Performance Analysis of Vanets Routing Protocols

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Abstract

Vehicular Ad Hoc Networks (VANETs) are a particular class of Mobile Ad Hoc Networks (MANETs). The VANETs provide wireless communication among vehicles and vehicle-to-road-side units. Even though the VANETs are a specific type of MANETs, a highly dynamic topology is a main feature that differentiates them from other kinds of ad hoc networks. As a result, designing an efficient routing protocol is considered a challenge. The performance of vehicle-to-vehicle communication depends on how better the routing protocol takes in consideration the particularities of the VANETs. Swarm Intelligence (SI) is considered as a promising solution to optimize vehicular communication costs. In this paper, we explore the SI approach to deal with the routing problems in the VANETs. We also evaluate and compare two swarming agent-based protocols using numerous QoS parameters, namely the average end-to-end delay and the ratio packet loss which influence the performance of network communication.

Keywords: Routing protols; Performance Analysis ; Vanets   ; Optimization;

1. Introduction

Vehicular Ad Hoc Networks (VANETs) are an emerging new technology for realizing inter-vehicle communications. They are considered as one of the influencing areas for the improvement of an Intelligent Transportation System (ITS) in order to offer safety and comfort to drivers and passengers [1]. In the ITS system, a mobile node can communicate wirelessly with others without any central access point where every vehicle may act as a router, a sender and a receiver.

The VANETs assist the vehicles to communicate and to coordinate among themselves to keep away from any critical situation (e.g., accidents, traffic jam…) through Vehicle-to-Vehicle (V2V) communication. In addition to safety services and applications, the VANETs provide also another type of applications, called comfort applications, like internet access, looking for a free parking place, etc [2]. The VANETs' architecture presents two principal types of communication. The first one is purely ad-hoc,

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which allows communication only between vehicles (V2V). However, the second type requires an outside infrastructure or road-side elements. Figure 1 exhibits the overall working architecture of the VANETs.
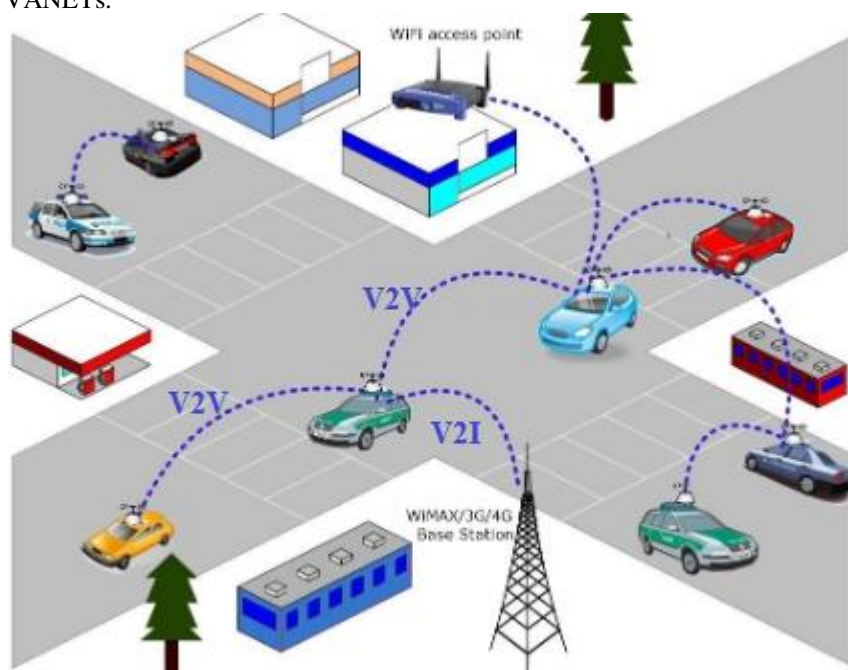

Fig1. VANETs' architecture

The VANETs have some characteristics similar to those of Mobile Ad Hoc Networks (MANETs), often in the form of multi-hop networks with a decentralized nature. Nevertheless, they have a number of specific properties that distinguish them from other types of networks, such as highly dynamic topology [3]. Thus, given the high mobility, the next position of the vehicle is not feasible to be predicted. As a result, a temporary, frequently disconnected network fragmentation may appear.

All these properties bring numerous challenges. One of them is routing [4]. In fact, to develop an efficient protocol for routing in the VANETs, the spatial-temporal constraints in terms of speed and mobility of vehicles, as well as environmental changes, must be considered. Recently, a new class of routing algorithms, inspired by Swarm Intelligence (SI) is developed to tackle the routing problems for vehicular networks [5]. Lately, the SI is considered as a promising approach to solve different complex problems like routing in dynamic networks (VANETs) [6]. The SI system utilizes a multi-agent system for network management. These agents are autonomous entities, whether proactive or/and reactive, having the ability cooperate, adapt and move intelligently from one situation to another in a communication environment network [7]. The SI, in particular, uses stigmergy, which defines the communication through the environment, to ensure interaction between agents [8, 9, 10, and 11]. The SI demonstrates an emerging behavior in which interactions of autonomous agents, with simple primitives, produce a complex behavior that has not been itemized explicitly [12].

Motivated by some behavior of the SI approach, we previously proposed [13, 14] two swarming-based protocols to solve the routing problems in vehicular networks. In this paper, we evaluate and compare these suggested solutions using numerous QoS parameters, namely the average end-to-end delay and the ratio packet loss, which directly influence the performance of network communication.

The remainder of this paper is organized as follows. Section 2 focuses on the routing issue in vehicular networks. Section 3 deals with the motivations that underlie the requirement for the SI to overcome the VANETs' routing problems. It also presents the proposed approaches. Section 4 discusses the obtained

simulation results. Finally, in section 5, the conclusion is drawn on the basis of the results and the future plan of the present work is also presented.

2. ROUTING IN VEHICULAR AD HOC NETWORKS

The routing task in VANETs is a big challenge due to the unique features of these networks such as the dynamically changing network topology caused by the high mobility of vehicles. It is an issue of guaranteeing reliable and efficient communication in the presence of speeding nodes [4].

The nodes in the vehicular networks may join and leave the network rapidly, which causes a frequent path disruption [3]. The vehicle variable density leads to rapid changes in network topology. Consequently, designing an efficient protocol remains as an issue where preserving a route is a difficult task. In order to overcome routing problems, many investigations have been done in this area and a lot of VANET routing protocols have been proposed. Indeed, and since the vehicular networks are a particular class of mobile ad hoc networks, several researchers have led to the use of dedicated protocols for these networks for routing in the VANETs.

In the literature, different MANET routing protocols have been developed. These approaches are mainly classified into two classes: table-driven based protocols and demand-driven based protocols [15]. A table-driven algorithm, as the dynamic Destination-Sequenced Distance-Vector (DSDV) protocol [16], is purely proactive where all nodes maintain, at all times, routes to all other neighbors' nodes. As a result, each node keeps track of all network topological changes, which can be a hard task if there are lots of nodes or if the nodes are very mobile. Whereas, a demand-driven protocol, like the Ad-hoc On-demand Distance Vector (AODV) protocol [17], is purely reactive. This means that the nodes only collect routing data when a source node wants to communicate with a desired destination, but it does not have a route in its routing table or in case of link failure. In general, reactive protocols are more efficient in terms of routing overhead [18].

However, numerous simulation and experimental studies have been proposed and they have proved that the routing protocols of the MANETs are facing several challenges and present some weaknesses in the context of VANETs [19]. As a result, they cannot be directly applied due to the specific features of the VANETs. Therefore, the inadaptability of these protocols pushes other researchers to design protocols specifically dedicated to the VANETs that can be classified into three categories [20], as shown the figure 2.
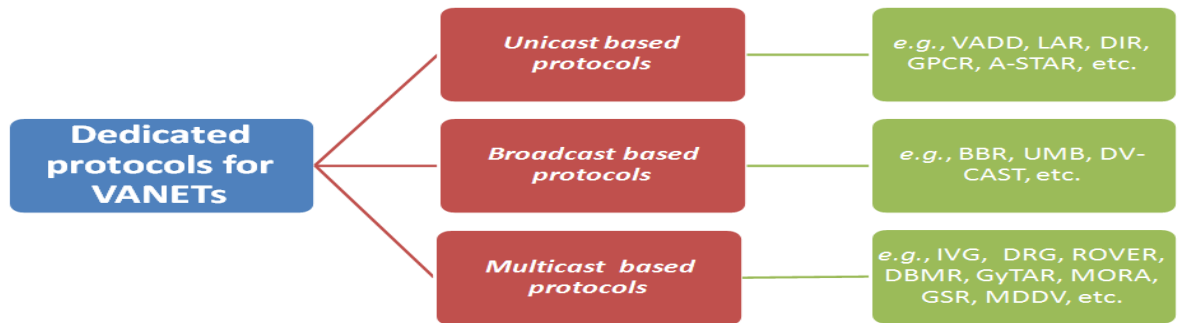

Fig.2. VANET protocols

Although these protocols are specifically proposed to address the routing problems in vehicular networks, the simulation studies have demonstrated that these methods do not take into account all the properties of VANET networks. As a result, they have some shortcomings [21, 22]. Table 1 illustrates the performance evaluation of these categories.

Table 1. Performance analysis of VANET protocols [21, 22].

Protocols	Advantages	Disadvantages
GPSR	It is more efficient on highways	Its performance goes down with high mobility
GSR	It is more efficient on large scale networks	It generates a high traffic control volume
A-STAR	It possesses an important network connectivity	It is only efficient on urban environment
VADD	It generates a high packet delivery ratio	Its performance goes down with high vehicles density
GyTAR	Its performance goes up with high mobility	It requires pre-existing infrastructure
UMB	It presents a low packet collisions rate	It generates a high packet loss rate

These results prove that routing in VANET networks is far from obvious and its difficulty lies essentially in these intrinsic characteristics. To perform efficiently the routing function in vehicular networks, a protocol must take into consideration all the properties and factors that can affect its performance. This demands a highly adaptive approach to deal with the dynamic scenarios by selecting the best routing and forwarding strategies and by using appropriate mobility and propagation models.

To this end, it is important that a vehicle may be able to perceive its communication environment in order to act in the face of problems that can appear as network fragmentation caused by rapidly changeable topology, etc. Therefore, it will be interesting if a routing protocol can be robust, be able to observe changes in the communication environment and adapt to them with respect to variations in environment constraints.

The SI has recently become a source of inspiration for the development of distributed and adaptive routing algorithms for VANETs [6, 7].

3. SWARM INTELLIGENCE FOR ROUTING IN VANETS

The SI approach has appeared in biological swarms of certain insect species. It has resulted in a complex and often intelligent behavior via a complex interaction of thousands of autonomous swarm units. The interaction behavior is on the basis of primitive instincts without any supervision. The final results are an accomplishment of different complex forms of social behavior as well as an achievement of other tasks [9].

The important principle behind these interactions is named stigmergy, and is called also the communication through the environment. From an architectural point of view, the SI is a compound system of a number of totally or partially autonomous units. These units, called agents, have various basic processing and interaction capabilities [8, 9, 10, and 11]. For example, the particles used in Particles Swarm Optimization (PSO) [23] technique are modeled after birds' behavior. There is a certain redundancy level between the agents. Consequently, the system behavior can be more robust with respect to the decrease and increase of the agents' number. In fact, an agent is expected to possess some skills in order to solve and optimize a complex task, and interact with others (agents and environment).

Moreover, they are able to perceive, act and re-act face to their communication environment in which they live. The behavior of the SI system as a whole is the synergistic result of the combination of the actions of these individual agents and their interactions with each other and with their environment. There is no required centralized controller. Using the interactions and communication behavior, the SI system is able to be suitable to overcome the routing challenge of VANETs and provide data transmission with an optimal communication cost [6].

The SI boasts a number of advantages due to the use of the multi-agent system and stigmergy [8, 9, 10, 11, and 12] which are:

1. *Scalability:* The number of agents can be adapted related to the size of the network. In addition, this feature is also promoted by distributed as well as local agents' interactions.

2. *Fault tolerance:* An SI procedure does not rely on any centralized control mechanism. Thus, the loss of a node or a communication link does not lead to a catastrophic failure, but rather causes very scalable and graceful degradation.

3. *Adaptation:* The agents can move, reproduce or die depending on the network changes.

4. *Speed:* Unlike the Bellman-Ford algorithm [24], changes in the network may be quickly propagated.

5. *Modularity*: The agents proceed and act regardless of other layers of the network.

6. *Autonomy*: No human supervision is needed.

7. *Parallelism:* The different agents' operations are parallel.

Thanks to these properties, an SI based approach has recently become the most suitable for a variety of applications, apart from routing in VANETs [25,26,27]. In this context, we proposed previously in [13 and 14] two SI-based routing protocols named, PSO-Clustering Multi-Agent DSDV (PSO-C-MA-DSDV)[13] and Optimized Agent-based AODV Protocol for VANET (OptA²PV)[14].

3.1. PSO-C-MA-DSDV

Motivated by the advantages of the SI approach, we suggested in [13] a PSO-C-MA-DSDV protocol to deal with routing challenge in the VANETs networks. This approach was an enhanced version of the DSDV [16] protocol on the basis of multi-agent system and PSO techniques. The PSO [23] is one of the most successful and popular example of the SI. It is based on the behavior of birds which fly through space and share information in order to find an optimal position.

The PSO-C-MA-DSDV mainly combines clustering techniques to divide the network into different regions (clusters), as presented in figure 3. The main goal of this contribution is to group the vehicles according to their spatial and temporal distribution.
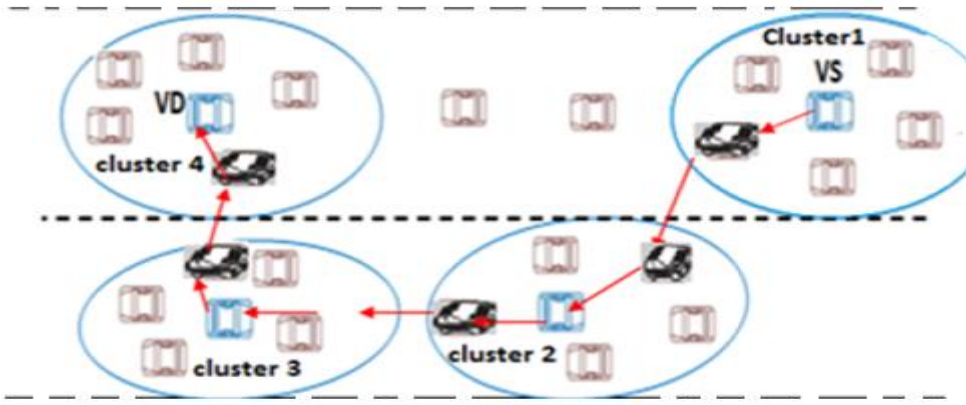
Fig.3. PSO-C-MA-DSDV protocol [13]

For each cluster, the proposed protocol adopts an optimization strategy to select the most suitable cluster-head node. The main goal of this strategy is to make the communication between clusters or between vehicles of the same cluster more efficient with an optimal cost in terms of number of neighbors, average value of speed and distance between neighbors. For this reason, the selection of cluster-head nodes takes into account these parameters, which directly affects the stability of routes as well as the communication cost. For this reason, the PSO-C-MA-DSDV uses during the cluster-head selection phase a function F defined in [13] as follows:

$$F = \sum_{it=1}^{N_{it}} (w1 * d_{Vi,Vj} + w2 * |Avg_{Vi} - S_{Vi}| + w3 * N_{neigh_{Vi}})$$

(1)

where SVi represents the speed value of a vehicle Vi, Nneigh defines the total number of the neighbors of a vehicle, Nit is the possible number of iterations, it is an iteration, w1, w2 and w3 represent random constants, and dVi,Vj is the Euclidean distance between the two neighbors of the vehicles Vi and Vj which respectively have the coordinates (x_{Vi}, y_{Vi}) and (x_{Vj}, y_{Vj}). The distance is represented with this expression:

$$d_{Vi,Vj} = \sqrt{(x_{Vi} - x_{Vj})^2 + (y_{Vi} - y_{Vj})^2}$$

and AvgVi defines the speed average value of the vehicle Vi and it is calculated as follows:

$$Avg_{Vi} = \frac{1}{N_{neighVi}} \sum_{k=1}^{N_{neighVi}} S_{Vi}$$

The basic principle of our algorithm is that each particle tries to find the optimal solution, and the optimized result corresponds to the best position of the particles in the search space based on an F value. In each iteration step, the particles are updated to the two values. The first one is the best position (Xp) of the local solution and the second one is the best position of the global optimal solution (Xg). Through the sharing of these values, it determines the next position. Then it progressively travels toward the optimal

solution using the velocity value. The position and the velocity are represented respectively by the following equations (2 and 3):

$$V_i(t+1) = w.V_i(t) + c_1.r_1[p_i(t) - x_i(t)] + c_2.r_2[p_g(t) - x_i(t)] \qquad (2)$$
$$X_i(t+1) = V_i(t+1) + X_i(t) \qquad (3)$$

where w, c1, and c2 represent the acceleration coefficients, r1 and r2 define the random values between 0 and 1, i is a particle, and pi and pg are known respectively as the personal best fitness value of particle i at time (t) and the global best fitness value among all particles. The position corresponding to the best value is known as Xp and the best value among the entire solution is represented by Xg.

Figure 4 summarizes the functional principle of PSO-C-MA-DSDV.
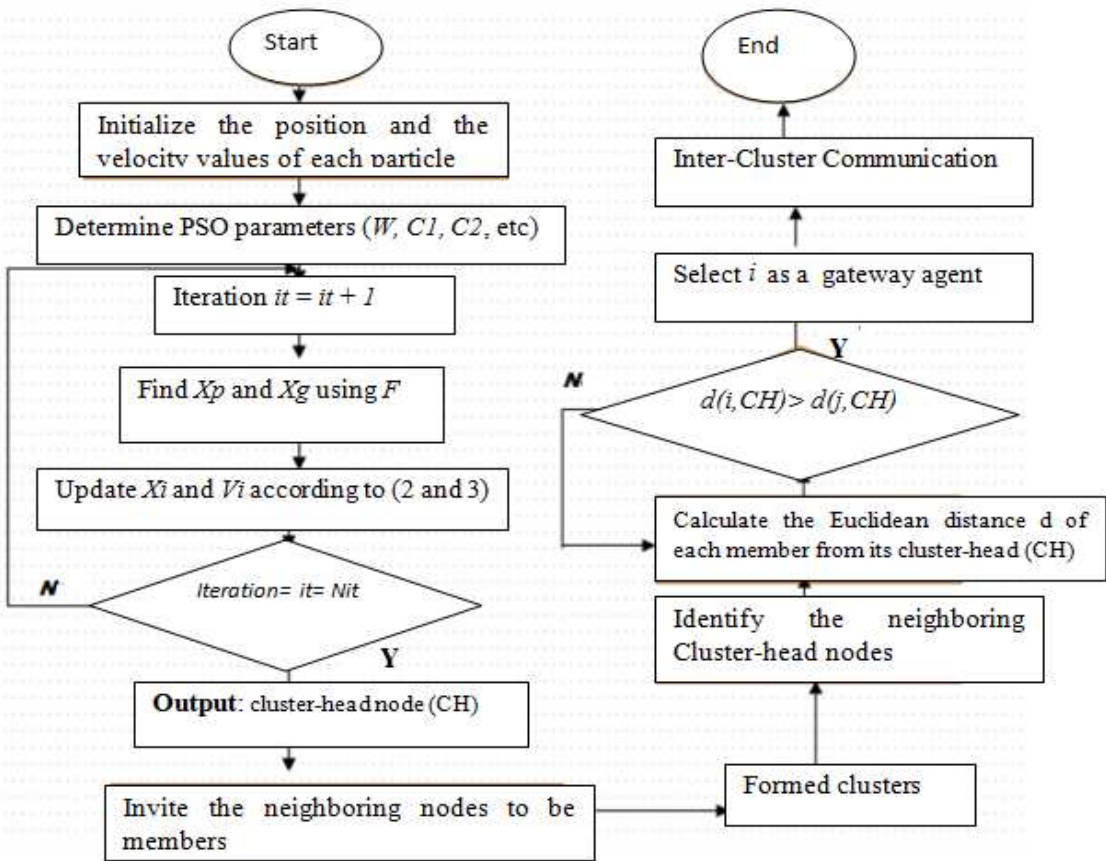
Fig 4. Principal PSO-C-MA-DSDV steps

In [13], the simulation results confirmed the effectiveness of PSO-C-MA-DSDV under different performance metrics like the throughput and the *packet drop rate*. Nevertheless, as it is a proactive protocol, it presents some deficiencies in terms of routing overhead. For this reason, we have focused in the second proposed approach on another kind of protocols, which is the reactive protocol, in order to improve the routing performance in terms of overhead.

3.2. OptA²PV

To minimize the routing overhead, road construction must be done with minimal traffic. To do this, the establishment of routes must be done only if an agent wants to communicate with a neighbor. This is what was defined previously as on demand-driven or reactive routing. The OptA²PV [14] is an improved and optimized version of the reactive AODV protocol [17] on the basis of the SI.

As aforementioned, the high mobility of vehicles in the vehicular network generates a very dynamic topology, which can cause some routing problems, namely network fragmentation. As a consequence, the communication link will be very fragile. In fact, a communication link is characterized by various metrics like the number of hops and the number of neighbors. In order to ensure the inter-vehicular communication with a lower cost, these parameters must be processed and shared in such a way that the most efficient and optimal route can be reached. The communication cost is calculated using these parameters.

On the other hand, because of the high mobility of nodes, these parameters can be modified at any time. For this reason, it seems interesting to use the SI approach to improve the routing overhead by reducing the average number of the route request packet (RREQ) generated during the route discovery step.

As a result, in [14], we opted for the same metrics as in [28], which directly influenced the number of generated RREQ. Thus, we have defined the fitness function f as follows:

$$f = \sum_{n-1}^{H} 4) \; 3^{H-1} \sum_{i=2}^{4} [(\; n-1-i\;) - \sum_{j=1}^{H-1} Nj\;] \, pCi \qquad (4)$$

Where H is the number of hops in the network, Ci is a coverage index assigned to each intermediate node between the source and the destination, and Nj is the number of neighbors at the hop.

In OptA²PV, to optimize the routing discovery phase, we utilize the PSO algorithm with the same parameters and equations related to the velocity (Vi) and the position (Xi) of the particle as it is done in PSO-C-MA-DSDV. In addition, since the routing performance will degrade if the route maintenance is ignored and is not taken care of, we focus also on improving this phase. The maintenance process starts when a link failure happens.

To reduce the control traffic generated during this phase, in OptA²PV, the node that will detect this problem (V4) must cooperatively and autonomously find another path using RREQ without sending a route error packet (RERR) to the source node (V0) or re-triggering the process of the discovery route, as shown in figure 5.
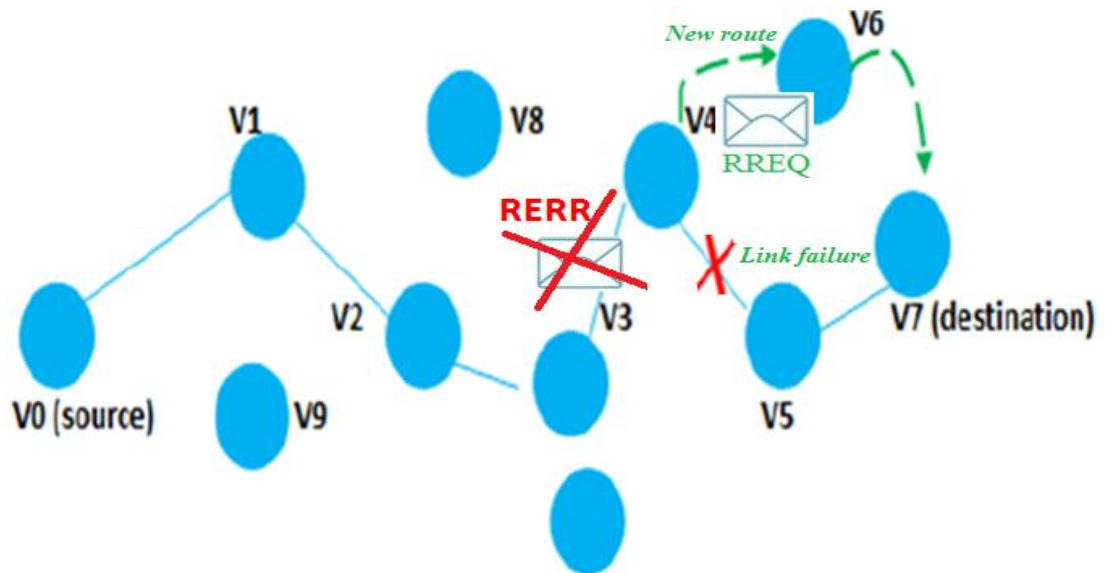
Fig 5. Route maintenance process

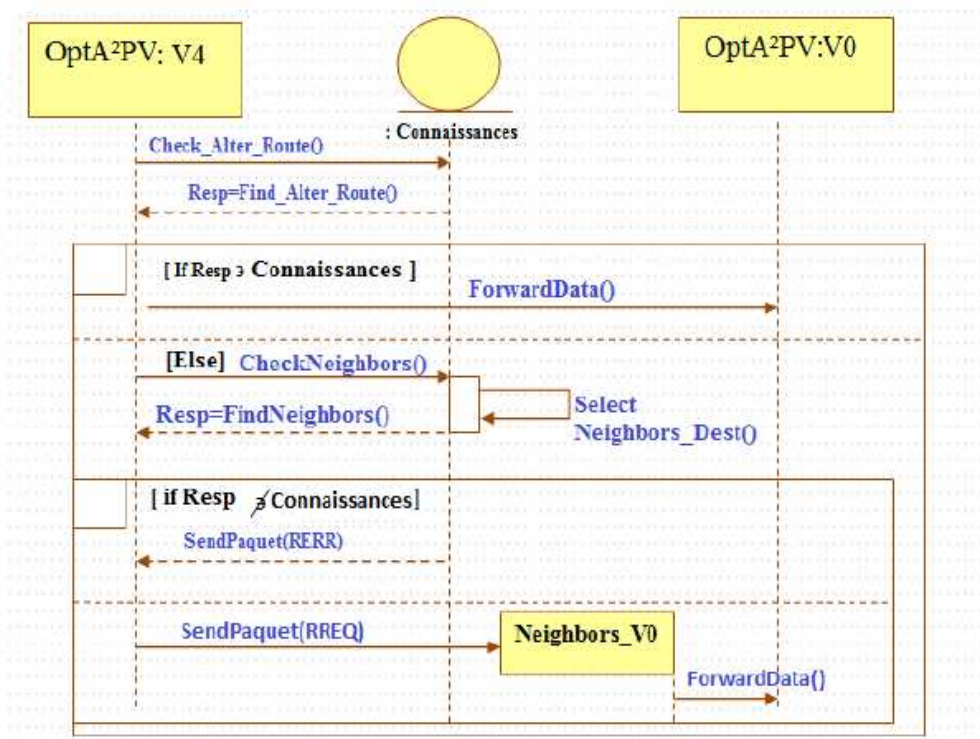The maintenance phase is presented by the sequence diagram illustrated in figure 6.

Fig 6. OptA²PV sequence diagram of finding new route

The principle of the proposed approach OptA²PV can be summarized by figure 7.
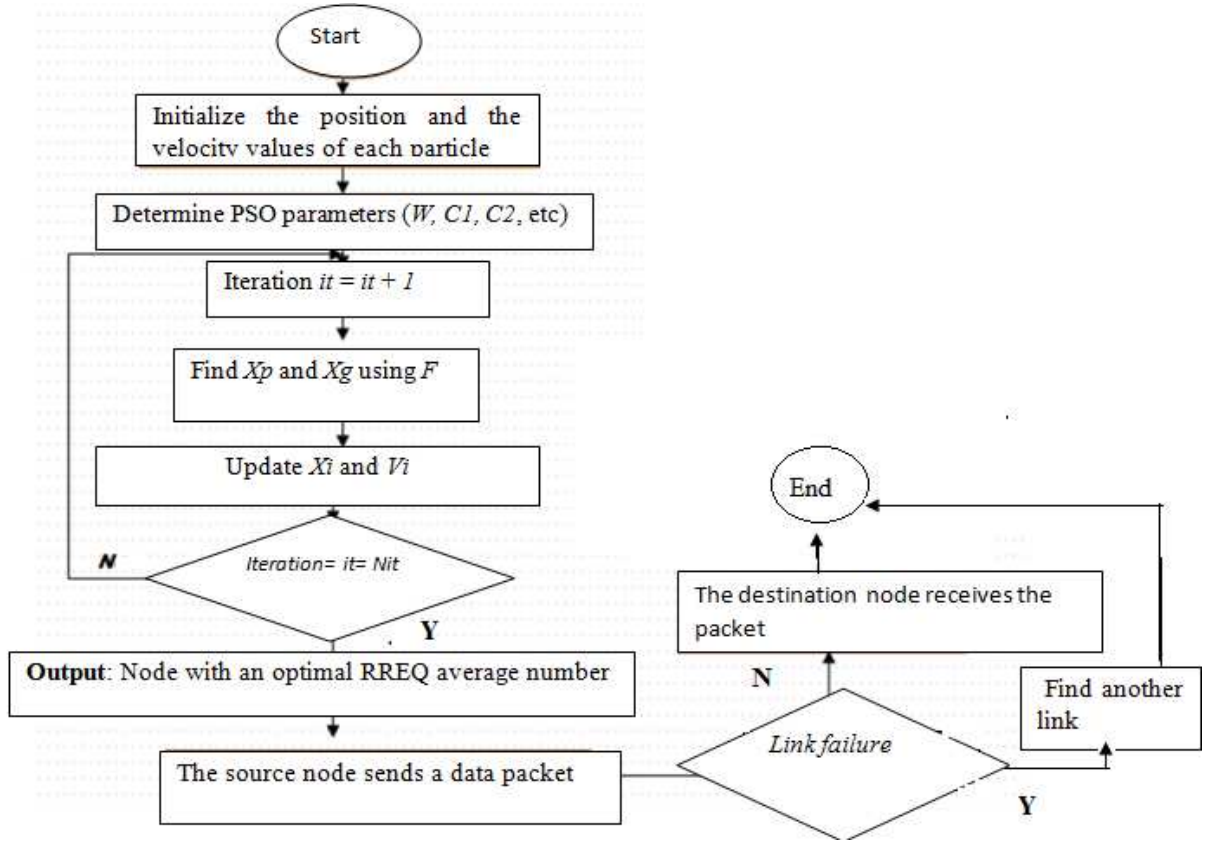

Fig.7. OptA²PV approach

4. EXPERIMENTAL RESULTS

In this section and using the JADE platform [29] and MATLAB [30] tools, we compare the performance of the PSO-C-MA-DSDV and OptA²PV routing approaches. The performance evaluation is done on the basis of a number of simulation tests. We analyze the behavior of these protocols as a function of numerous properties of the network scenario. The speed value is taken between 0 and 30 m/s, and the number of nodes varies from 10 up to 50 moving in a rectangular network area of 1300x700 m².

The Random WayPoint (RWP) mobility model is used also to generate the movement patterns [31]. According to this model, the node moves toward a random destination with a random speed. Then it rests there for a fixed value of time, known as the 'pause time' before choosing a new destination with new speed. All the simulation tests choose 10, 20, 30, 40, and 50 second pause time. Each simulation runs for 50 seconds. At the medium access control layer, the IEEE 802.11p [32] is utilized. For the PSO algorithm, the used parameters are presented in Table 2.

Table 2: PSO parameters

Parameters	Values
Population size (n)	50
Number of iterations (K)	30
c1,c2	2
r1,r2	0.5
w	0.9

To evaluate and compare the performance of the PSO-C-MA-DSDV and OptA²PV protocols, we define two metrics, which are the *average end-to-end delay* for data packets as well as the *rate of dropped packets*.

We first investigate the performance for varying levels of mobility by varying the pause time. A higher value of this time means a lower mobility. After that, we present the simulation results reporting the performance of both protocols as a function of various values of nodes. The results reported in figure 8 show the performance of PSO-C-MA-DSDV and the OptA²PV in terms of average delay and packet loss rate for different levels of mobility. From the obtained results, it is clear that OptA²PV is much more effective than PSO-C-MA-DSDV, in terms of average end-to-end delay and ratio of packet loss. The good performance of the OptA²PV protocol is due to its reactive aspect. In fact, the high mobility of nodes has a greater impact on the performance of this kind of routing protocols.
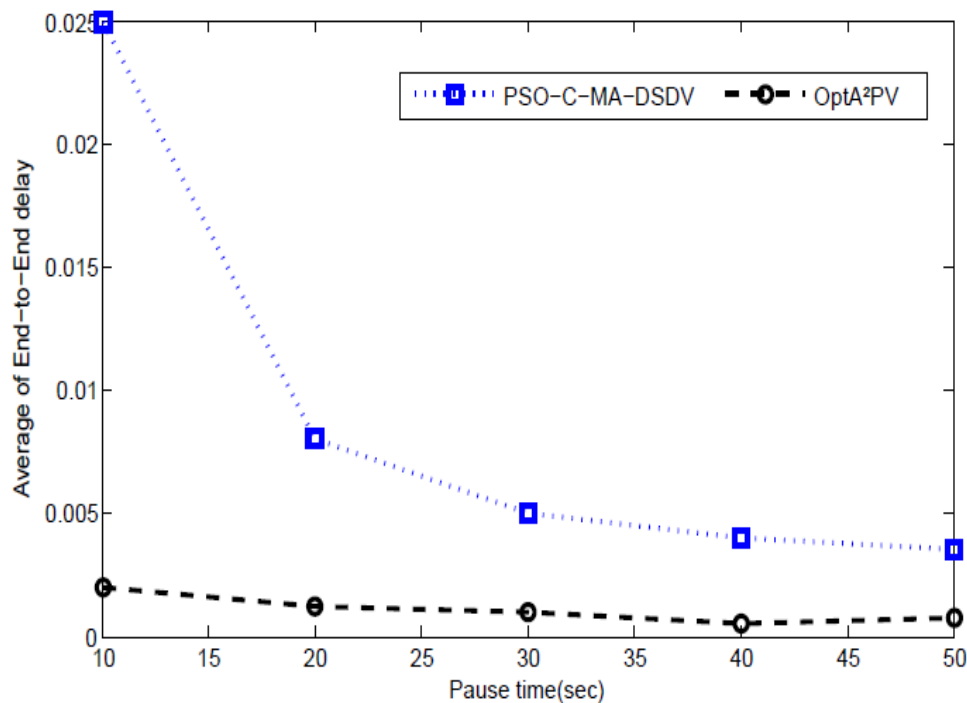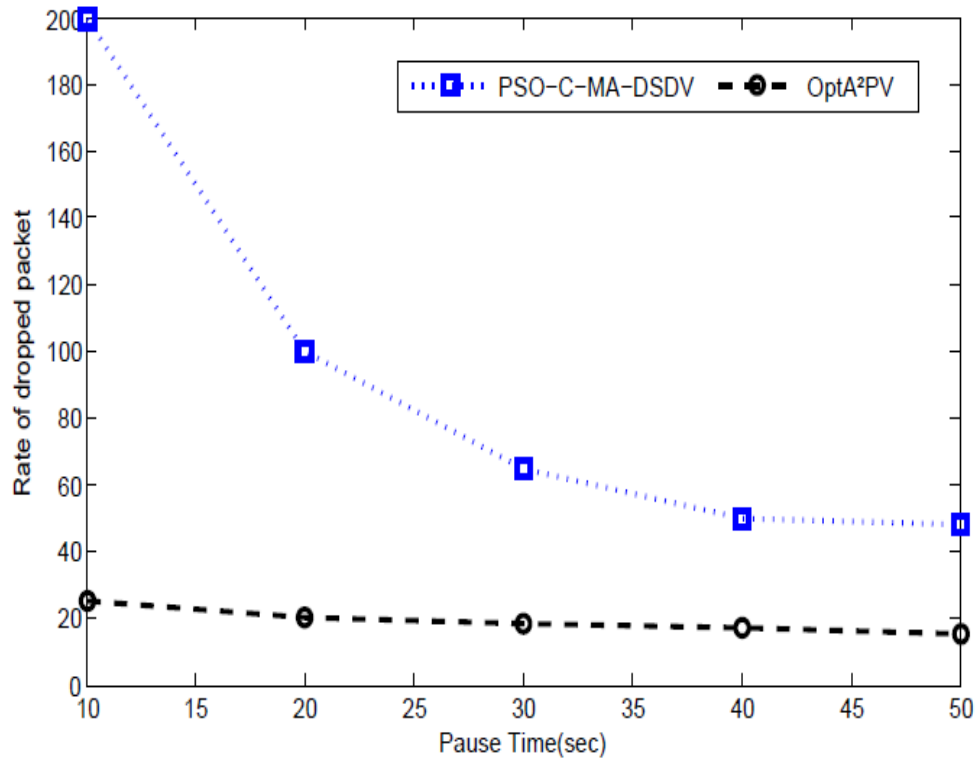
Fig.8.. Average delay and ratio packet loss for different levels of mobility

Obtaining multiple levels of node density is done by raising progressively the number of nodes from 10 to 50 nodes. The obtained results are reported in figure 9 and demonstrate that PSO-C-MA-DSDV performs better than OptA²PV in terms of rate of dropped packets. One thing which is important to consider is that the clustering technique used in PSO-C-MA-DSDV makes it more stable.

The simulation results indicate also that the difference between the performances of both protocols is smaller. However, with the growth of the land at 50 nodes, PSO-C-MA-DSDV is worse than OptA²PV. For various levels of node density, figure 9 proves that the average of end-to-end delay of OptA²PV goes up less fast than that of PSO-C-MA-DSDV.
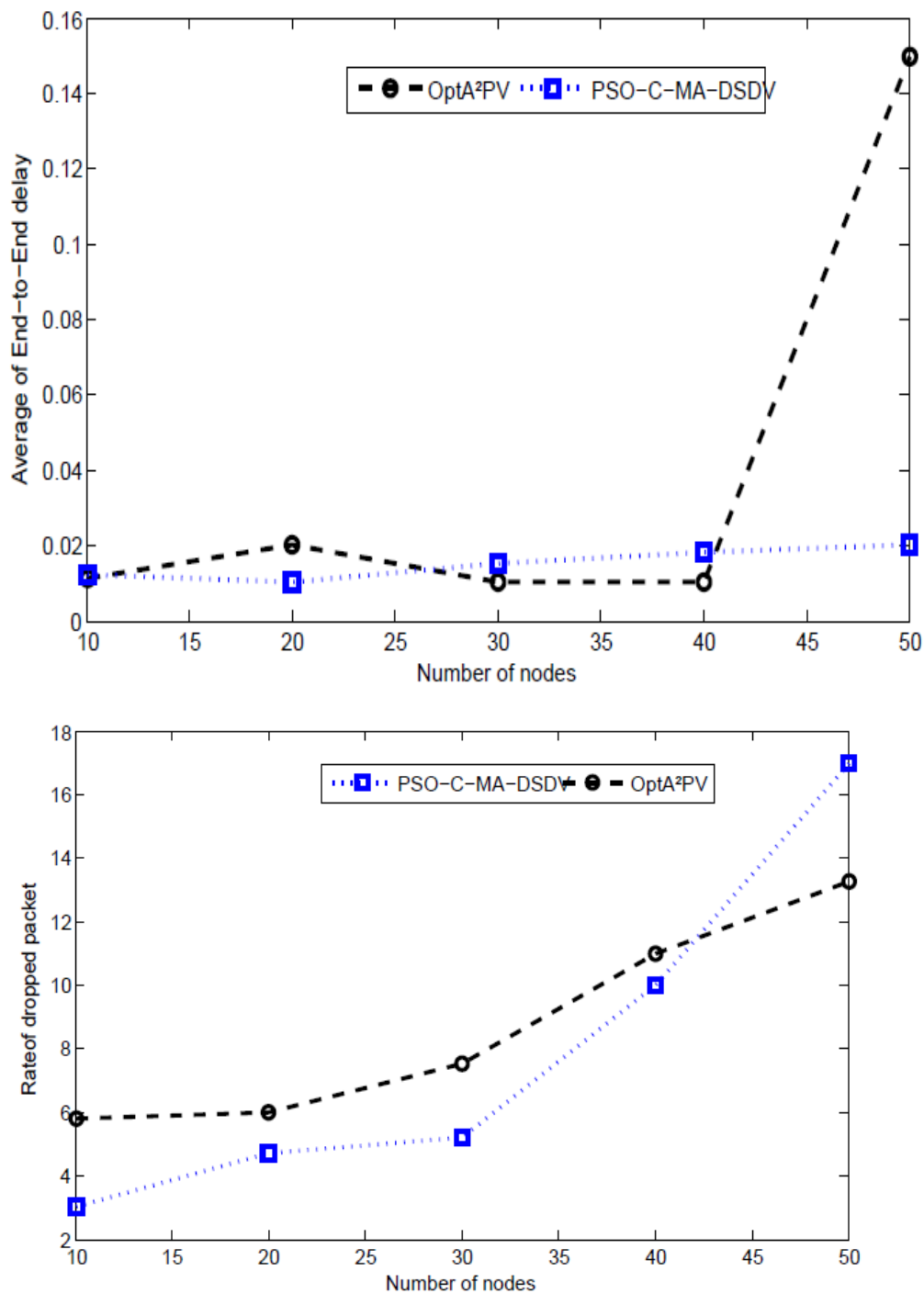
Fig.9. Average delay and ratio packet loss for different levels
of node density

From the obtained simulation result presented by figures 8 and 9, we can conclude that the OptA²PV
protocol has the highest efficiency in terms of packet loss when the density reaches the maximum value

(50 nodes). Nevertheless, PSO-C-MA-DSDV is much more efficient than OptA²PV in terms of end-to-end delay for the same level of node density.

With respect to the pause time, we can observe that varying the level of mobility has a greater impact on the OptA²PV routing performance than PSO-C-MA-DSDV in terms of packet loss rate as well as end-to-end delay. In fact, for higher mobility (lower value of pause time), the obtained results show that OptA²PV loses less packets than PSO-C-MA-DSDV and is faster in terms of end-to-end delay.

5. CONCLUSION

Vehicular networks have particular network features such as dynamic topology caused by the higher mobility of nodes. Consequently, various inter-vehicular communication problems may appear, namely the frequent network fragmentation problem caused by rapidly changeable topology, which can badly influence the performance of data transmission and make routing in VANETs a difficult task. The key challenge is to overcome these problems in order to provide routing approaches with a good performance.

In this context, this work evaluates two routing protocols, which are OptA²PV and the PSO-C-MA-DSDV, and analyses the importance of using the SI for designing routing protocols in VANETs in terms of ratio packet loss and end-to-end delay.

As future work, we envision testing the performance of the analyzed protocols under another SI, which is the genetic algorithm.

6. Declarations

- Funding: The authors declare that the present research is not supported by any one.
- Conflicts of interest/Competing interests: The authors declare no conflict of interest.
- Availability of data and material: The data used to support the findings of this study are included within the article.
- Code availability: The code used to support the findings of this study is included within the article.

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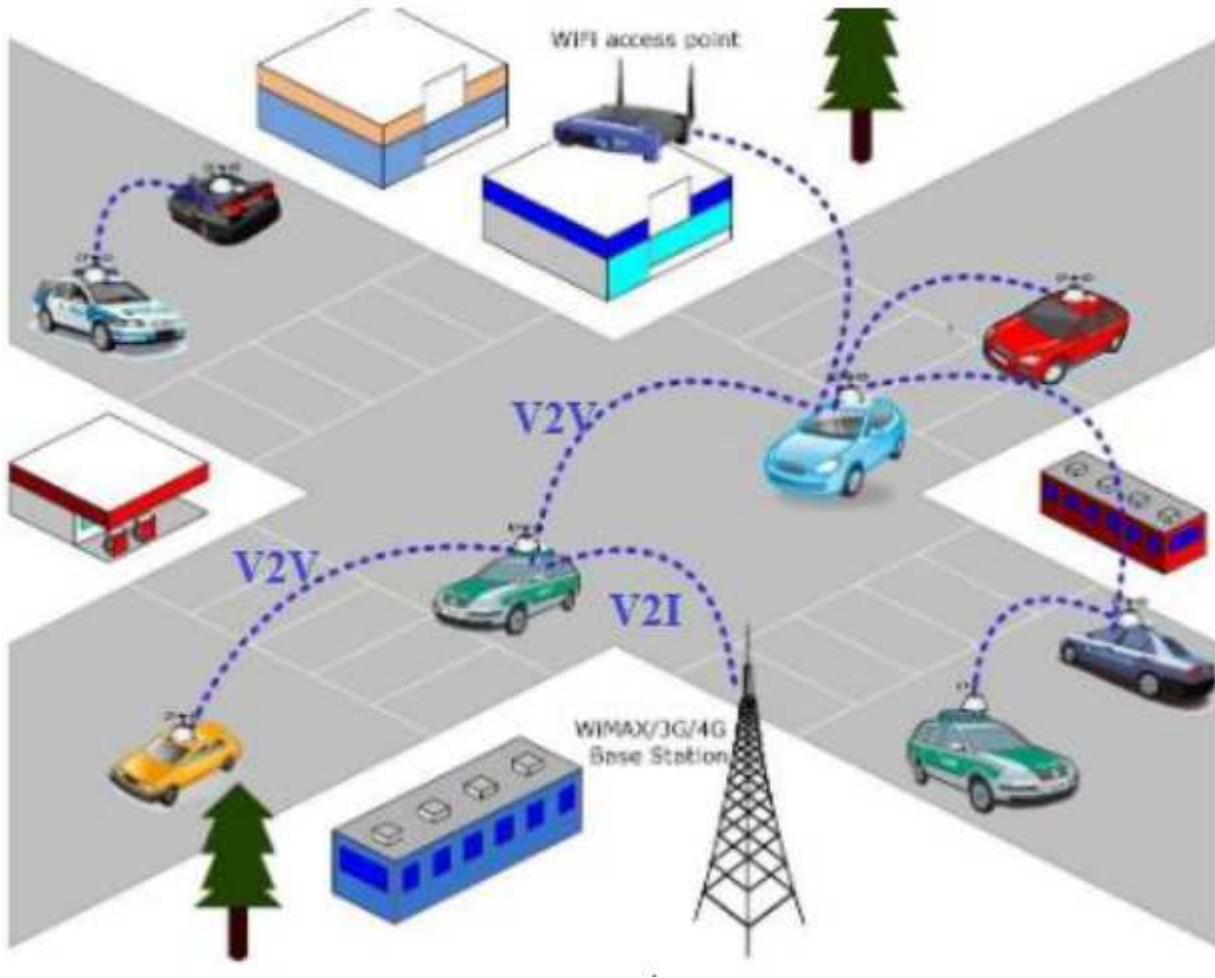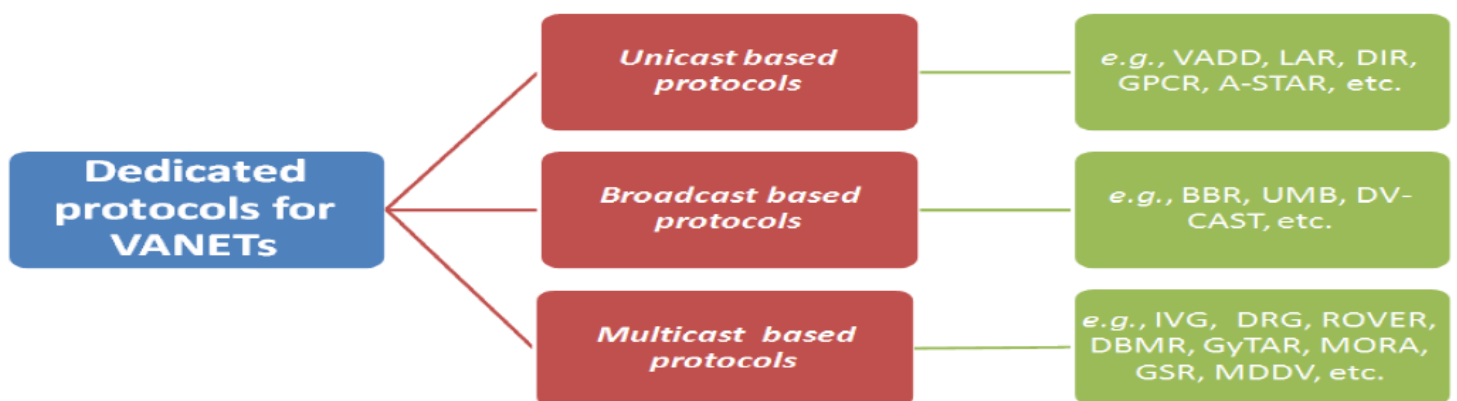
Figures

Figure 1
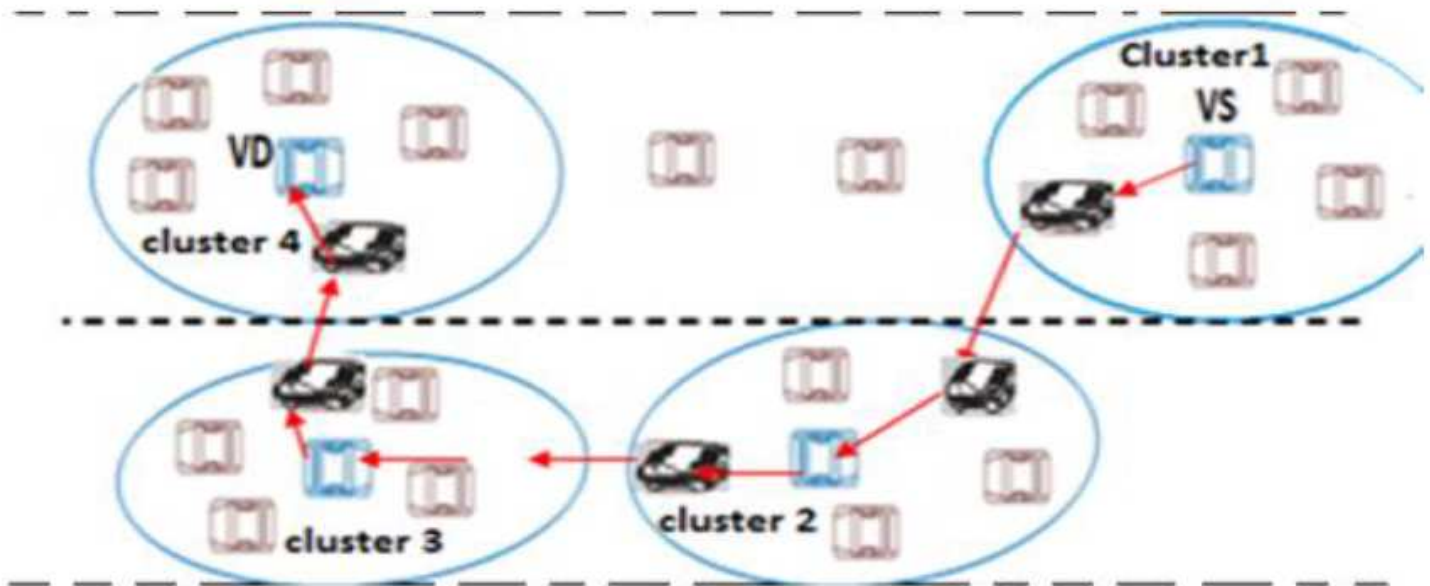
VANETs' architecture

Figure 2

VANET protocols

Figure 3
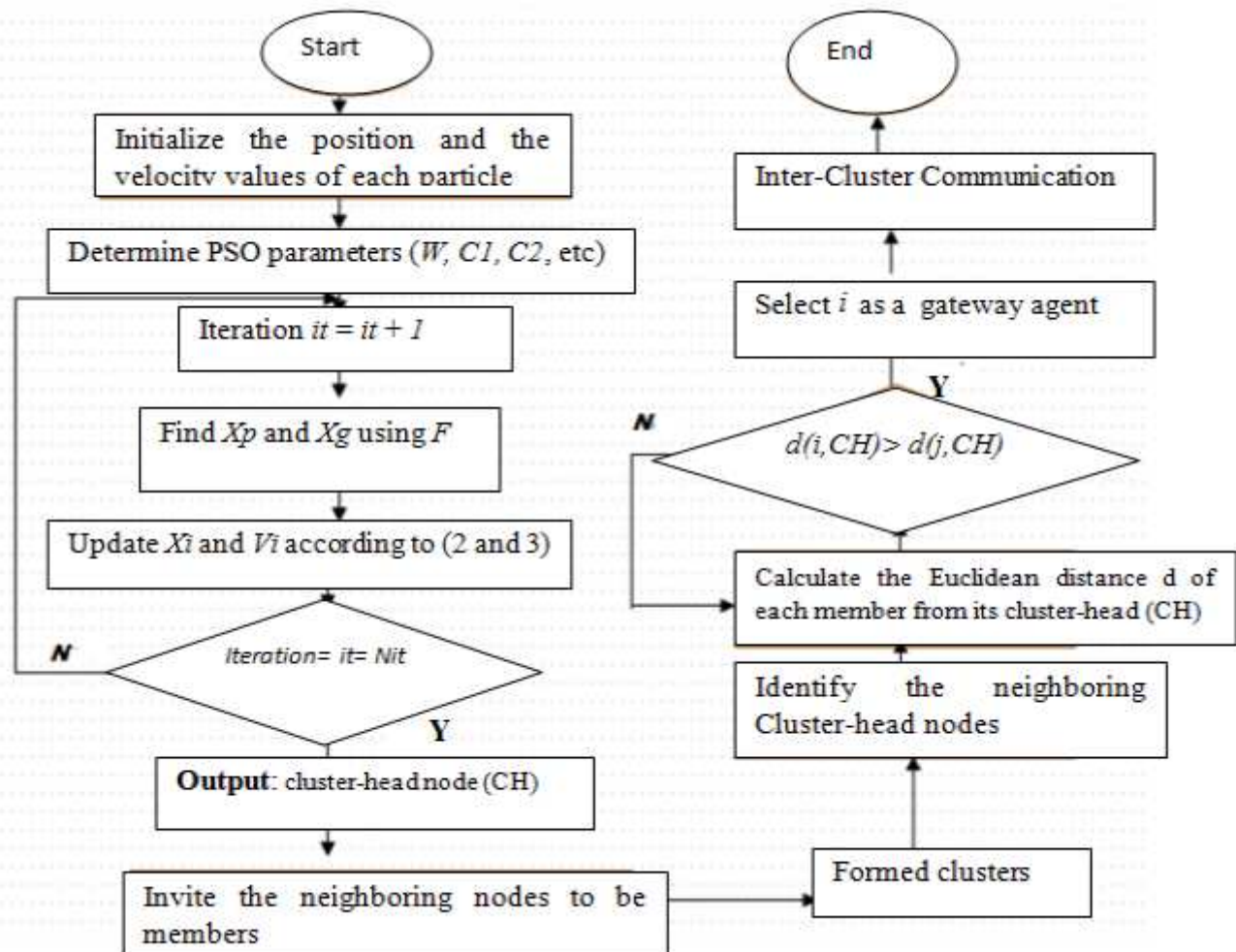
PSO-C-MA-DSDV protocol [13]

Figure 4

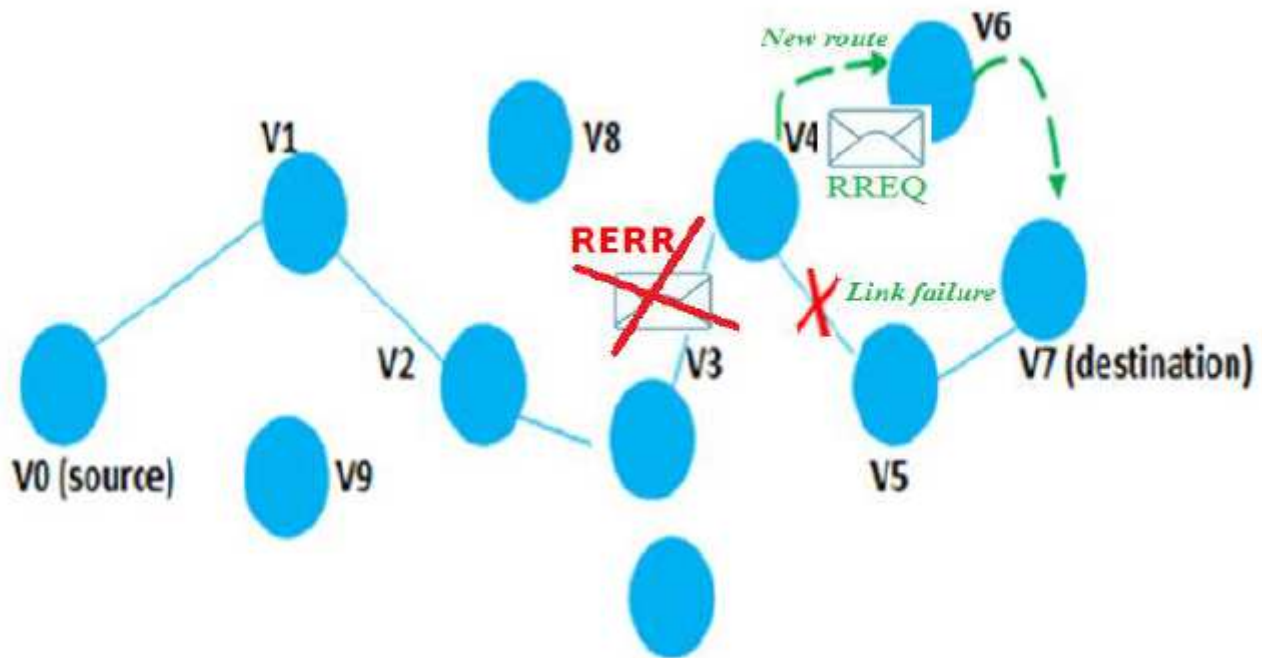Principal PSO-C-MA-DSDV steps

Figure 5
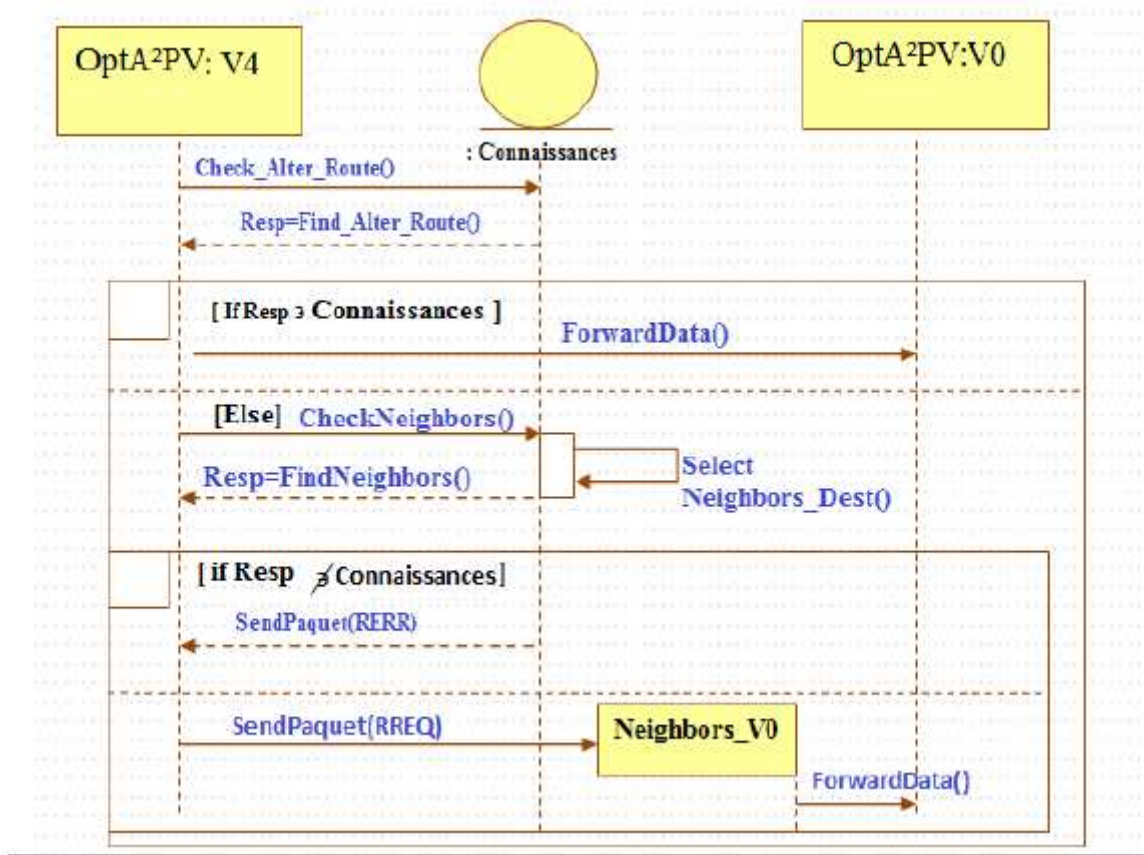
Route maintenance process

Figure 6

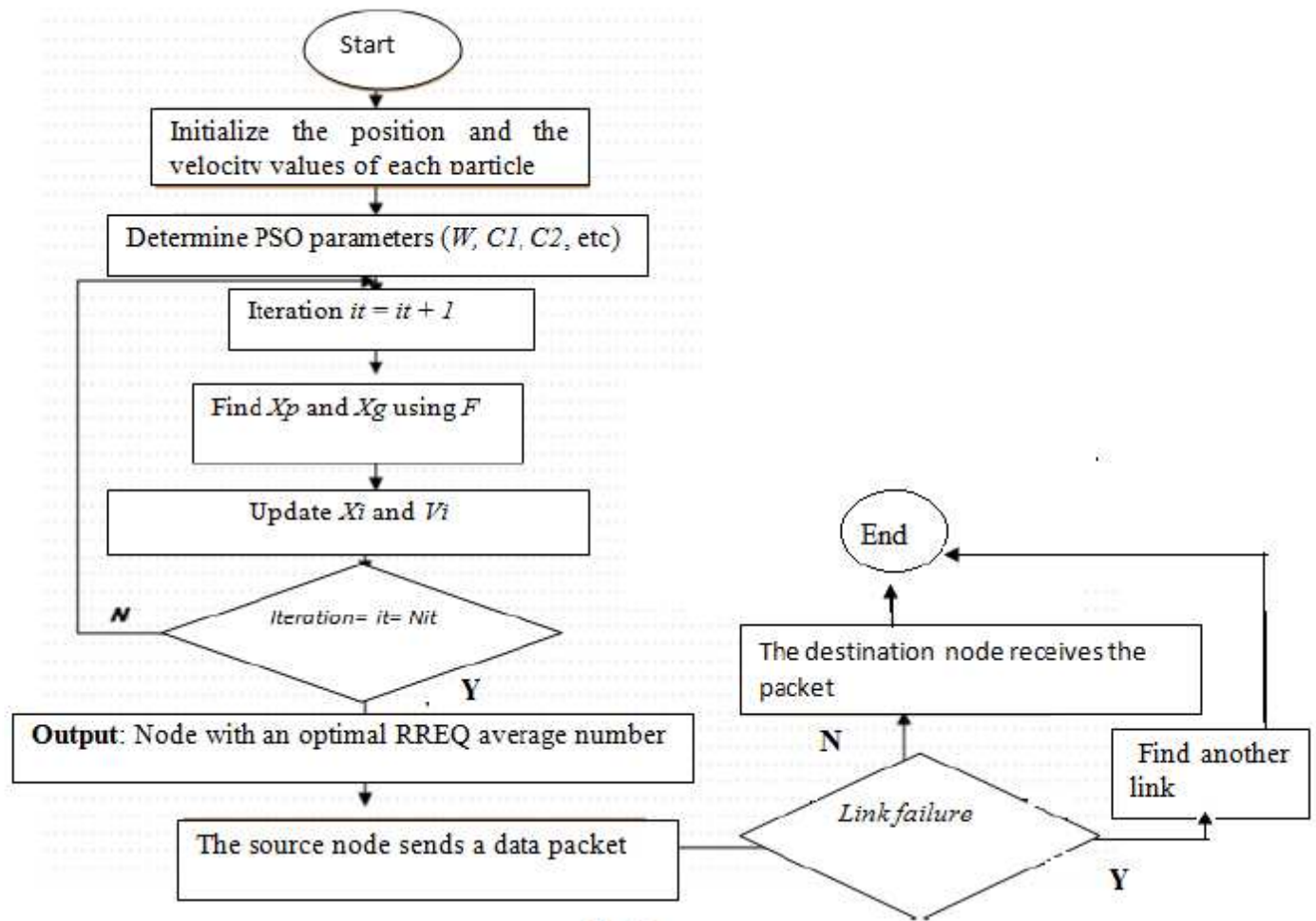OptA²PV sequence diagram of finding new route
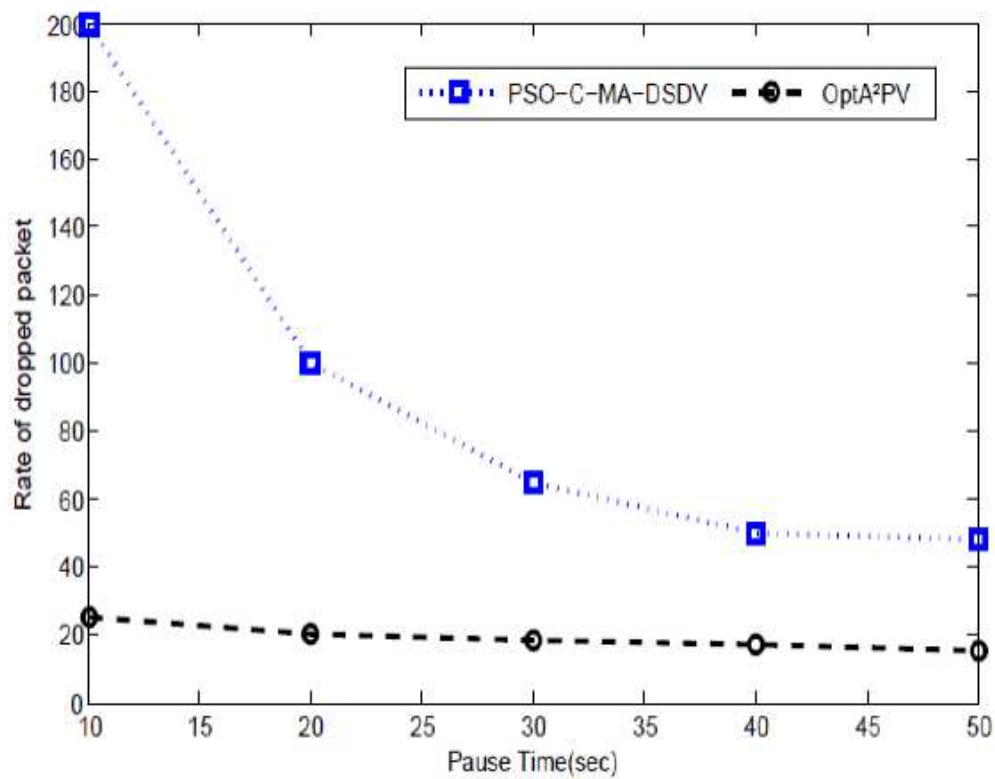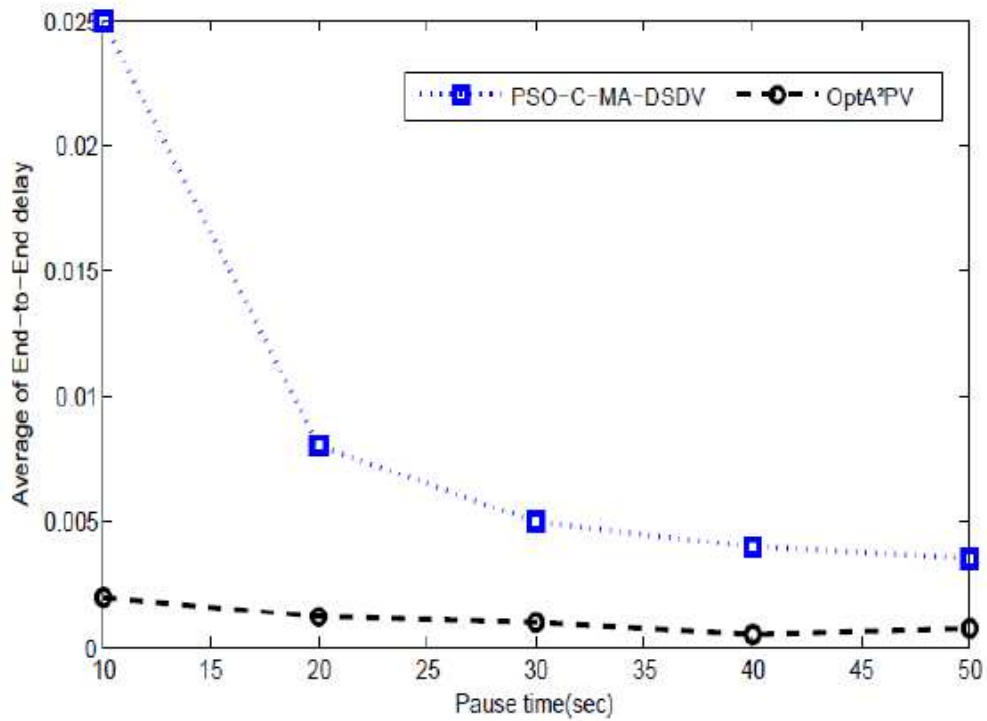
Figure 7

OptA²PV approach

Figure 8

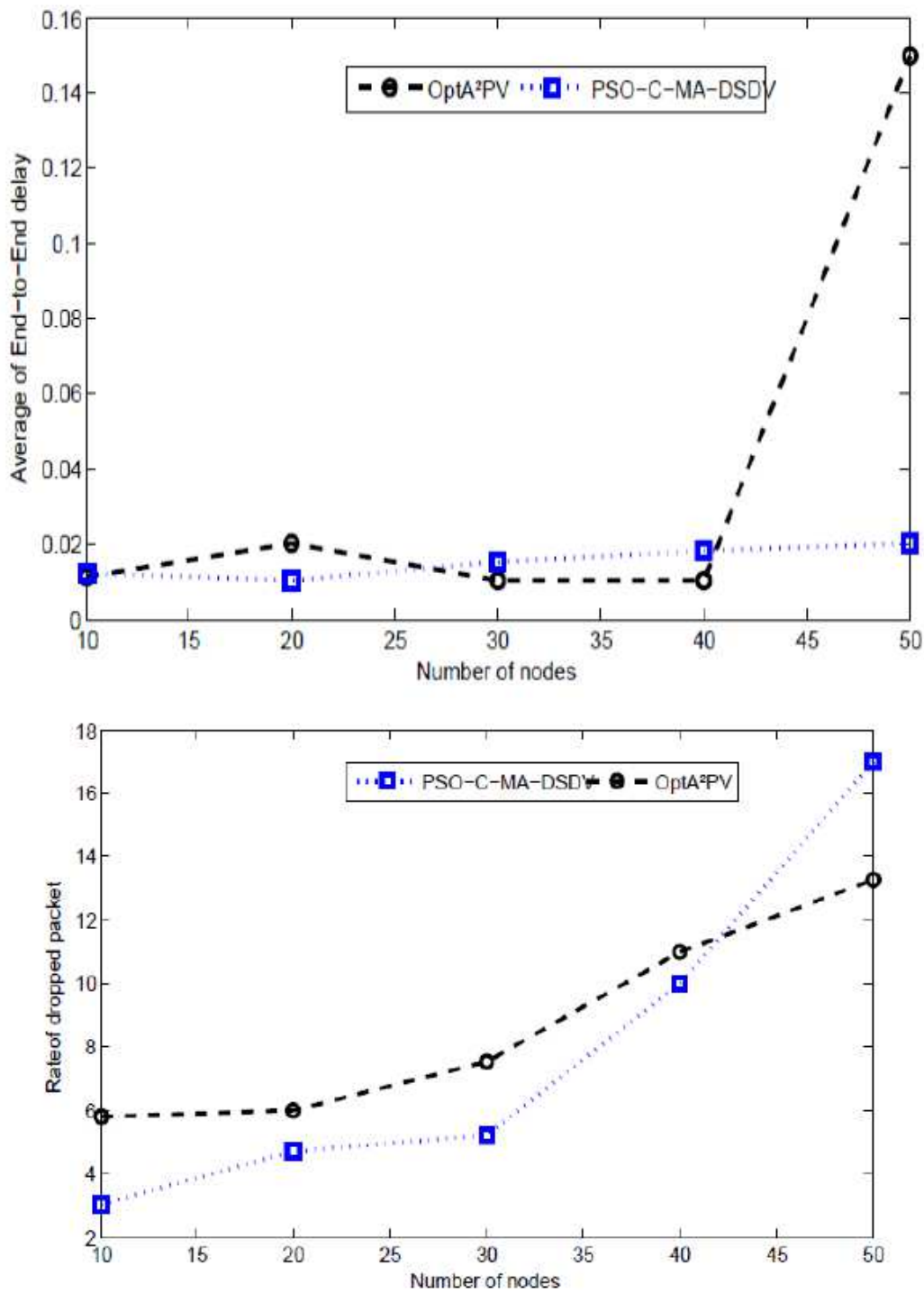Average delay and ratio packet loss for different levels of mobility

Figure 9

Average delay and ratio packet loss for different levels of node density