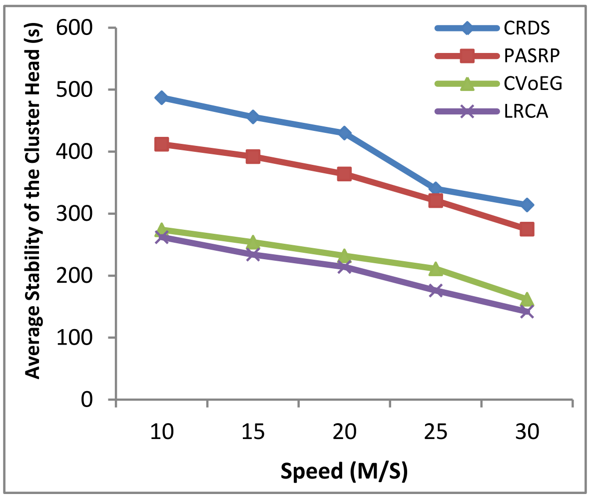

Fig. 24. Average stability of the cluster head.

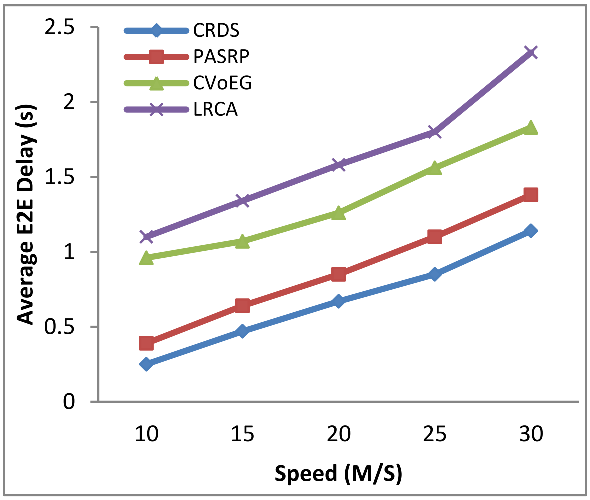

Fig. 26. Average E2E delay.

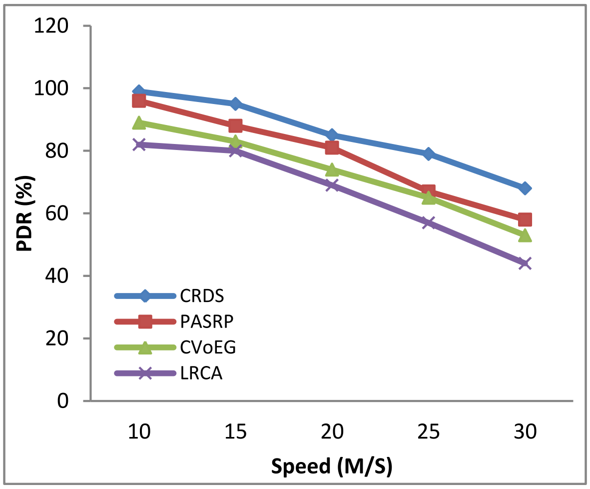

Fig. 27. PDR.

nodes (parked and stopped vehicles) can help increase the stability of links, cluster heads and gateway nodes and result in the entire network. This stability can help in solving these challenges. The proposed clustering technique and routing protocol exploit this concept in enhancing the routing operation of critical data of emergency applications. The proposal of this paper can reduce the re-construction of clusters and correction operations and as a result, reduce the transmission time, overhead, bandwidth and packet loss.

Sending the data about the emergency events such as accidents, traffic jam, etc., to the drivers with minimum time gives them the required time to change their road. It can help them avoid future accidents and stop in the traffic jam, which increases the oil consumption, CO_2 generation, and wasting of the driver and passenger time.

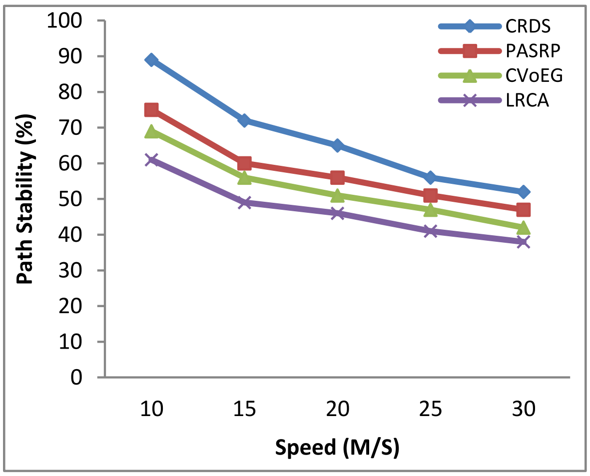

Fig. 28. Path stability.

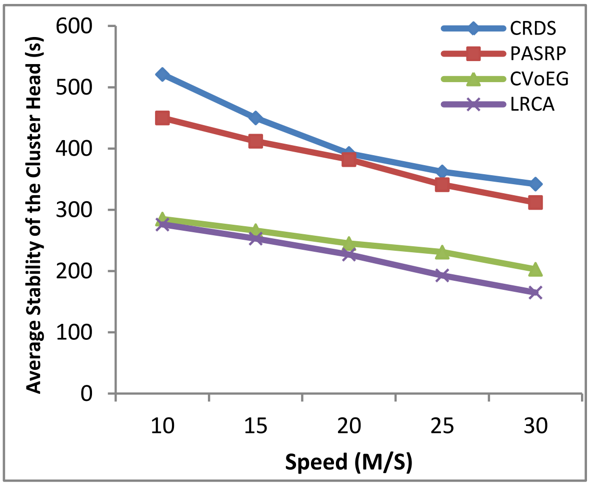

Fig. 29. Average stability of the cluster head.

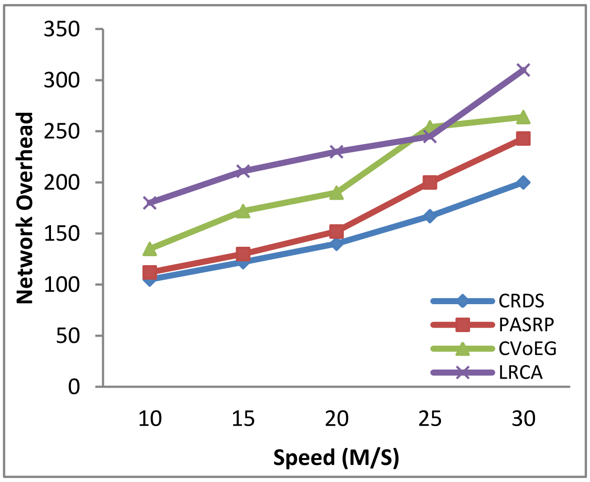

Fig. 30. Network overhead.

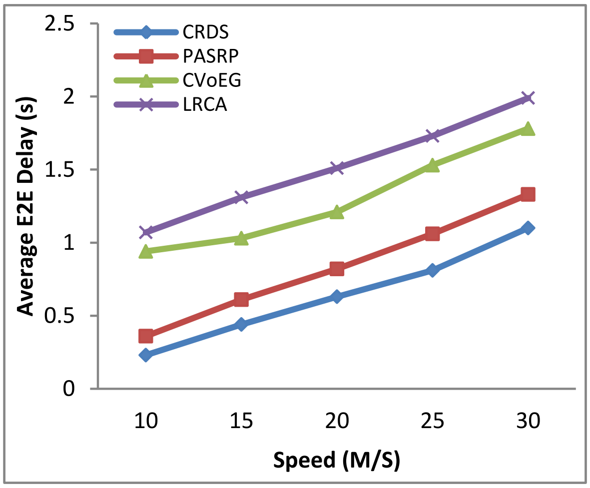

Fig. 31. Average E2E delay.

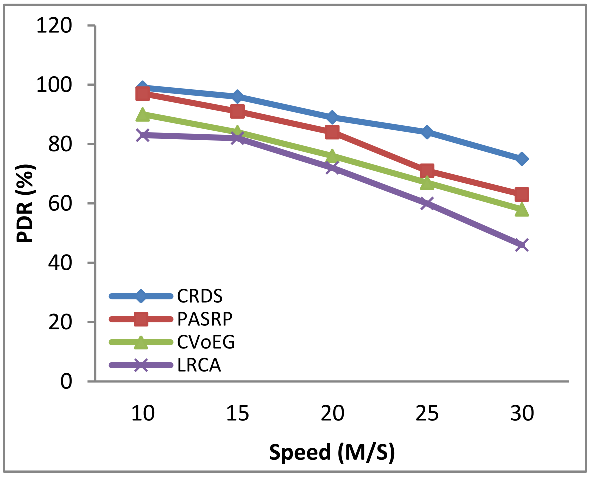

Fig. 32. PDR.

The current focus of most researchers is reducing the negative effect of dynamicity of many network types such as VANET, MANET, etc. From the above results, we can see that the proposal of this paper produces an efficient solution for the significant challenge in one of these dynamic networks (i.e. vehicle mobility and frequent link disjoint) and contributes to enhancing its performance.

7. Conclusion

It is known that the link stability increases the efficiency of the network and guarantees that the data arrive at the destination very quickly. However, one of the significant problems in classical VANET is the lack of link stability due to the mobility of vehicles at an unpredicted speed, making the routing process very difficult. Several types of routing strategies were produced to overcome this challenge. Cluster-based is the famous one of these strategies. Several researchers focused on this category and presented a large group of cluster-based routing protocols and cluster formation techniques depending on several parameters. Unfortunately, the cluster and routes to the targets can be destroyed and disconnected frequently due to the vehicle's movement. This paper focused on these challenges and presented a new cluster formation strategy and cluster-based routing algorithm for classical VANET. First, the proposed cluster formation technique exploits the parked and stopped vehicles to increase the stability of links, cluster head, gateways, and the whole network. Second, the proposed cluster-based routing protocol (CRDS) aims to construct the route to the target vehicle with minimum delay and maximum stability. It depends on a proposed optimization model in determining the best route to each target. In this model, each link takes a priority to display its stability. The performance of CRDS is proved using various simulation scenarios with various numbers of parked and stopped vehicles and mobility speeds. Moreover, it has been compared with LRCA, PASRP and CVoEG according to path stability, average stability of the cluster head, packet delivery ratio, network overhead and average end to end delay. It presented promising results in all performance metrics. Unfortunately, the clustering technique needs to exchange high numbers of messages frequently, leading to increased overhead and bandwidth consumption. Therefore, solving this problem is one of the future directions of this paper. Moreover, we will use one of the most representative computational intelligence algorithms like monarch butterfly optimization, earthworm optimization algorithm, elephant herding optimization, moth search algorithm, and Harris hawks optimization to solve the optimal route selection problem. In addition, we will produce a new two-layer clustering strategy for hybrid VANET to increase link stability. Finally, the effect of parked and stopped vehicles on the routing protocols will be studied soon. This research work will apply to the different topologies of VANET like flat, cluster-based, etc. Moreover, it will execute various types of classical routing protocols and new routing protocols such as LRCA, CVoEG, CRDS and PASRP.

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