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Bio-inspired VANET routing optimization: an overview

A taxonomy of notable VANET routing problems, overview, advancement state, and future perspective under the bio-inspired optimization approaches

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Abstract

This paper demonstrates a recapitulated historic evolution further to a future overview of all vehicular ad-hoc network (VANET) routing problems that concern either directly related routing tasks or targeting a set of diverse routing-related techniques with the aid of the bio-inspired approaches. In this lecture, we serialize, in a synchronous observation, the evolution and tendencies of the VANET routing problem's solving simultaneously with the emergence of different classes of nature-based meta-heuristics, by bringing a proposed taxonomy of different major VANET routing problems seen their nature, studied range and metaheuristic types used for their optimization. Then, we follow with a visionary deduction of the other appearing routing issues of VANETs that can be approached or already began to be solved by nature-inspired optimization algorithms. Noting that each spread routing problem is illustrated with notable related works, describing initially realized conventional protocols to vulgarize different routing modules, then detailing bio-inspired protocols for VANET routing to explain the utility of nature-inspired optimization techniques. The motivation of this work came from the lack of a reference classifying the VANET-related routing problems within the notion of nature-inspired optimization. That's further to giving and up-to-date literature on the context for opening out a visionary opinion on the tendencies of either emerging recent bio-inspired optimization approaches or the different metaheuristic-based combinations on specific VANET routing problems.

Keywords VANETs · Swarm-inspired optimization · Parameters tuning · VDTN routing · Evolutionary algorithms · Clustering algorithms

Abbreviations

5G	Fifth generation

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ABC	Artificial bee colony
ACO	Ant colony optimization
ADR	Average delivery rate
AE2ED	Average end-to-end delay
AISs	Artificial immune systems
AODV	Ad-hoc on-demand distance vector
AOMDV	Ad-hoc on-demand multipath distance vector
BCO	Bee colony optimization
BFOA	Bacterial foraging optimization algorithm
CBR	Cluster based routing
CBRP	Cluster based routing protocol
CH	Cluster head
CM	Cluster member
CMs	Cluster members
CN	Cluster node
CNs	Cluster nodes
CSA	Cuckoo search algorithm
DE	Differential evolution
DSDV	Destination sequenced distance vector
DSR	Dynamic source routing
DTN	Delay-tolerant network
E2ED	End-to-end delay
EA	Evolutionary algorithm
ED	Euclidean distance
GA	Genetic algorithm
GPS	Geographic positioning system
GPCR	Greedy perimeter coordinator routing
GPSR	Greedy perimeter stateless routing
Greedy-V2V	Greedy vehicle-to-vehicle
GRP	Geography-based routing protocol
GSR	Geographic source routing
IARP	IntrA-routing protocol
ID	IDentifier
IERP	IntEr-routing protocol
IoT	Internet-of-things
IRC	Inter-roadside communication
MANETs	Mobile ad-hoc networks
MAS	Multi-agent system
MOPs	Multi-objective optimization problems
MRP	Multicast routing problem
NRL	Normalized routing load
NS2	Network simulator
OBU	On-board unit
OLSR	Optimized link state routing
PDR	Packet delivery ratio
PSO	Particle swarm optimization
QoS	Quality of service
RREQ	Route REQuest
RSSI	Received signal strength indicator

RSU	Road side unit
SA	Simulated annealing
SCF	Store-carry-and-forward
TCP	Transmission control protocol
TS	Tabu search
TSP	Travel salesman problem
TTL	Time-to-live
UAV	Unmanned aerial vehicle
V2C	Vehicle-to-cloud
V2I	Vehicle-to-infrastructure
V2R	Vehicle-to-roadside
V2U	Vehicle-to-UAV
V2V	Vehicle-to-vehicle
VCC	Vehicular cloud computing
VDTN	Vehicular delay-tolerant network
VNI	Virtual navigation interface
VRP	Vehicle routing problem
ZBR	Zone based routing
ZRP	Zone routing protocol
WANETs	Wireless ad-hoc networks
WSNs	Wireless sensor networks

1 Introduction

Routing problem in VANET refers to the different operational tasks that have impact on improving the quality of data dissemination between sender and receiver (requester) nodes in term of numerous criteria which are referred to QoS metrics such as forwarding delay (end-to-end delay), ratio of data packet delivery among others. Such tasks refer to defining the behavior of routing strategies in establishing routing paths to gather the best possible conditions for data dissemination under permanent mobility of VANET nodes which constitutes the main challenge of VANETs.

The nature-inspired algorithms, taking a huge part in VANETs (Moustafa et al. 2009) routing has evolved last decade as an evolution to what started in MANETs (Dorronsoro et al. 2014) market by the efficiency of the classic bio-meta-heuristics like the GA (Holland 1975), PSO (Kennedy and Eberhart 1995) ABC (Karaboga 2005), which furnished a profitable basis for ad-hoc network routing and particularly in VANETs. Such approaches treated earlier the static wireless networks, classic routing-related problematic issues such as the VRP (Golden et al. 2008) where it worked successfully and pulled to think of propagating these bio-techniques for mobile networks. The variety of meta-heuristics whether bio-inspired or not and the different classes that categorize the VANETs from topology-based, geography-based and also cluster-based protocols (Qureshi et al. 2015) has opened a large research area to target the routing level of VANETs in different ways: routing task modification, protocol layers, protocol parameters and so on.

Particular sorts of contributions target more generic purposes, including routing among other things, the case of k-cluster problem (Aloise et al. 2009; Arthur and Vassilvitskii 2007) in vehicular clustering algorithms which can be approached to enhance VANET bio-routing, and few other contexts that will be detailed in this paper. Other methodologies for improving routing in VANETs concentrate on specific routing functionalities in most VANET routing protocols such as the route discovery, route maintenance, beaconing (Ghafoor et al. 2013), collision avoidance (Thenmozhi and Govindarajan 2017), and among others, producing a sort of partially bio-inspired algorithms that consists of completing or replacing less performing tasks with intelligent nature-inspired optimization techniques.

Our survey opens a window that exposes the latest advancements in bio-inspired VANET routing as a hypothesis to anticipate the emerging research topics that can deepen more to contribute for routing quality increasingly with the vulgarization of nature-inspired optimization algorithms last decade in the framework of np-hard problems solving. This paper deducts which routing problems are more or less saturated after discussing both distribution and advancement of bio-inspired routing realizations.

The organizational flowchart presented in Fig. 1 demonstrates the evolution of this survey:

As drawn in the presented organizational flowchart, this paper is splatted the way to form the following skeleton pursuing the opening section: Sects. 2 and 4 give an observation about the bio-inspired approaches and their utilization on VANET routing. Sections 4 and 5 expose our suggested classification of VANET-based routing problems ranged separately into classic and emerging categories by considering their chronological evolution shown in realized contributions and the advancement stated of implemented metaheuristics in each category, and illustrating with notable contributions in the context. Section 6 gives a description of emerging nature-inspired metaheuristics particularly the swarm-inspired optimization algorithms (Yang 2012) that began to be concerned with VANET routing optimization. Finally, Sect. 7 concludes with a proposed taxonomy of different types of bio-inspired optimization techniques used to solve routing issues in VANETs.

2 Overview of the bio-inspired approaches

The bio-inspired approaches, also recognized as metaphor and nature-based metaheuristics, are optimization methods for solving hard, np-hard and np-complete optimization problems (Woeginger 2003). Hard optimization problems are approached to problems that cannot be solved to perfection since they treat huge amount of candidate solutions what complicates attaining global optimum in a reasonable time. Np-hard problems are hard problems for which there is no known polynomial algorithm, in order that the time to find a solution grows exponentially with problem dimension, hence finding the optimum solution becomes impossible in case of substantial solution populations.

Bio-inspired approaches or metaheuristics are problem-independent techniques inspired from either natural, biological or human phenomena in real life contrary to ordinary metaheuristics. Such approaches treat several kinds of np-hard optimization problems since they don't consider any assumption about treated problems. Metaheuristics have the ability to approach near optimum solution in an acceptable time using their intelligent stochastic search methods. Noting that every metaheuristic has tendencies towards particular optimization problems in which they perform better comparing to other problems.

Almost all metaheuristics combine two stochastic search properties namely, intensification and diversification. The former forces exploitation of search space solutions by small subareas, that's by mixing the values of random candidate solutions as an initial step and repeating the process for a certain number of times on the best-resulted candidate solutions, the case of GA's selection and crossover operator, tracking the near-best local optima. The

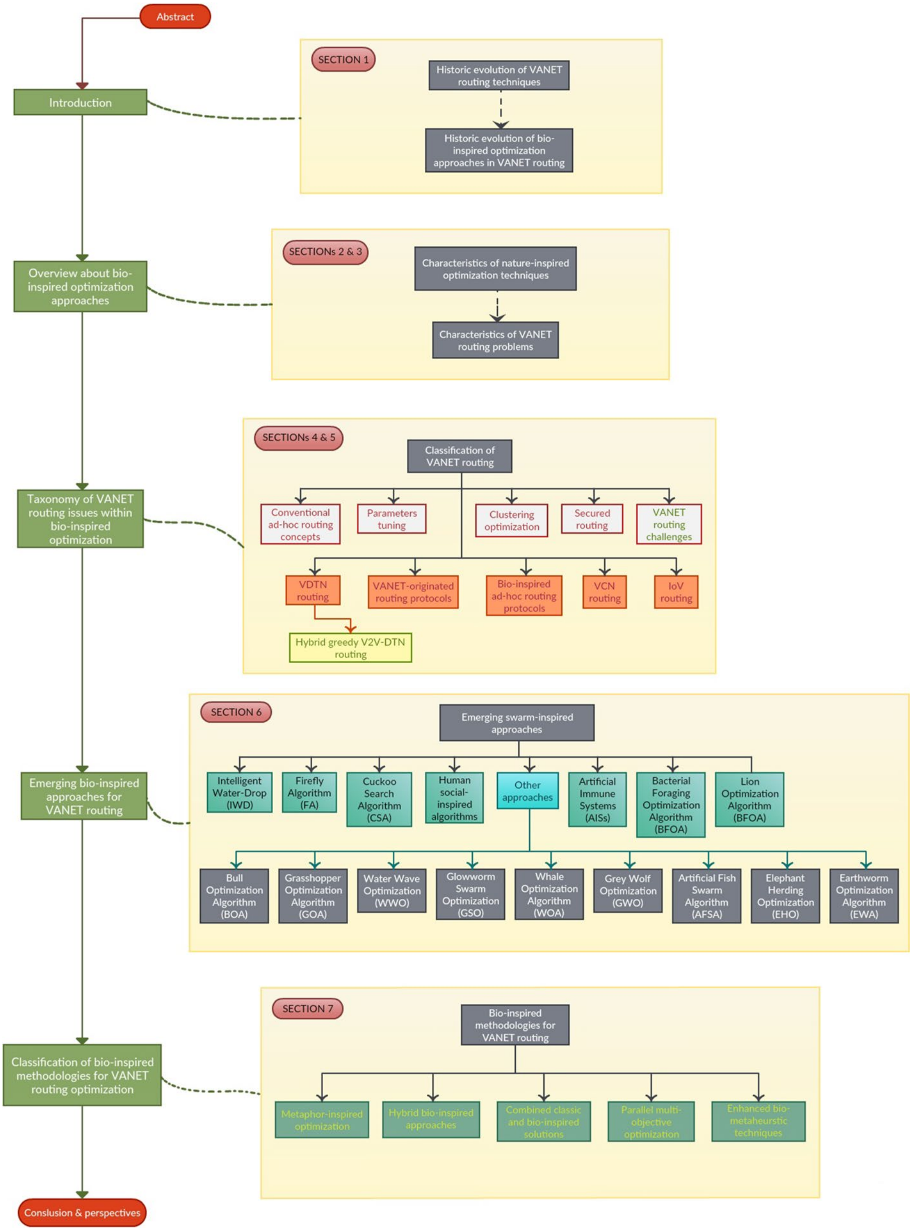

Fig. 1 Organizational flowchart of the manuscript

latter forces exploration by treating larger search areas by involving randomly faraway candidate values, combining the best-local solutions of distant subareas, seeking better solutions, the case of GA's mutation operator. This phase is indispensable for extracting global-best solution among collected local optima and avoiding local search saturation. The qualitative adjusted balance between these two properties is what characterizes the profitability of any metaheuristic. That's to say, the most harmonized combination the metaheuristic adjusts, the better performances it produces depending also on the hard problems it treats.

3 Nature-based optimization algorithms in the framework of vehicular ad-hoc routing

Every np-complete problem can be solved with exhaustive search algorithms. But, in the case when search space size is huge, the rising complexity of algorithmic treatments can entail uncontrollable resolution time, which doesn't constitute the ideal solution. That's the case with numerous hard optimization problems like the TSP (Matai et al. 2010), Job-Shop Scheduling problem (Binitha and Sathya 2012). VANET routing has been proved as an np-hard problem in several cases, namely:

- Holding a large number of mobile nodes (vehicles) to produce the best path can't be resolved in a polynomial time when numerous tens or even hundreds of quickly and randomly moving vehicles are involved in each path's hops selection.
- Finding the best combination of routing parameters of a given VANET protocol for better routing performances, which can't be resolved with polynomial optimization algorithms seen the number of involved parameters which is converged to exponential complexity calculation.
- Optimizing the number of clusters and CH changes in the framework of CBR in VANETs (Dhawale et al. 2016) is considered an np-hard problem in case of a large number of clusters and crowded clusters with a high number of vehicles in each cluster.
- Every VANET routing problem's np-hardness will be explained well next in this paper.

Started to gain breadth through VANET routing optimization during the middle of 2000s, when it took inspiration from MANETs (Corson and Macker 1999), bio-inspired metaheuristics are considered effective optimization algorithms to solve ad-hoc routing weaknesses since the first idea was to overpower a large number of mobile nodes for more consistent and reliable routing paths with reduced dissemination delays and limited packet losses. We expose in this survey the commonly used nature-based metaheuristics either single-solution (Talbi 2009) or population-based (Boussaïd et al. 2013), (Ali and Hassanien 2016) used to optimize VANET routing.

We illustrate the swarm-inspired routing imitation with the ant colony example in Fig. 2 which have been used as one of the earliest bio-inspired optimization techniques for VANET routing assistance; the intelligence of ants in tracing adaptively paths from their nest to food sources has constituted an inspiration to be approached as request packets for discovering optimized routing paths in order to link data source and destination vehicles with consideration to nodes mobility:

Second example, we demonstrate the EA optimization with the stochastic genetic recombination technique of GA which includes selection, crossover and mutation. The GA flowchart is illustrated in Fig. 3:

As the reference of EAs, GA have been used as a stochastic approach by taking advantage of the genetic recombination operators, namely crossover (Fig. 4) and mutation, for generating optimized routing paths, where chromosomes and genomes are

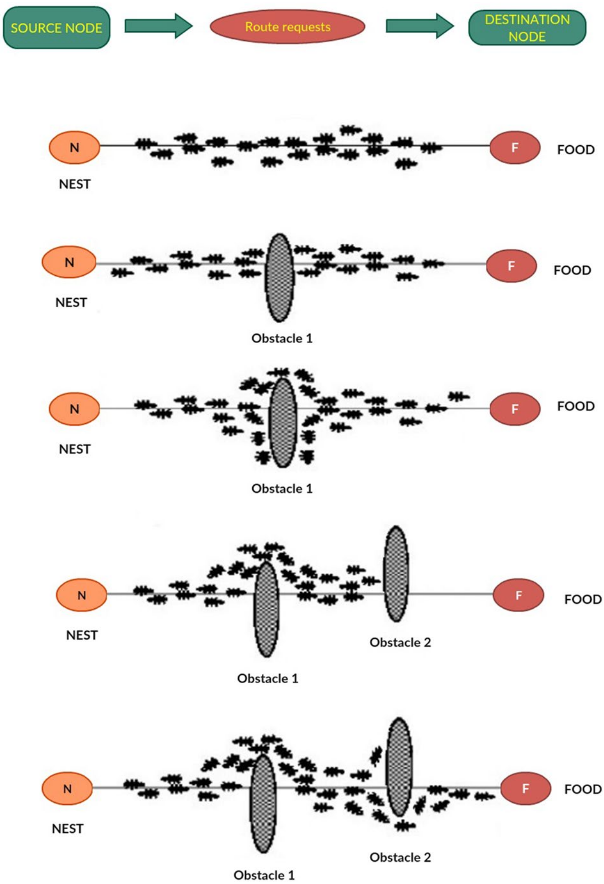

Fig. 2 Illustration of Ant swarm in VANET routing

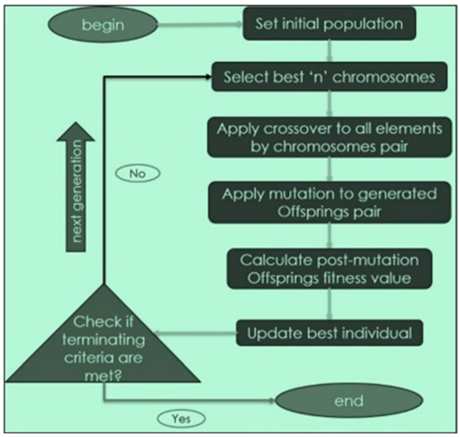

Fig. 3 GA flowchart

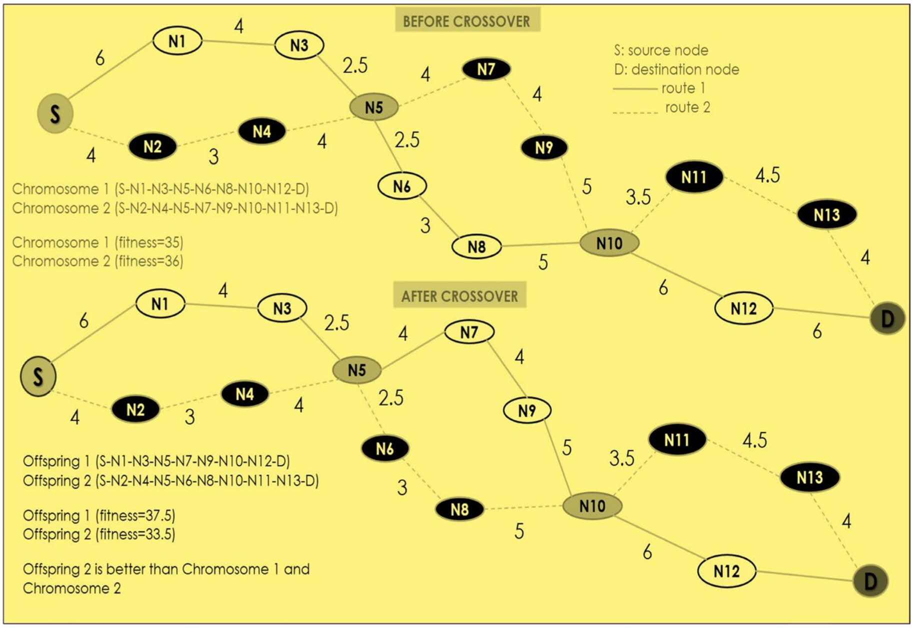

Fig. 4 Implementation of GA crossover in routing path optimization

approached to routing paths and path's nodes respectively. Every chromosome's quality is evaluated using fitness formula.

Further both EA-based and swarm-based optimization solutions on the basis of different existing bio-inspired metaheuristics have been proposed to overcome diverse VANET routing problems, the next sections spread in details the literature review in this context.

4 Majors treated VANET routing problems using the bio-inspired approaches

Numerous surveys discussed the implication of nature-inspired metaheuristics in VANET routing optimization such as the taxonomy realized by Bitam et al. (2014) which gives an overview of notable bio-inspired metaheuristics introduced in VANET routing optimization, their evolution, and the major related realizations. In Zhang et al. (2017); Cañas et al. (2017), the notable ACO-inspired (Dorigo 1992) routing protocols for MANETs are specified as well.

We tidied the globality of papers, dissertations, and conferences that came up with enhancing solutions for the most treated vehicular routing problems using bio-inspired approaches. Each routing problem is detailed, by citing its: evolution in ad-hoc networks, current state of research advances, kind of bio-inspired metaheuristics used, related notable both classic and nature-inspired contributions further to future perspective, right in the below section.

4.1 Concepts of conventional ad-hoc routing

This topic is considered the earliest VANET bio-routing area on which nature-inspired approaches and metaheuristics have been implemented on the basis of relaying on the concepts of classic ad-hoc routing protocols like AODV (Perkins and Royer 1999), DSR (Johnson et al. 2001) protocols among others to conceive bio-inspired VANET routing schemes.

The routing in that kind of conventional schemes belongs majorly to topology-based routing category figuring reactive, proactive and hybrid routing, despite few protocols that are geography-based such as GSR (Lochert et al. 2003). Such routing concepts consist of applying stochastic approaches on ad-hoc based protocols in order to be adapted for disseminating data packets under VANET mobility environment considering vehicle characteristics' differences to mobile devices such as GPS, unbounded energy resources and large transmission range (Chouhan et al. 2016). In this research branch, classic ad-hoc routing protocols are reinforced by one or multiple metaheuristics in a specific or many routing tasks like beaconing, route discovery or route repair processes, where the behaviors modelled bio-inspired approaches are integrated in the optimized routing tasks of the protocol. Generally, the integration of bio-inspired metaheuristics seeks optimizing specific routing tasks of such classic routing protocols in order to be adapted for VANET routing.

Numerous bio-inspired routing protocols based on classic ad-hoc routing concepts have been tested out with slight modifications on vehicular mobility scenarios as a first discovering step to develop VANET-based protocols and gave satisfying performances in terms of QoS returns. A second step was led by a more implied bio-metaheuristics algorithm with a relatively limited number of functionalities of a given classic ad-hoc protocol, the idea is to minus more the roles of the latter for a more generic bio-inspired routing algorithm. We expose below a few examples of bio-inspired modified ad-hoc routing protocols for VANETs:

A typical source routing contribution is the G-NET protocol suggested by Wille et al. (2016) a source routing-based route discovery similar to DSR and a GA-inspired route maintenance and optimization. GA's initial population is composed of the collected route from route discovery phase codified into chromosome which is a set of genomes representing route hops. Route fitness calculates route latency which determines the quality of population's solutions. Latency shows the adaptation degree of individuals to the environment. For G-NET, the tournament selection is applied, then a one-point crossover operator, while the mutation operator is performed in some parents and offsprings to keep alternative routes in route cache. A route repairing treatment comes after the mutation operator to eliminate the reappearing genome sequences within the same route to avoid loops. G-NET is compared to both AODV and DSR on two performance indicators, namely the ADR and routing overload using VanetMobiSim (Eurocom 2007) and NS2 (nsnam web pages 2018).

Garg and Wadhwa (2016) suggested a GA-improved hop-by-hop topology-based protocol based on AODV concepts (G-AODV), a secure backup on-demand routing algorithm which seeks enhancing route stability and reliability of participating nodes. G-AODV minimizes RREQs flooding to reduce bandwidth wastage, and implements GA on the destination node to extract three delay-optimized paths from multiple established routes between the source and destination after route discovery phase. The GA process (Fig. 5) starts with regrouping the request paths which represent the initial

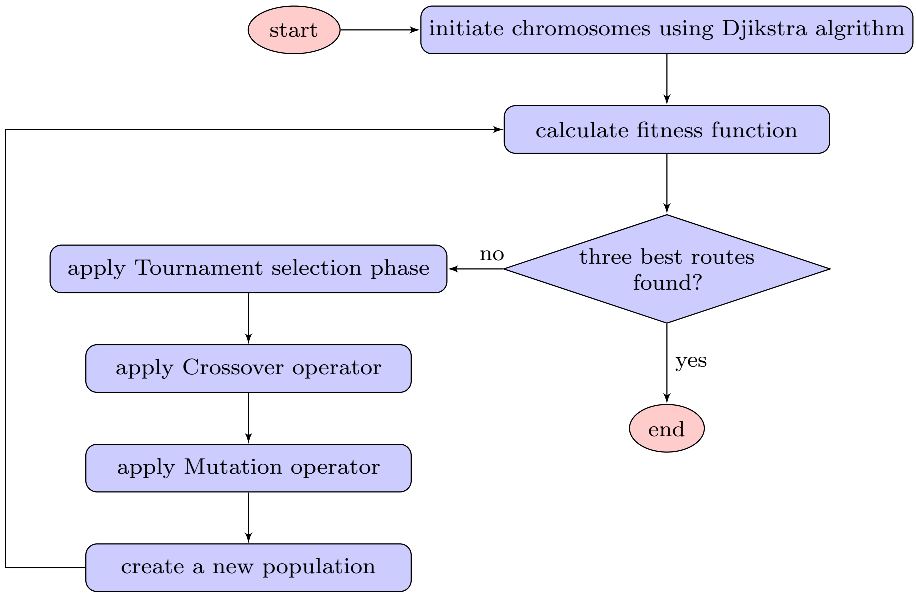

Fig. 5 RREQ phase of G-AODV protocol

population's chromosomes, then tournament selection and genetic operators are proceeded to improve the existing candidate solutions stochastically. a two-point crossover is thrown, if possible, whereas mutation operator varies those local-best evaluated chromosomes to reach better faraway solutions. The fitness considers the bandwidth and cost as parameters.

Rana et al. (2013) suggested the Mobility Aware Zone based ACO Routing for VANET (MAZACORNET) for VANETs, an ACO-inspired ZBR protocol conceived to establish numerous routes to a given destination following IARP and IERP. To reinforce route link scalability, uses GPS is to calculate vehicles' velocity and position. For each link, ACO adjusts a deposited pheromone concentration depending on link's scalability value, which quantifies its quality. Different evaporation rates are set depending on links' longevity. MAZACORNET uses concept internal and external ants for intra-zone and inter-zone routing respectively. MAZACORNET follows route repair principle of ZRP (Haas et al. 2002) with cyclic updates for internal breaks, while for outer zone interruptions the broken links are signaled to source node by the mean of notification ants. Compared to AODV, GPSR (Karp and Kung 2000) and AOMDV (Marina and Das 2002), MAZACORNET displayed less forwarding time and better PDR under different network density levels.

Azzoug and Boukra (2019) proposed a Reactive Routing Protocol based on the Bull Optimization Algorithm (BVRRP), a multipath source routing algorithm which seeks enhancing the quality of routing paths for both regular and recovery routing separately. BVRRP establishes a controlled flooding of RREQs in late stages of discovery phase and uses an enhanced EA named the Bull Optimization Algorithm (BOA) (Findik 2015) on the collected discovery request paths on the destination where request routes are the chromosomes of the BOA's initial population. The BOA procedure is based on the information collected from the discovery phase aided with an adaptive beaconing. The latter has a dynamic hello frequency based on the node's level of participation in routing. Two fitness evaluation formula are set in the BOA to extract one main path for post-discovery routing and few recovery paths for post-route break routing. BVRRP adopts an enhanced route break prediction of the proposed in Multipath DSR (Shrivastava and Motwani 2014) with the exploitation of both hello and special prediction notifiers (PRED) for tracking more accurate RSSI values of established path's hops, that's moreover to notifying the close neighbourhood area of this path to reduce the number of expiring close route discoveries.

To conclude, Yahiabadi et al. (2019) proposed a hybrid routing protocol (TIHOO) based on AODV principles and CSA metaheuristic (Yang and Deb 2009) used in combination with fuzzy logic to shorten the route discovery operation and reduce overheads consequently by performing two steps namely, controlled request broadcasting and CSA-based route optimization phase. The former step seeks reducing the number of flooded requests using fuzzy logic which specifies the link through which RREQ copies are passed so that every sought destination receives different request routes. The fuzzy calculation is performed on each intermediate node between the source and destination vehicles and requires the speed, direction and distance of candidate next-hops to choose the best profitable hops for request flooding. The latter step implements the CSA with Lévy flights which added randomization aspect to CSA's diversification aspect to form paths based on stability parameters figuring reliability factor, link lifetime and buffer availability. The path with optimal CSA fitness is selected for data forwarding.

Conventional ad-hoc routing has been the context of other kinds of research contributions for VANET routing challenges like parameters tuning, security techniques for routing, CBR and other fields, which will be spread ahead in the upcoming sections of this survey.

A considerable work on the bases of conventional ad-hoc routing concepts has been attained with nature-inspired algorithms for VANET routing, especially for reactive routing exploiting the most effective metaheuristics such as GA, DE, and others. Meanwhile, still further finishing touches remain on that problem, where still the proactive routing did not touch enhanced works for VANETs either for purely-proactive or inter-zone proactive routing in the framework of hybrid routing. A few related cases of IARP are Road-Based using Vehicular Traffic Proactive (RBVT-P) (Nzouonta-Domgang 2009), OLSR (Clausen and Jacquet 2003), DSDV (Perkins and Bhagwat 1994) among others. The same case is recorded in geographical position-assisted routing protocols, discussed previously in this section, where still not been discovered well by the research community like Location-Aided Routing (LAR) protocol. Other nature-inspired optimization algorithms, not tried in this context, can contribute to routing performances, which will be spread next in this paper.

4.2 Parameters tuning of VANET routing protocols

Routing protocol parameters tuning field is one of the most effective optimization techniques on ad-hoc networks routing and particularly for VANETs. It has a direct impact on protocol's behavior which redirects the basic routing operation like beaconing, route repair procedures, and others. Several parameters are common for the same protocols such as the established routes' hop count limit, maximum number of allowed received Hello packets, maximum number of saved routes to a given destination, routing packet's TTL and so on, while some other parameters are particular for their related protocols. For example, zone radius parameter in ZRP, cluster size parameter in CBRPs (Jiang et al. 1998), maximum allowed time of carried packets in DTN routing protocols, and among other protocol-specific parameters.

Tuning parameters controls protocol's behavior which has direct impact on its performances: the case of ZRP's zone radius, since reducing its value leads to merging plus to a more reactive routing, while elevating it entails a more proactive routing. This process tries different combinations of parameter values in order to find the set of values that offers the best possible solution in terms of routing quality. This operation is executed in an off-line runtime (Khan 2009), meaning that, is not tested during routing but routing protocol is adjusted with found values from metaheuristic algorithm after execution. Metaheuristics, particularly EAs, are profitable approaches in such fields and can find very satisfying serial parameter values in a reasonable time. The evolution of tuning process is based on the results of each generation, while each solution vector is tests out using a fitness function which considers optimized QoS metrics as factors, each one with a given coefficient which fixes its weight in the solution. It's worth pointing that not necessary that all protocol parameters are called for tuning, just crucial ones enter for adjustment and choice is free for researchers according to the nature of each protocol.

The combination of selected parameters differs from a protocol to another seen the importance of each parameter, its values range, further to the nature of the protocol and how many parameters it employs. The bio-inspired parameters tuning optimization shows its advantage in case of a large number of parameters, usually thereabouts 10 parameters in minimum cases. That's to say, with N parameters there are 10^N possible configuration values. An illustration of tuned routing parameters is given in Fig. 1 of AODV protocol.

GA, DE and PSO are the most used optimization algorithms for ad-hoc parameter adjusting. That's due to the tendency of EAs to solve discrete optimization problems. Parameters tuning has been applied particularity on classic topology-based protocols like OLSR, DSDV, AOMDV among others, for mobile random mobility motion. As typical examples, we cite OLSR and GRP (Sahota and lal 2016) which tests the logical grouping for OLSR and the quadrant-based routing concept for GRP on four metrics, namely: NRL, throughput, delay and MPR count for control flooding. A better idea utilizing stochastic approaches for tuning: a few initial cases with ad-hoc routing issues

Table 1 AODV's tuned routing parameters

Parameter	Default values	Interval
Active route timeout	3.0 s	[1.0, 10.0]
Allowed hello loss	2 Hello packets	[1, 10]
My route timeout	2 × Active route timeout	[1.0, 10.0]
Net diameter	35 nodes	[1, 50]
Node traversal time	0.04 s	[0.01, 1.0]
Net traversal time	2 × Node traversal time × Net diameter	[1.0, 10.0]
RREQ retries	2 attempts	[1, 10]
RREQ ratelimit	10.0 kbps	[1.0, 10.0]
TTL start	1.0 s	[1.0, 10.0]
TTL increment	2.0 s	[1.0, 10.0]
TTL threshold	7.0 s	[1.0, 20.0]

like data congestion, power over-consumption, like in (Montana and Redi 2005) for multi-objective automated parameters selection using GA on two parameters, namely dropped packets and transmission delay.

The routing requirements in VANETs excludes few MANET constraints like energy or transmission range limitations of mobile nodes which are out of Vehicular Networks' characteristics seen regular vehicles possess a larger dissemination range with an infinite energy source. Numerous works treated parameters tuning field majorly on classic routing protocols the case in:

The reactive routing like for the example of AODV proposed by Mane and Kulkarni (2013), which exploits ACO's pheromone attractiveness to propose an optimized mobility model to reduce the AE2ED. Ants follow more concentrated pheromones ways and so, parameter vector draws its final convergences by establishing all parameter values. A comparative experimentation of GA and Grasshopper Optimization Algorithm (GOA) (Saremi et al. 2017) parameters tuning is proposed by Tabar and Farazkish (2019) on AODV showing the quality of each approach on PDR, AE2ED and NRL. For AOMDV proposed by Lobiyal et al. (2015), routing parameters are tuned using PSO metaheuristic (Fig. 6), inspired from the migration of flock bird particles in nature. PSO candidate solutions, each one represented by a set of eleven tuned parameters forming bird particle, merge towards a set of dependently-migrant parameter values, entailing an optimized set among a set of 10^{11} possible parameter combinations advantaging AE2ED and NRL above PDR.

The proactive topology-based routing parameters are tuned equally with the example of DSDV in Sharma et al. (2014), where it applied a PSO-based tuning on a six-length parameter vector. OLSR by (Toutouh and Alba 2012a), which implements DE algorithm, a stochastic population-based algorithm which follows the path of GA in its structural steps (selection-crossover-mutation) for optimizing an eight-length parameter vector. In Zukarnain et al. (2014) on OLSR protocol equally for urban VANETs to reduce routing overheads. (Gunasekar and Hinduja 2014) proposed an IWD-based parameter tuning of OLSR to improve the QoS performances under high quick VANET mobility. Hammoodi

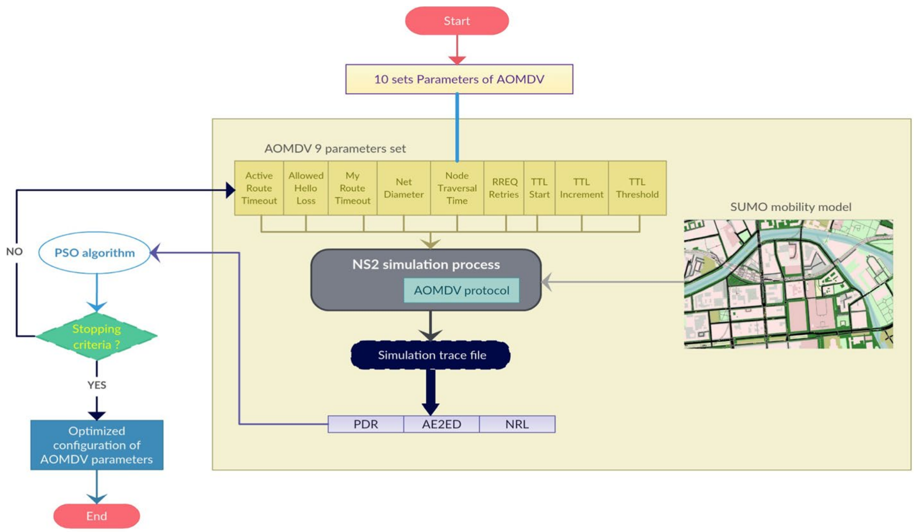

Fig. 6 AOMDV parameters tuning scheme

Table 2 Major emerging nature-inspired metaheuristics for VANET routing

Tuning approach	Pros	Cons
PSO-tuned AOMDV	Large optimization of 9 parameters set	Missing comparison to other metaheuristics
	Improved QoS results under different area sizes	
ACO-tuned AODV	Improved AE2ED results in ACO-tuned AODV	Missing comparison to other metaheuristics
	Effective solution in highly-dense networks	Comparison limited to AE2ED results
GA and GOA tuning comparison on AODV	GOA better than GA in E2ED and PDR	GA better than GOA in NRL
PSO-tuned DSDV	Improved QoS results in PSO-tuned DSDV	Limited optimization of 6 parameters set
		Missing comparison to other metaheuristics
IWD-tuned OLSR	Quick improvement in PDR along with IWD iterations	Prioritizing PDR weight over other IWD fitness's QoS metrics
HSO-tuned OLSR	Better than GA and PSO tuning in routing overheads	Close results in PDR and E2ED comparing to GA and PSO tuning
	Balanced weight priority between HSO fitness's QoS metrics	

and Muniyand (2018) suggested an optimized parameters configuration of OLSR using Harmony Search optimization (HSO) (Gao et al. 2015) reaching better AE2ED, PDR and overheads results that GA-tuned OLSR and PSO-tuned OLSR.

We resume in Table 2 both positive and negative aspect of the marking parameters tuning solutions discussed in this subsection:

It's worth noting that realized works didn't include VANET-originated protocols, so a great challenge is exposed to propagate this research among geography-based protocols, VDTN protocols and vehicular CBR protocols. There is other possibility of applying the bio-inspired parameters tuning on bio-inspired protocols by finding the best combination of metaheuristic parameters to increase the metaheuristic performance within the protocol.

Second, the extension of experimented bio-inspired approach can potentially improve the quality of tuning, where further swarm-based metaheuristics can be generalized for this kind of off-line optimization (Khan 2009), and the enhanced EAs are other promising solutions for parameters tuning like the case of the BOA, a GA-modified metaheuristic. Parallel metaheuristics can be more spread as well for parameters tuning seen their advantages on QoS metrics evolution.

4.3 Clustering algorithms for VANET routing

Clustering algorithms constitute an elementary part in the majority of CBR protocols (Dhawale et al. 2016). Clustering is a use case of MOPs (Amudhavel et al. 2015a) and has its direct impact on routing particularly for ad-hoc networks. When, numerous factors influence classic QoS performances namely, AE2ED, PDR, NRL and bandwidth consumption. Cluster optimization includes: number of clusters' minimization, optimizing the number of CH changes and number of CMs switching their CH, ideal cluster degree size, cluster formation, CH selection, cluster re-organization. All these optimization tasks are shortened as cluster stability (Khakpour 2015), which is classified as an np-hard problem, hence the possibility to optimize clusters' performance indicators using metaheuristics and particularly bio-inspired optimization approaches. Let's explain some of the previously cited clustering operations:

- CH election process: applies a set of conditions on each CN to check if it can hold cluster management tasks.
- Cluster formation procedure: accomplishes the major operations to form an intra-connected cluster of mobile nodes managed by an elected super CN (equally to a CH).
- Cluster stability: includes the number of CH changes and number of CNs switching their CH.
- Cluster degree: means to fix how many CMs to form a cluster. Cluster size control looks for finding the best number of CMs (or CNs) which reduces bandwidth wastage and avoids overheads duplication.
- Cluster re-organization procedure: restructures the cluster form by joining new nodes, removing exiting nodes and CHs replacement.

Numerous bio-inspired vehicular clustering algorithms have been realized; we mention the notable ones below:

Mottahedi et al. (2013) proposed the Intelligent Based Clustering Algorithm in VANET (IBCAV) which tries to improve VANET routing by implying traffic-aware methods, inter-layered methods and Artificial neural network-based mechanism for CH selection, taking into account cluster size, CNs' velocity and network density.

Fathian and Jafarian-Moghaddam (2015) proposed the New clustering algorithms for VANETs in a highway communication environment, suggesting two clustering approaches for cluster stability: the first using a Multi-objective Data Envelopment Analysis (DEA) algorithm and the second employing an Ant Colony System (ACS) algorithm (ASVANET). ASVANET presents a stable clustering algorithm that tends to form stable clusters. Where each vehicle acts as an ant. It includes five sub-procedures for CHs selection and CMs grouping: Sub Cluster for splitting clusters into several sub-clusters, Vehicle Merge for joining vehicles into their appropriate cluster, Clus Merge for merging similar sub-clusters within one main cluster, Remover for pulling out different CM vehicles from sub-clusters and CH selector for CH election.

Aadil et al. (2016) proposed the ACO-Based Clustering Algorithm for VANET (CACONET) which discusses VANETs scalability issues. CACONET consists to optimize two clustering operations: cluster stability by minimizing the number of CHs changes and reducing the number of clusters, hence saving network resources. Since it's proved that CHs' optimal selection is an np-hard problem (Aloise et al. 2009), ACO offers an effective stochastic swarm-based search among candidate CNs for captivating the almost-best CH that last longer and controls the maximum amount of CMs in a very reasonable time comparing to conventional exhaustive search methods. ACO forms its initial population from vehicles' IDs located in the network vertices, while the final solution is composed of all vertices (IDs). Each vehicle's ID that codifies its vertex is the CH of the cluster zone it's located inside it. So, every solution is composed of all CHs that guide to their solicited destination. Each ant constructs its solution CH by CH until no more vertices are found, and launches its tour by choosing randomly a vertex from the search space, respecting two main constraints of CH uniqueness and loop-freedom. CACONET adopts two stopping criteria namely user-defined tour number and redefined stall iteration number. CACONET is compared to MOPSO and CLPSO algorithms and shows an optimized number of clusters under different area sizes, transmission ranges.

The full CACONET Algorithm is illustrated in Algorithm 1 below:

Algorithm 1 CACONET full algorithm

```
Initialize all vehicles' positions stochastically on a highway mobility portion
Initialize each vehicle's direction randomly
Initialize each vehicle's velocity
Create a mesh topology between vertices (vehicles), where each vertex is coded with the
appropriate vehicle ID
Initialize a unique pheromone value for all edges in the built mesh topology
Calculate all distances separating vehicles from the others, normalize and associate these
distance values with the corresponding edges in the built mesh topology
while Iteration == Total_Iterations ∨ Stall_Iteration == 20 do      ▷ no improvement
marked after last 20 Iterations
    for Ant_i = 1 to Swarm_size do
        Ant_i.tour = empty
        Ant_i.cost = infinity
        Vertices (Vehicles) Available for clustering = {All Nodes}
        while Vehicles Available for clustering != empty do
        end while
        Ant_i.cost = Evaluation(Ant_i.tour)
        if Ant_i.cost < Ant_best.cost then
            Ant_best = Ant_i                                   ▷ update partial best
        end if
        Ant_i ++
    end for
    for Ant_i = 1 to Swarm_size do          ▷ update pheromone value of all passed edges
        Update Pheromone (Ant_i.tour, Ant_i.cost)
        Pheromone Evaporation()
        if Ant_best.cost == Last iteration Ant_best.cost then
            Stall_Iteration ++;
        else
            Stall_Iteration = 0;
        end if
        Ant_i ++
    end for
end while
CHs = Ant_best.tour;
```

Fahad et al. (2018) proposed a grey wolf-inspired node clustering in VANETs (GWOCNET) which consists of optimizing the number of clusters by exploiting the social and hunting behaviors of grey wolfs (GWO) (Mirjalili et al. 2014). GWOCNET models the decreasing linear factor convergence noticed in the different steps of wolf's hunting starting by the social hierarchy for hunting guidance, search for optimum prey, encircling and attacking prey in order to optimize the number of clusters mobilizing the vehicle's speed, direction and position. The improvement of leader wolf election reflects updating the quality of CH during all the optimization process. GWOCNET is evaluated using MATLAB and shows higher number of nodes per cluster under different areas and transmission ranges comparing to CLPSO and MOPSO.

Shah et al. (2018) proposed the Mothflame-based clustering algorithm (CAMONET) which seeks the ideal number of CHs and cluster lifetime as main network stability factor by using the Moth Flame Optimization (MFO) inspiring from the tracking path behavior of moths while flying during night following the moon light. As moth explores flames in search space and keeps updating its position while keeping contact with the best flame, this mechanism allows to catch CHs than reduce the number of cluster in network by evaluating CNs' speed direction and transmission range where moth position and calculated fitness using decreasing factor are used to update its position which leads to converge toward the perfect number of clusters for reliable communication. CAMONET improves the results reached by CACONET under different transmission ranges and density values.

Joshua et al. (2019) proposed a firefly-based weighted clustering protocol for VANETs (RWCP-MFO), a multi-objective Firefly Algorithm (FA) (Yang 2009) solution seeking longer cluster lifetime higher PDR and less cluster overheads by optimizing the parameters of RWCP exploiting each vehicle's velocity, direction, reputation, neighborhood size and lane ID in the framework of a multi-objective firefly optimization paradigm involving the FA metaheuristic which models the twinkling behavior during interactive movement between fireflies seen their flashing light intensity. The local attraction and global regrouping are two specific properties in FA that offers better subdivision and regrouping abilities which are used in this algorithm to form cluster with longer longevity based on five parameters namely: node position, cluster size, time interaction of CH for joining message, duration of CM to join CH's cluster and CH time interval. RWCP-MFO reached better results comparing to CLPSO and MOPSO in term of PDR and average number of clusters.

We resume in the Table 3 both qualities and shortages of notable bio-clustering approaches discussed in this subsection.

Nature-inspired clustering optimization took a great step forward treating different aspects of clustering under VANETs using nature-inspired metaheuristics surpassing conventional contributions. Although, the majority of realized works concentrated on main clustering tasks, namely, CH election, CHs lifetime and cluster formation, whereas other aspects like cluster rebuilding, adapting cluster degree in different mobility areas among others are still not treated. Also, few treated problems can perform further influencing modifications the case of CH election which can include other selecting criteria like CH lifetime, cluster formation which can consider both vehicular traffic lights and nature mobility areas, which open a supplementary research area to boost clustering stability and routing as a consequence.

A promising future for bio-inspired clustering optimization. Since better works are still to fulfill increasingly with the appearance of new recent swam-based metaheuristics the illustrated examples above with the FA and GWO approaches. Similar swarm-inspired approaches, we can mention the Elephant Herding Optimization (EHO) (Wang et al. 2015b) among others. Hybrid metaheuristics can also give more effective solutions for multi-criteria clustering parameter optimization. Existing bio-contributions, as discussed above in this section, can also be the kernel of new bio-inspired works in this context.

4.4 VANET-originated routing challenges and problems

This is the most generic field of VANET routing, developing independent nature-inspired routing algorithms for VANETs. The major routing challenges on VANET routing has been emerged towards bio-inspired approaches to optimize five factors namely, the scalability, quantitative complexity, self-organization, adaptability and robustness (Bitam et al. 2014). Numerous taxonomies discussed major upcoming challenges of VANET-based routing issues like (Moustafa et al. 2009) which exposes VANET routing requirements comparing to conventional WANETs like different transmission priorities according to application type, controlling the broadcast storm problem in a crowded network topology and finding an effective dependency between dissemination algorithms and network density. Liang et al. (2014) discussed the main challenges for designing VANET routing protocols that can hold variant vehicular mobility and quick dynamic topologies. We expose below some

Table 3 Major emerging nature-inspired metaheuristics for VANET routing

Clustering approach	Pros	Cons
CACONET	Better than conventional clustering solutions	Based on conventional ACO
	Better than PSO clustering	ACO fitness considers only density factor
	Reduced number of clusters	Not destined for VANET routing
CAMONET	Stable clusters under density changes	Not destined for VANET routing
	Surpasses largely performances of PSO clustering and CACONET	Missing further parameters for cluster stability as node's historic clustering information
GWOCNETs	GWO offers alternative clustering solutions	Same drawbacks as CAMONET
	Stable clusters under density changes	Slight advantage comparing to PSO clustering
RWCP-MFO	Advantageous MO-FA over conventional FA	Same drawbacks as GWOCNETs
	Effective MO-FA clustering parameters configuration	

major routing problems extracted from VANET routing categories for bio-inspired routing optimization:

- Next-hop selection, which concerns all ad-hoc routing protocols.
- Carry-And-Forward principle, found in VDTN perimeter routing mode, which exposes the risk of infinite waiting of packet's vehicle carrier and targets (destinations) loss.
- Flooding process (Hello messages, probes, etc.) used for topology updates, which overloads the network and monopolizes the bandwidth.
- Masking of recent routing data by old data found recurrently during neighborhood updates and destinations up-to-date position.
- Backup of unnecessary data in routing tables, noted in the majority of VANET protocols.
- Route repair process that blocks the movement of subsequent packets coming after route fails.
- Loops engendered after route discovery in their three types, namely: node loops, edge loops or vertex loops, noted on reactive topology-based routing and perimeter mode in VDTN routing.
- Reception of routing information from several vehicles the example of zone-based routing, since the problem occurs during inter-route discovery due to overlapping zones. This issue provokes reliability information conflict and enhances routing overheads.
- The existence of cross-links noted especially in intersection-based routing under urban scenarios which entail routing loops.
- CBR-related optimization problems like CH election, number of CHs minimization, number of cluster changes minimization and so on.
- Multicast routing issues like highly-rated network overheads.
- Unicast routing problems like highly-rated packet losses and lack of alternative routes.
- Traffic congestion problem.
- V2R communication problem.
- Among others.

Bio-inspired VANET routing contributions touched different routing problems as those described above in this section, specializing in numerous VANET-destined routing fields like CBR, DTN routing, QoS routing, security among others. We expose a few cases below:

Bitam and Mellouk (2013) proposed the Bee-Life multicast routing optimization Algorithm for VANETs (BLA) to solve a routing np-complete problem namely, the QoS multicast routing problem (QoS-MRP) in VANETs. That's by implying the ABC algorithm to find an optimal multicast tree between a source and its sought destinations by current hop with minimum cost, reduced delay, decreased jitter and maximum bandwidth exploitation. To achieve this, three QoS constraints are counted, namely: delay, jitter and bandwidth. Proposed BLA mimics bee behaviors, namely foraging and reproduction, to build multiple paths based on BLA neighborhood search approach: a greedy approach to generate neighbor individual. The full BLA process is illustrated in Fig. 7.

Traffic congestion is resolved by Jayachithra et al. (2017) suggesting an ACO-inspired shortest path routing algorithm exploiting both V2V and V2I communication paradigms to implement intelligence of ants for predicting average velocity of road traffic by tracking vehicular and RSU information. Proposed ACO system chooses the best two path which offers the shortest distance extracted from RSU and GPS-collected position of vehicles then calculates the congestion factor seen number of cars in road and road capacity. The

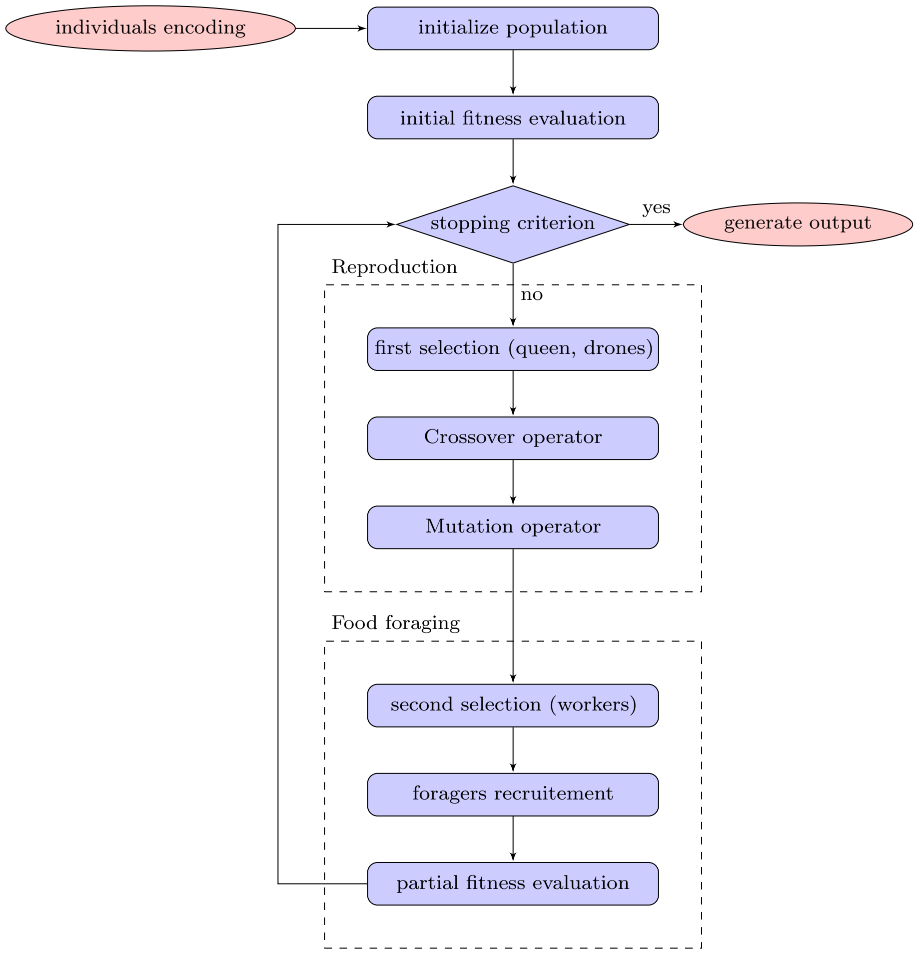

Fig. 7 BLA flowchart

travelling time is calculated for each chosen route and the best one is selected for data routing. The proposed protocol acts better than AODV, DSDV and DSR in classic QoS metrics.

Zhang et al. (2018) proposed a GA-based QoS perception routing (GABR), an intersection-based routing (IBR) (Chou et al. 2010) protocol which uses the GA to optimize available paths. GABR implements IBR for selecting dynamically the next-hop intersection and enable carry-forward request forwarding toward road segments. GA intervenes in global optimization by recombining genetically IBR-collected paths to extract best QoS paths. GABR shows better PDR and reduced segment delays under different communication ranges and density levels when compared to IBR and CAR (Naumov et al. 2007).

A considerable amount of bio-inspired contributions has been realized to solve VANET-originated routing issues. This field is open for more contributions, especially seen the effectiveness of new emerging nature-inspired metaheuristics and the variety of different bio-inspired methods used for VANET routing like hybrid metaheuristics, this part is well detailed next in this paper.

4.5 Security-related VANET routing

Routing performances in VANETs can be determined by the quality of adopted security mechanisms, since numerous protocols include security defenses in their routing policy. For example, detection and elimination of malicious attacks that engender packet falsification, attack vehicle's authenticity and waste network resources which degrade directly routing performances. Secured routing techniques seek the protection of data communication under its different paradigms (V2V, V2I or for IRC) from different kinds of active and passive attacks that may provoke packet loss and disorientation. Active attacks seek congesting network with fake packet proliferation, while passive attacks seek to gain information about and from vulnerable targets in which no data is changed or damaged.

Different taxonomies discussing security issues and techniques related to VANET routing have been realized. Kaur and Kaur (2017) discussed different presented techniques to prevent Sybil attacks which can be either active or passive. Patel and Jhaveri (2015) describes with notable works the marking approaches for trust establishment between vehicles in VANETs, followed with resumed descriptions of realized approaches for trust establishment in VANETs. The thesis written by Zhou (2015) treats data collection, dissemination and security mechanisms in VANETs, focusing on methods protecting vehicles' privacy. Gadkari and Sambre (2012) describes main security issues marked in VANETs, suggesting classification of security attacks and giving a short description of different proposals on security techniques in VANETs like identification mechanisms, creation and use of pseudonymous certificates and information confidentiality.

Numerous classic security-related routing protocols have been promoted earlier for MANETs then for VANETs especially those interested in secured routing protocols for Sybil attacks detection are mentioned in Kaur and Kaur (2017) notably: a hybrid trust model proposed by Gazdar et al. (2012), a Beacon-based trust management (BTM) technique proposed by Chen and Wei (2013), a new technique to detect and isolate Sybil attack on vehicles is proposed by Saggi and Kaur (2015), several made contributions on trust establishment in Patel and Jhaveri (2015), a privacy-preserving scheme to detect Sybil attacks (P2DAP) is proposed in Zhou (2015), and a Junction Based Urban Scenario High-Speed Node Detection (JBUS-HSND) and Alerting System on VANET is proposed by Sharavanan and Balajee (2016).

Numerous frameworks spread many protocols realized by Mazhar and Farooq namely, BeeSec (Mazhar and Farooq 2007b) based on digital signatures which are calculated using source and destination IDs, packet ID and routing information. BeeSec defends against fabrication attacks in BeeAdHoc and counterattacks them. BeeAIS (Mazhar and Farooq 2007a), an AIS-based model which uses negative selection (Forrest et al. 1994) for anomaly detection through antigen types: scout antigen and two forager types. Scout antigen detects abnormal behavior, whereas foragers detect anomalies in the source route and carried routing information. iBeeAIS (Mazhar and Farooq 2011), an integrated AIS-security framework for misbehavior detection in BeeAdHoc. iBeeAIS possesses an active dynamic learning of both self and non-self-systems and can perform good detection precision with low false alarm rates for both scout and forager related attacks.

Passing to VANETs is a progressive step that has captivated research community interests for developing secure routing field. To our knowledge, few works have been tried for VANET. We found the bio-inspired version, namely a Secured and Enhanced VANETs Using DSR Protocol and Bacterial Foraging Optimization Algorithm (BFOA), suggested by Devi et al. (2017) which looks for preventing vehicles from selective forwarding attacks that aim to halt different VANET communication ways and to unavailable the network resources. That's by combining DSR protocol with BFOA metaheuristic. The flowchart of this contribution is presented in Fig. 8. Simulation experiments show an increasing PDR and decreasing AE2ED under BFOA+DSR comparing to classic DSR.

An ACO-based Secure Routing for VANETs (ACO-ECDSA) proposed by Gayathri et al. (2018) based on Elliptic Curve Digital Signature Algorithm (ECDSA) implementing an ACO-inspired flooding for route selection on the basis of intersection-based paradigm introducing the intersection terminals to route packets based on source and destination nodes. ACO relies on such terminals to formulates optimized paths to destinations. ECDSA takes charge of the cryptography of the generated routing paths to secure data exchange.

Finally, a secured AODV for VANET using fuzzy ANN-SA is suggested by Mo et al. (2018) consisting of improving in first step node stability by removing the parameters that alter link stability, and implementing an improved neural network using genetic SA to calculate node stability based on three parameters, namely speed distance and load. In second step node security is enhanced by the ANN which is used to calculate node trust value which helps to reduce attack probability of malicious nodes.

To summarize, secured routing in VANET-destined routing protocols is a challenging field seen the realized works in conventional ad-hoc protocols such as AODV, while for VANETs securing communication between vehicles and disseminated packets' protection from falsification and damaging helps enormously to the optimization of network resources

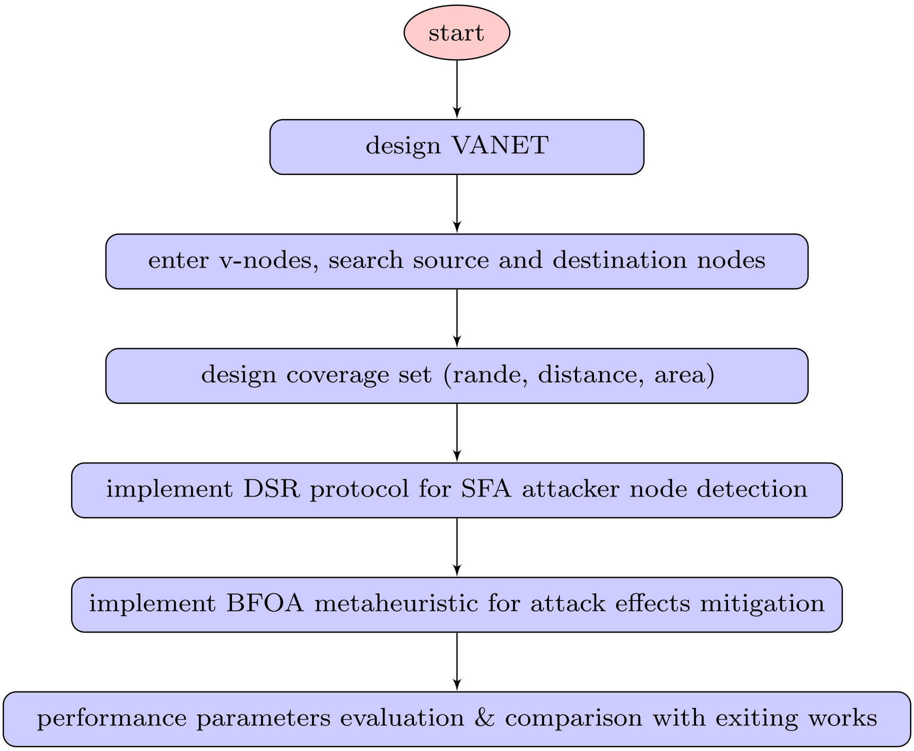

Fig. 8 (DSR+BFOA) plan

and average dissemination delays. This field is open as well for VANET-originated protocols like geography-based and VDTN routing discussed previously in this survey, opening a large area of numerous potential contributions. BFOA is tried well for VANETs and the AIS equally in MANETs which incites to think about merging metaheuristics that fit with security mechanisms for VANETs.

5 Critics and future problems in the context

The above-mentioned routing problems took enough time to reach a rich contributing research depth in the framework of bio-inspired approaches to a level that makes think that's almost saturated. Thus, we stated that these problems are:

- *Vulgarized routing problems* meaning contexts that are treated usually and broadly since a considerable time such as conventional ad-hoc routing concepts, clustering algorithms and VANET routing challenges, hence the bio-contribution becomes readable where almost no considerable novelty is proposed.
- *Saturated routing problems* meaning that are treated broadly by the bio-inspired approaches where the probability of considerable bio-contribution reduces seen the consumption of notable bio-inspired techniques.
- *Problem-specific use cases* the case of parameters tuning and security-related problems, meaning that are restricted to a very narrow area and does not open alternatives to broaden bio-inspired optimization application in a part, and the diversification of VANETs to further assisting devices such as cloud and RSU infrastructures in other part.
- *Indirect routing-related problems* as described for the cases of parameters tuning and clustering, meaning that the impact on routing performances does not rely on targeting routing operations as route discovery or route repair. This is considered a constraint since it requires that the improvement of these problems solving does not gather surely an enhancement of routing quality.
- *Limited-scope routing-related problems* meaning that these problems are treated for classic V2V and V2R communication area, whereas they are not applied yet on other emerging technologies in wireless communication such as V2U and V2C.

Meanwhile, it still not the hole possible research problems in this context and still other rising fields that belong vehicular ad-hoc routing hasn't been injected within the bio-inspired optimization research. In this section, we present an opinion on notable of those vehicular routing research issues that can have a long thrust ahead to nature-inspired metaheuristics related research context:

5.1 VDTN routing

DTNs (or Disruption Tolerant Networks) are a particular class of wireless partitioned networks characterized by a continuously stopping and starting connections due to either network nodes' mobility or varying critical conditions of wireless communication. DTNs enable communication between regions where reliable communication for performing common standards for wireless communication are constrained by intermittent connectivity, long propagation delays, asymmetric data, high latency and high error rates (Karimi et al. 2011). DTNs have various applications like interplanetary networks, military networks, and vehicular networks (Omidvar and Mohammadi 2014).

DTN data routing is the suitable mode of communication in distinguished challenged environments such as deep-space networks, ad-hoc networks and underwater sensor networks. DTN routing is based on finding the almost best SCF node that tends better, comparing to among the available potential next-hop vehicles, towards the destination's direction in case of missing enough available candidate next-hop neighbors which move towards the destination or having the same destination's direction.

The union of VANETs and DTNs has come up with a specialized networking form introducing a new research field, namely VDTNs (or Vehicular DTNs). VDTNs are derived from DTNs for vehicular applications that extend classic VANETs applications. Generally, VDTNs fit with any applications that don't require rigorous restrictions like email applications, parking lot tracking or weather updates where DTN principle can be applied. VDTN routing is the restriction and adaptation of DTN routing for the requirements of Vehicular Network applications. VDTNs are associated with either topology-based and geography-based routing paradigms seen it uses both topology and GPS information.

Numerous taxonomies have been proposed for VDTN routing relating it to different types of routing algorithms. According to Benamar et al. (2014), VDTN routing is associated with numerous forwarding algorithms, like the geographic-based forwarding, multicast algorithms, optimization-based algorithms, vehicular mobility and movement prediction, social-based forwarding and congestion control algorithms. A totality of other marking VDTN protocols is presented in numerous literature surveys as in Agarwal et al. (2017) citing several notable versions of DTN protocols for VANETs like MaxProp, Probabilistic Bundle Relaying Scheme (PBRS) and Adaptive Store-Carry-Forward (ASCF). Notable remaining conventional VDTN routing protocols are spread in Agarwal et al. (2017); Ahmed et al. (2015). We give a window of the notable contributions of VDTN routing policies as is given ahead: GeoSpray proposed by Soares et al. (2014), VANET DTN routing strategy based on Trend of Delivery (ToD), abbreviated VDTN-ToD protocol proposed by Vieira et al. (2013) and GeoVDM algorithm proposed by Cherif et al. (2017).

Seen the properties of DTNs, it's clearly shown that VDTN routing provides huge advantages for VANET routing. Since, the conditions for applying classic reactive, proactive routing or greedy forwarding is quite complicated in sparse or disconnected vehicular motion areas, hence DTN routing can be very effective for VANETs and next DTN forwarder selection can be optimized via stochastic approaches, inspiring from the existing living being particles' behaviors in nature. That's what we're going to prove with the existing bio-inspired DTN routing protocols to show the possibility of passing this experience to VDTNs.

So far, few bio-inspired DTN-based routing protocols are proposed for VANET to solve DTN-classic weaknesses as connectivity loss, uncontrolled delays and routing under sparse areas. Meanwhile, numerous works have been proposed for classic DTN destined for ad-hoc routing, we mention few versions ahead:

Ababou et al. (2014a) proposed the AntProPHET protocol, a geography-inspired protocol for DTNs which combines probabilistic metric of PRoPHET routing protocol and foraging behavior of ants when seeking food nest from ACO algorithm, to raise up PDR and reduce overheads. AntProPHET proceeds predictability calculation between nodes as PRoPHET, quantified with pheromone concentration to deduct visibility of available candidate relay nodes toward the routed packet's destination. Pheromone updates between a relaying node i and the destination follow the model of cities of TSP. Simulation results show that AntProPHET surpasses PRoPHET in terms of average delay, overhead ratio and delivery probability quality.

Ababou et al. (2014b) proposed the BeeAntDTN protocol which is inspired from both bee colony to collect information and ant colonies to seek best paths. Each BeeAntDTN node sets up and saves connectivity degree list, gathers connectivity information by sending artificial bees namely, and refreshes three data tables: TableHops which saves three nodes having highest direct connectivity degree with each relay node, TableEnegie which saves nodes' remaining energy on reception of Fbees, and TableBees which contains path duration between source-destination pair plus the related global connectivity degree. ACO model is used to discover optimized paths by calculating the visibility between a given neighbor and the destination using TableBees information. BeeAntDTN is compared to PRoPHET, Epidemic and Spray and Wait (Spyropoulos et al., 2005), and shows better performances on the same metrics evaluated for AntProPHET besides a lower average latency.

Omidvar and Mohammadi (2014) proposed the PSODTN algorithm which uses PSO algorithm to control the number of sent message copies to avoid both packet drops and uncontrolled overhead amounts to face lack of node resources as energy, buffer cache storage, message treatment capacities and so on. PSODTN tries to cut down overheads, while keeping the message delivery ratio at a good level. PSODTN considers the delivery ratio as fitness function's sole parameter and calculates the OR using eq. (1) below:

$$OR = \frac{Number\_of\_relayed\_messages - Number\_of\_delivered\_messages}{Number\_of\_delivered\_messages} \tag{1}$$

According to our research, one found work turned around VDTN routing is: Message Routing in VDTNs Based on Human Behavior proposed by de Andrade et al. (2016) which seeks to improve estimation of the nodes' position by referring to human meeting concept and surpassing RSUs dependency. It applies the Human Behavior-based Routing (HBR) computational model (Ahmadi 2016) inspired from human behavior to get nodes' location-related information. HBR involves the Last Encounter Routing (LER) technique which assumes that each node saves information about time, place, velocity and direction of other nodes through beaconing. Thus, HBR sets up a Table of Contact Awareness (TCA) to keep such information. Then, a Mathematical model is executed to estimate destination's future location and fresher direction evolution from nodes having latest contacts with the destination. Simulation of HBR shows a higher average message delivery rate and a much lower number of transmissions started messages comparing to classic DTN protocols.

VDTN routing exposes huge challenges under nature-inspired optimization approaches on the different kind of vehicular routing scenarios. This field is open for other contributions the way bio-inspired DTNs routing algorithms have been proceeded. Seen the different forwarding categories VDTNs routing uses like flooding-based, geography-based, information-based, infrastructure-based and others, many metaheuristics can be adapted to such routing strategies as was largely proved in nature-inspired protocols realized for geography-based routing like in Chen et al. (2016) or the hybrid greedy-V2V DTN routing discussed in this paper. According to our investigation, no swarm-inspired optimization algorithms, except human-inspired behaviors which have been tried for VDTN routing, which opens a vast new research context that can be effective for VANET routing.

5.1.1 Hybrid Greedy-V2V DTN routing

This particular class of VANET routing combines both Greedy-V2V routing and DTN forwarding, discussed in this section. The Greedy-V2V is a geography-based routing based on V2V communication paradigm which uses exhaustive routing based on target's position. This hybrid mode takes greedy forwarding a default routing mode under normal conditions and switches carry-and-forward principle of DTN routing to recover greedy routing limitations. Numerous bio-inspired contributions focused on DTN routing and geography-based routing involving greedy forwarding mode, which gave very promising performances.

The hybrid Greedy-V2V DTN routing combines the greedy, perimeter and DTN forwarding modes. We discuss below the sole conventional contribution that belongs to this routing category, namely the Hybrid Geographic and DTN Routing with Navigation Assistance in Urban Vehicular Networks (GeoDTN+Nav) for VANETs proposed by Cheng et al. (2010) which is a geography-based protocol that liaises the DTN routing to the Greedy-V2V routing. GeoDTN+Nav is conceived to repair shortages of the classic geography-based routing protocols for VANET routing like GPSR, GPCR (Lochert et al. 2005) and VCLCR protocol (Lee et al. 2008).

GeoDTN+Nav uses a restricted greedy forwarding as in GPCR where packet forwarding is executed on streets and junctions rather than sending packets across a junction. Thus, GeoDTN+Nav's greedy strategy takes transmission decisions on road junctions and intersections to cope with radio obstacles, namely buildings, urban obstacles and congested areas to avoid packet collision. For perimeter forwarding, the VCLCR's version is used, to recover greedy mode by tracking nodes moving around the destination following the right-hand rule. This mode is kept until switching back for greedy forwarding if available. GeoDTN+Nav switches DTN mode to recover from greedy and perimeter forwarding limits, where each perimeter hop follows three indicators to switch DTN forwarding, namely network disconnectivity levels, delivery quality of nodes holding packets and neighbor's direction.

The switching conditions between GeoDTN+Nav's three forwarding modes are illustrated in Fig. 9 below:

GeoDTN+Nav proves a consistent improvement in term of PDR, lower latency and hop count, comparing to RandDTN (Spyropoulos et al. 2004) a randomized DTN routing algorithm, GPSR and GPCR.

The motivation for referring to bio-inspired optimization algorithm is to recover greedy, perimeter and DTN forwarding modes' weaknesses discussed above. Moreover, metaheuristics can intervene in the next DTN hop selection which is a particular case of next-hop selection in case of a large number of nodes.

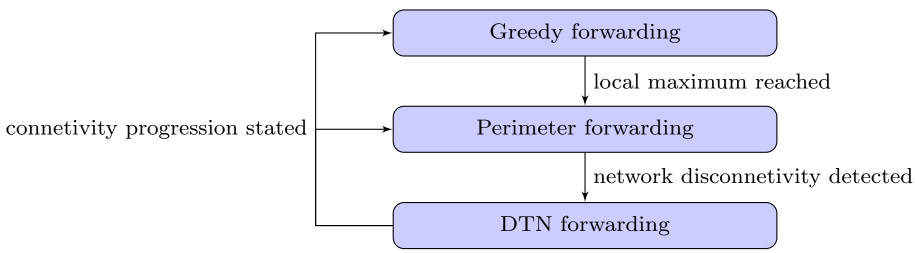

Fig. 9 GeoDTN+Nav forwarding modes' switching conditions

One of the few found bio-inspired works in this context is GA-assisted GeoDTN+Nav suggested by Bitaghsir and Hendessi (2011) implementing a GA-based DTN mode to solve the customized switching time to DTN forwarding of GeoDTN+Nav which engenders numerous drawbacks such as the requirement for a VNI system on vehicles and critical privacy routing vehicular constraints. Moreover, the switching formula from the perimeter to DTN mode doesn't consider few crucial factors like the next-hop candidate's velocity, position and streets traffic model. Consequently, GA-based GeoDTN+Nav protocol includes other more effective parameters that are responsible to decide passage to DTN forwarding mode by choosing stochastically the almost-best available next DTN hop vehicle. This switching decision requires vehicle's speed (S), direction (D), distance between that vehicle to the final destination (F) and network disconnectivity probability (P) which is based on a hop counter (eq. (2)).

$$\alpha S(N_i) + \beta D(N_i) + \gamma F(N_i) + \delta P(h) > Thresh \tag{2}$$

GA intervenes when the current hop is in the perimeter mode during the allocated time interval to captivate a cooperative DTN node. The application of GA consists of finding the best combination of the predefined switching parameters which constitute the solution structure. The termination condition is fixed at four generations. GA-assisted GeoDTN+Nav shows better performances than classic GeoDTN+Nav in terms of both average ratio and delay under different vehicle's speed and obstacles clearly starting from the second (2nd) generation.

The GA-assisted GeoDTN+Nav protocol incites to focus on that kind of routing in VANETs with the use of other nature-based metaheuristics. The hybrid greedyv2v DTN routing isn't spread enough either under classic or bio-inspired search, hence the domain is open for a large number of contributions for this routing mode. Moreover, a plenty of metaheuristics can be used for reinforcing each of the three routing modes in this field, namely: greedy, perimeter and DTN. GA-assisted GeoDTN+Nav was modified specifically on its DTN routing strategy, what opens to think of enhancing greedy or perimeter strategies similarly.

5.2 Classic VANET-originated routing protocols

Other kinds of routing protocols, apart destined for MANETs then adjusted for VANETs, are conceived specifically for vehicular motion patterns like streets, junctions, freeways and rural routes with considering the characteristic of vehicular nodes as unlimited energy resources. Similar to the experience on adapted MANET-originated protocols like DYMO and AOMDV, the purpose is to improve functionalities of VANET-originated protocols that influence routing quality such as anchor-based routing decision, street-based routing under urban obstacles, clustering management under city networks among others, with the stochastic optimization abilities that nature-inspired metaheuristics can offer.

Notable VANET-destined routing protocols are ranged into three classes: geography-based, cluster-based (Sood and Kanwar 2014), (Punia and Patial 2016) and Geocast protocols (Allal and Boudjit 2013), (Chawla and Kamboj 2014). Out of VANET-originated protocols, few versions have been proposed in topology-based routing specifically for VANETs like RBVT-R and RBVT-P protocols (Nzouonta-Domgang 2009). Other works focused on enhancing existing copies, the case of Joshi et al. (2014) spreading the main enhanced versions of AODV specifically for VANET mobility.

Conventional VANET-originated routing protocols' issues are discussed in numerous surveys and works the case with: (Lopez 2010) discussing realized geography-based and cluster-based protocols for VANETs. It classifies such protocols under Unicast, Broadcast or Geocast routing categories (Lin et al. 2010) and shows the conversion of some MANET-originated protocols. Wang et al. (2014) discusses a comparison of main intersection-based routing protocol destined for city scenarios following several indicators, namely: forwarding and restoration schemes, traffic light and accident, besides their advantages and drawbacks. Allal and Boudjit (2013) and Chawla and Kamboj (2014) explain Geocast routing context which includes main characteristic techniques as Zone-of-Relevance (ZoR) shapes, simple and directed flooding, and chain with an overview of existing Geocast-related protocols for VANETs.

The schema presented in Fig. 10 presents an overview of different VANET routing modes that concerns bio-inspired routing works:

The diagram shown above illustrates the taxonomy of VANET routing categories which we classify according to bio-inspired routing schemes to four main classes, namely:

- *Topology-based routing* as in conventional routing, considerable bio-inspired protocols proceed reactive, proactive and hybrid routing. The case of reactive source routing illustrated with G-NET (Wille et al. 2016) and BVRRP (Azzoug and Boukra 2019), explained previously in this survey, in which reactive source routing schemes based on EAs are proposed, or TIHOO (Yahiabadi et al. 2019) which is a CSA-inspired hop-by-hop routing scheme that uses AODV principles. The case of proactive routing is illustrated with Multi-agent PSO-DSDV (Harrabi et al. 2016) routing protocol, whereas for the hybrid topology-based routing, we introduce the example of MAZACORNET (Rana et al. 2013), detailed previously in this survey, a ZBR protocol inspired from ACO and FBFO-ZBR (Mehta et al. 2016) which is inspired from BFOA.
- *Position-based routing* numerous bio-inspired routing protocols refers to geographical coordinates of nodes to trace its routing strategies likewise conventional protocols to perform either intersection-based routing or greedy V2V routing, the case of GABR (Zhang et al. 2018) which conceives an intersection-based routing strategy based on GA or Cuckoo-HyBR (Kaur and Devgan 2018), detailed next in this paper, which is based on CSA-inspired greedy forwarding.

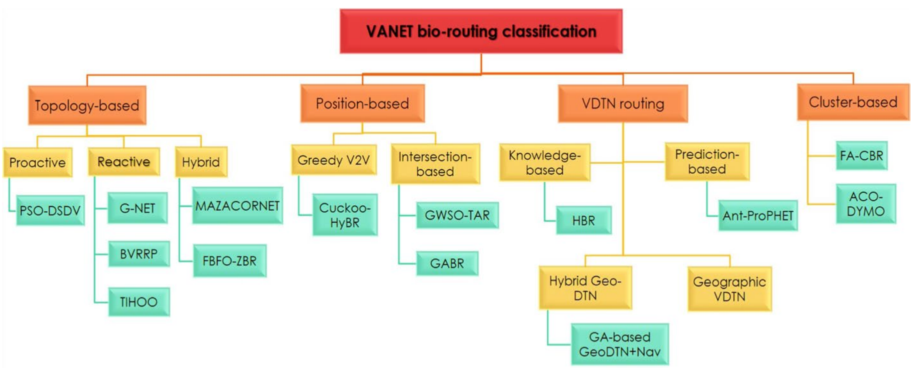

Fig. 10 Classification of bio-inspired VANET routing protocols

- *VDTN routing* DTN's SCF forwarding technique is used in bio-inspired VANET routing protocols, the case of HBR-VDTN (de Andrade et al. 2016) a human social-based VDTN dissemination models that applies human walking behavior on routing under sparse network zones. As for conventional VDTN routing, we distinguish four bio-inspired VDTN forwarding modes, namely: knowledge-based routing, geographic-based routing, prediction-based routing and hybrid geographic-DTN routing. The first mode refers to the topology information while the second is based on GPS-collected information of vehicles. The third is a probabilistic forwarding whereas the last mode is the alternate between geographic routing and DTN routing.
- *Cluster-based routing* the advantages of cluster-based routing figuring network scalability and cluster stability, discussed previously in clustering problem section, are exploited for bio-inspired routing. The illustration with two cluster-based routing examples, namely the ACO-DYMO (Balaji et al. 2013) inspired from ACO and the weighted FA-CBR (Joshua et al. 2019) based on FA.

Actually, very few VANET-originated protocols have been modified with bio-inspired optimization algorithm. Meanwhile, numerous approaching enhancing contributions are initiated by the research community in all mentioned VANET routing classes, especially in street-based and cluster-based categories. Few nature-inspired protocols have been proposed combining geography-based routing and CBRPs. Notable examples of this context, we mention:

GA-assisted GeoDTN+Nav protocol proposed by Bitaghsir and Hendessi (2011), spread previously in this paper.

Balaji et al. (2013) proposed the Cluster-Based ACO Routing for VANETs (ACO-DYMO) which deploys a clustering architecture followed by an ACO-inspired routing procedure. ACO-DYMO is applied to DYMO protocol (Thorup 2007).

Sachdev et al. (2016) proposed a CBR using Firefly algorithm which uses FA metaheuristic to find more suitable route links within a clustered network. FA is based on the flashing behavior produced by fireflies, which produce flashes to communicate with other fireflies. They move towards attractive ones based on their brightness. This property FA uses it to deliver proper and prominent data by increasing and decreasing transmission range in a way that gives better dissemination.

Other example, an enhanced version of the Traffic Aware Routing (TAR) protocol (Darwish and Bakar 2015) using a fractional Glowworm Swarm Optimization (GSO) (Krishnanand and Ghose 2006) algorithm (FGWSO-TAR) is proposed by Rewadkar and Doye (2017) suggesting an intersection-based routing based on road segments which performs a k-path discovery as performed in TAR. The suggested GSO includes the fractional theory to optimize the collected solutions from discovery phase. The fitness evaluation considers road length and predicted average velocity of its road segments. FGWSO-TAR improved E2ED and vehicle distance comparing to other methods lie, Cuckoo and PSO.

The huge enhancements made on bio-inspired reactive and proactive routing protocols in VANETs made us think of extending the experiments on VANET-originated protocols seen their rich context what makes this area of research a particular branch as one of the most important routing issues in VANETs. The challenge now is to attack a specific protocol, as from one of the mentioned in this subsection and among other similar ones, to produce modified bio-inspired versions.

5.3 Existing bio-inspired ad-hoc routing algorithms

This field is less known even if it began to be a wide interest for the research community working on VANET-based routing. It is based on existing bio-inspired ad-hoc routing protocols such as G-NET (Wille et al. 2016) or GA-assisted GeoDTN+Nav (Cheng et al. 2010). This context is an extension to VANET-destined routing contributions realized with a partly or fully involved nature-inspired which still are the basis of further modifications seen numerous shortages. It involves all discussed kinds of problem-solving in the framework of bio-inspired routing in VANETs, discussed in this paper, as parameters tuning, congestion control, clustering algorithms, bio-inspired MANET-originated protocols among others.

Recently, very few initiatives have been started in this context, we mention the enhancement of HyBR protocol (Bitam et al. 2013b) which is a hybrid unicast multipath protocol that fit with rural and urban scenarios that imitates Bee-swarm behaviors on vehicular mobility motions. HyBR mobilizes the topology-based routing in case of dense areas and geography-based routing with GPS for sparse networks to adapt well to the environmental changes in real-time. HyBR refers to GA which intervenes in the geography-based procedure to find shortest paths for destinations.

Kaur and Devgan (2018) proposed a bio-inspired enhanced version of HyBR named the Cuckoo-HyBR, a CSA-based method for HyBR route optimization assistance which involves the CSA in the route selection in crowded areas. The proposed Cuckoo-HyBR surpasses HyBR in terms of PDR and routing path length.

This field is open for more contributions since almost all realized papers in the framework of VANET routing context have been proposed to improve conventional protocols. Numerous realizations should be interested in the future to improve existing bio-inspired protocols by changing the used metaheuristic by another more effective nature-inspired optimization algorithm, or adding up further metaheuristic techniques on the bases of bio-inspired protocols destined for overall ad-hoc networks not specifically VANETs such as the IWDRP (Sayad et al. 2016). The idea for forming hybrid optimization algorithms is another likely solution for this context as well.

5.4 Vehicular cloud network (VCN) routing

The evolution of cloud computing as one of latest ITS innovations in the recent few years in vehicular environments has brought a new research topic as an extension of VANET routing area, opening the integration of emerging VCC technology in vehicular routing schemes which can carries the QoS routing performances to other levels by exploiting the advancements stated in transmission ranges and bandwidth availability that cloud devices provides.

VCN routing began taking its area in assisting VANET routing, numerous taxonomies discussed the perspective role of VCC in this context, starting with Gu et al. (2013) whom discussed the centralized cloud platform coordinated with RSUs and base stations to provide aid for vehicular communication in its different services and applications. Whaiduzzaman et al. (2014) discussed the position of VCC within ITS area and its origins from mobile cloud computing focusing on its different aspects like inter cloud communication, cloud formation and cloud-related security challenges. Mekki et al. (2016) discussed the extension of cloud architecture in VANET environments explaining the resulting VCC challenges notably the efficiency of cloud resources exploitation for VANET traffic estimation and mobility. Ahmed et al. (2019) focused on the simulation and mobility generators that can be used for VCC applications which are similar to VANET tools like NS2 and SUMO.

Conventional realization on the bases on VCC have been made, notably:

Qin et al. (2012) proposed the VehiCloud, a VCC routing architecture for assisting V2V geography-based communication relaying on OBU and RSU equipment. VehiCloud sets a decision module based on a way point information framework by which the network is divided so that vehicles become capable to predict their position and the cited module can make V2V routing decision. Consequently, VehiCloud entails optimized routing paths in real road mobility tests comparing to AODV and Position-Based Routing (PBR).

Bitam et al. (2015) proposed the VANET-Cloud, a Cloud architecture for VANETs is proposed where the cloud architecture is introduced for ITSs assistance. VANET-Cloud extends the classic cloud infrastructures to VANET nodes permitting to liaise vehicles to stationary cloud devices in reduced costs by setting three-levels architecture, composed of client, communication and cloud layers.

Bitam and Mellouk (2015) proposed also a cloud-based VANET dissemination model protocol (ClouDiV) consisting of mobilizing both fix and flexible cloud structures moreover to cloud data centers and V2R communication to adapt forwarding of safety and non-safety data packets relying on a hybrid route discovery involving both proactive and reactive routing where the former is performed between data centers while the latter is restricted between vehicles.

Eltahir and Saeed (2018) suggested the Simplified Cluster-based Gateway Selection (SCGS) scheme for cloud-assisted VANET which seeks solving unsuccessful connectivity of dead spot areas due to high vehicular velocity by implementing a enhanced hybrid wireless mesh protocol which offers better reliability than AODV.

Poonia and Raja (2018) spread different possibilities of applying VCC on-demand routing protocols under realistic mobility patterns.

VCN is a promising field for bio-inspired optimization techniques seen its direct interactivity with VANET and its related research topics on routing-related application.

5.5 Internet-of-vehicle (IoV) routing

IoV has emerged last few years as a new effective suppliant in smart transportation systems in cities and vehicles exploiting the internet connectivity, evolution of sensors and OBU devices along with the vulgarization and extension of IoT and VCC domains, thus another emerging area in the framework of VANET routing assistance called the IoV routing is born. This type of routing consists of improving the travel time between vehicles which act like smart entities in network, differently to classic VANETs where node depends on human behavior.

Recent literature began spreading IoV field as Sari (2017) which introduced in its keynote speech the future of IoT along with the advancement of bio-inspired renovations explaining the importance of nature-extracted intelligent approaches from living organisms in evolving numerous aspects of IoT network entities with the its application in ITS and smart cities such as scalability, resources optimization, heterogeneity among others. Srinidhi et al. (2018) spread also the optimization algorithms for IoT networking mentioning EAs and swarm approaches, and liaising with the different fields that are context of intelligent optimization citing network routing amongst the major ones.

Alouache et al. (2018) discusses the emergence of IoV as a recent ITS feature, exposing the main challenges of IoV demonstrating the different network architectures based on Software-Defined Networking (SDN) paradigm on the basis of hybrid V2V-V2I communication mode moreover to security techniques that can improve the conception of routing schemes under IoV networks.

Bio-inspired optimization started already to cope with IoV routing challenges, starting lately with:

Chowdhary and Kaur (2017) whom suggested a coordinated dynamic route optimization using PSO and ACO algorithms to assist a central decision-making routing system considering three parameters, namely road quality, route length, and mobility congestion. This experimentation shows the profitability of ACO and PSO comparing to normal case in optimizing the travelling time.

Ebadinezhad et al. (2019) proposed an ACO-based clustering algorithm for IoV (CACOIOV) for optimized CH election considering that All vehicles are equipped with 5G. ACO codifies each vehicle as a solution where ant's behaviour is employed to chain the list of depicted CHs along with the evaporation updates allows which offer better topology stability. This algorithm is coupled with the Dynamic Aware Transmission Range on Local traffic Density that adapt dynamically transmission range regarding local traffic density. CACOIOV is simulated under NS2 and SUMO (ITS 2014) and offered better throughput and PDR when compared to AODV.

IoV routing offers a promising future for VANET routing seen the higher scalability, bandwidth availability with the appearance of 5G and superior cloud network coverage that characterize IoV networks which open a large area for the exploitation of bio-inspired optimization approach for IoV routing.

5.6 Synthesis

In this section, we summarize in two structure tables the spread VANET-related routing problems and the notable bio-inspired approaches used for each category, then we liaise with a recapitulation of the notable implemented routing optimization schemes ranged by each problem category, after that we chain with overall view of stated drawback of discussed bio-inspired approaches spread in the last two section. Finally, we conclude with an illustrative drawing explaining the involvement of bio-inspired technique in VANET-related routing issues.

First, we organize the different routing strategies that characterize each category of VANET routing schemes which are the context of nature-inspired optimization as shown in Table 4.

In a second step, we regroup the treated VANET-related routing problems for each spread bio-inspired approach as shown in Table 5.

Thirdly, after discussing all routing problems related to VANETs, we state that the majority of bio-inspired optimization techniques figuring EAs and swarm-inspired metaheuristics belong largely to classic approaches, where still a lot of work to be realized on bio-routing solution by taking advantages of:

- Spreading application of implemented metaheuristics for further problems.
- Introducing the recent emerging swarm-inspired approaches to VANET routing problems.

Table 4 Characteristics of VANET routing schemes

VANET routing category	Characteristics of optimization schemes
Conventional ad-hoc routing concepts	Flooding optimization
	Swarm-inspired hop-by-hop route discovery
	EA-based source routing
	Route break prediction
Parameters tuning optimization	EA-based parameters tuning
	Swarm-based parameters tuning
	Parallel tuning scheme
Clustering optimization	Cluster stability factors
	CH election process
	Inter-cluster routing optimization
VANET routing challenges	V2I routing and transmission coverage
	Vehicular congestion optimization
	QoS routing optimization
VDTN routing	Vehicular congestion optimization
	Bundle's SCF policy
	Optimization of SCF mechanism
	Bundles buffer management
Hybrid greedy-V2V DTN routing	Improvement of switching mechanism between greedy, perimeter and DTN modes
VANET-originated protocols	Route length and reliability optimization
	Intersection-based routing decision enhancement
	Greedy forwarding techniques
	Improvement of hybrid V2V-V2I routing
Bio-inspired protocols	Improvement of used metaheuristic
Security-assisted VANET routing	Intrusive attacks' detection and isolation
	Trust-based secure routing
VCN routing	Cloud-assisting communication
	Hybrid V2V-V2I communication
IoV routing	SDN-assisted routing
	VANET-derived routing techniques

- Improving bio-inspired alternative algorithms through combining advantages of existing nature-inspired metaheuristics.

The next remaining sections of this manuscript will provide clarifications of the above-described lacks.

Table 5 Major VANET-related routing issues with main bio-inspired protocols

Routing problem	Notable bio-inspired contributions	Related metaheuristics
Conventional ad-hoc routing concepts	G-NET, TIHOO, MAZACORNET	ACO, PSO, AISs, BOA
Parameters tuning	PSO-tuned AOMDV and DSDV parameters, DE-tuned OLSR parameters, GOA-tuned AODV parameters	EAs, ACO, PSO
VDTN routing	Human behavior-based massage routing for VDTN	BCO (Teodorović 2009), Human Social-modeled algorithms
Security techniques for VANET routing	Clonal-AODV, BFAODV	AISs, BFOA
VANETs routing challenges	Diverse works	Swarm-based metaheuristics
Existing bio-inspired ad-hoc routing protocols	Cuckoo-HyBR	All nature-inspired metaheuristics
Clustering algorithms	CACONET, GWOCNET, CAMONET	ACO, GSO, FA, ANNs
Hybrid Greedy-V2V DTN routing for VANETs	GA-assisted GeoDTN+Nav	GA, CS
Conventional VANET-destined routing protocols	Fuzzy GSO-based TAR	EAs, Swarm-based metaheuristics
VCN routing		
IoV routing	CACOIOV	ACO, PSO

6 Promising nature-based optimization algorithms for VANET-based routing

Further to well-known EAs like GA, DE and Population-based metaheuristics as ACO and PSO, numerous recently-created bio-inspired metaheuristics began to be involved in ad-hoc routing optimization such as IWD among others which have the optimization abilities and assumptions to predict and simulate better vehicular routing and find alternatives to numerous related issues like anticipating route beaks, next-hop redirection, secured routing mechanisms or other deciding kinds of stuff in mobile routing. Numerous of the following spread algorithms have already taken first steps in MANET routing, producing promising results that contend them to pass for VANET routing. We present below the notable emerging bio-metaheuristics in this studied context:

6.1 Intelligent water drop (IWD) algorithm

IWD's founder Shah-Hosseini took advantage of water-drop movement's evolution in riverbeds and the above-mentioned water-drop characteristics to write the IWD metaheuristic (Shah-Hosseini 2009). This metahor mimics the action-reaction phenomenon that occurs between water-drops and riverbed components (basically stones and soil). Thus, for each water-drop in this algorithm, two variable properties go with:

- *Velocity*(*IWD*) which represents the speed of water-drop
- *Soil*(*IWD*) which represents its related soil amount evolution

Actually, the only realized IWD-inspired VANET routing contribution is the IWD-based parameters tuning of OLSR (Gunasekar and Hinduja 2014) described previously in this paper.

IWD has been evolved in numerous works as the modified IWD algorithm proposed by Alijla et al. (2014), this version gave better results compared to the original IWD algorithm on few optimization problems like Multiple Knapsack and TSP. That's what encourages the opportunity to customize it for VANET routing.

6.2 Bacterial foraging optimization algorithm (BFOA)

Bacteria in nature are characterized by numerous biological phenomena notably the drilling strategy discovered in groups of Escherichia Coli (E.coli) bacteria seeking food sources, reproduction process and others. Thus, Passino (2002) wrote the BFOA to mimic these behaviors of E.coli whose are specifically: search for nutrients (chemotaxis), swarm behavior, reproduction behavior and finally, the elimination and dispersal, in order to solve numerous optimization problems.

To our knowledge, few routing protocols have been realized recently for VANET routing assistance using BFOA, namely:

Lee et al. (2009) suggested the Bio-inspired Multi-Agent Data Harvesting in a Proactive Urban Monitoring Environment (Datataxis), a unicast topology-based routing protocol inspired by the drilling of E.coli proposed for VANET urban environments. Datataxis uses a multi-agent system with harvesting meta-data strategy. Such agents move between network nodes where new information concentration is high, inspired by Lévy walk behavior, whereas they avoid regions having existing agents to prevent from harvesting metadata twice using a stigmergy-based prevention mechanism.

Kalia and Kaur (2015) proposed an Intrusion Detection System for VANET based on BFOA to create a specification-based Intrusion Detection System (IDS) using BFOA against Black Hole attacks.

Mehta et al. (2016) proposed the Fuzzy BFOA-inspired Zone Based Routing (FBFOZBR) which is divided into three phases: first-of-all, it implements ZBR, then calls BFOA for shortest path tracking. Finally, refers to fuzzy logic to determine wireless link status for controlling critical VANET conditions like vehicle's velocity variations and bandwidth instability.

Mehta et al. (2017) proposed three nature-inspired ZBR protocols (NIBC) including a BFO-inspired algorithm for QoS enhancement (BFOZBR) by simulating tumbling and swimming behaviors between every node and all its neighbors, where the cost of each neighbor is calculated following mobility factor and RSSI factor. The dispersal is applied on neighbor with highest cost and the process is repeated until meeting the destination whereas node stucking in local optima suffer an updated tumbling operation. BFOZBR showed an improved control overhead and better AE2ED for low transmission rates when comparing to AODV.

Secured and Enhanced VANETs Using DSR Protocol and BFOA (Devi et al. 2017), described previously in this paper, another hybrid protocol which combines BFOA with DSR for security and throughput improvement.

BFOA has been enhanced in few modified versions that can be more effective to apply on VANET routing optimization than the default BFOA like the hybrid GA and BFO approach for global optimization proposed by Kim et al. (2007), enhanced BFOA with Adaptive Elimination-dispersal Probability and PSO Strategy (EBFO) proposed by Xiongfa and Ling (2016), Crossover BFOA proposed by Panda and Naik (2012), and a Hybrid ABC Algorithm with the Chemotaxis behavior of BFOA (HABC) proposed by Zhong et al. (2011).

6.3 Artificial immune systems (AISs)

BISs usually show intelligent abilities to recognize and detect the existence of foreign micro-organisms in the human body quickly, effectively, accurately and correctly, detecting and eliminating pathogens such as viruses, bacteria or parasites by choosing adaptively the right immune responses. Immune systems and microbiological swarm-life reflects such biological interaction between micro-defensive body cells and malicious cells, to extract biologically-inspired optimization algorithms destined for several hard problems, including ad-hoc routing optimization. AISs, written by Hofmeyr and Forrest (2000), mimic the major BIS-real organic characteristics and immune behaviors to solve numerous applications. Numerous AISs models have been generated. According to (Zheng et al. 2010), AISs are divided into population-based and network-based algorithms. The latter algorithms call the immune network theoretical concepts, whereas the former type uses further theories like the clonal selection (CSA) and negative selection (NSA) algorithms (Forrest et al. 1994).

AIS is applied for VANETs, we found a recent contribution based on the Cellular Attracting Selecting Model for unicast routing (URAS) proposed by Tian et al. (2018) to improve the next-hop selection exploiting CASM's robustness and self-adaptability and

GPS-collected information of vehicles. A second approach is used to reduce the number of next-hop candidates which is the technique for order by preference in order to reduce the redundant neighboring candidates. The opportunistic forwarding is used in case no candidates are available. URAS showed better QoS performances than GPSR

AIS-inspired metaheuristics have several initiatives for security of ad-hoc networks serving routing optimization. But, according to our research, no particular contribution for VANET routing was proposed so far using the above-mentioned AIS-extracted algorithms, hence the opportunity is open for a wide research area on Immune-inspired vehicular routing due to common similarities between VANETs and MANETs. AISs possess numerous optimization algorithms (Liu et al. 2006) that can be effective to assist vehicular routing like the CSA or NSA which encourage to contend for solving different types of VANET routing-related problems like security, MANET-converted protocols, QoS routing and congestion control.

6.4 Firefly algorithm (FA)

FA metaheuristic, proposed by Yang (2009), is a nature-inspired EA which idealize some of the flashing characteristics of fireflies, or lightning bugs, inspired by their social behavior and the bioluminescent communication phenomenon. FA is proposed for both discrete (Tilahun and Ngnotchouye 2017) and continuous optimization problems (Łukasik and Żak 2009).

Tendencies for VANET appeared very recently, logically likewise several VANET routing problems due to the well-known similarities noted with MANETs. We expose here the realized FA-inspired contributions for VANETs

CBR using FA, described above in this paper. The second is, Efficient Routing in VANETs using Firefly Optimization suggested in the thesis realized by Chhabra (2016), which seeks transmission time and better connectivity by applying FA on each vehicle: source firefly applies controlled flooding, where the next-hop vehicle is selected seen its objective function that counts both velocity and neighborhood density. This operation is repeated until reaching the sought destination. FA intervenes in calculating the fitness value on each current hop of candidate fireflies for next-hop selection, choosing the most attractive one. Attractiveness depends on the cartesian distance between current firefly and next one, their movement harmony and the delay separating them.

A multi-objective FA-inspired weighted clustering algorithm for VANET (RWCP-MFO) (Joshua et al. 2019), described previously in this paper, which exploits the twinkling behavior of fireflies to settle cluster stability and better CH election.

FA has less impact on major routing tasks in VANETs comparing to classic well-known metaheuristics like GA or ACO, but it can intervene in particular tasks like the FA-inspired proposed routing solutions seen realized works on WSN, MANETs and especially latest merging tendencies for VANETs. FA can be an effective metaheuristic for VANET-originated routing categories besides cluster-based routing. Also, the use of FA-enhanced versions (Yang 2014) can give more stability and accurate dissemination comparing to original FA.

6.5 Lion optimization algorithm (LOA)

Lion-based populations present numerous common phenomena that are already noticed in other natural populations, the case with bees and ants, besides other behaviors such as the cooperation and antagonism aspects that characterize lion communities. The notable particularities in lions' swarm living are modelled mathematically in an optimization algorithm, namely the LOA metaheuristic provided by Yazdani and Jolai (2016). LOA is an optimization metaheuristic simulating both single and cooperative behaviors of lions such as prey hunting, mutation, territorial marking, coupling and defense. LOA includes a serial of nine steps described well in (Yazdani and Jolai 2016).

Numerous lion's behaviors can be approached to VANET-based routing optimization problem. For example, the hunting behavior can be a good method for mobile routing optimization since the intelligent way that lionesses show in catching preys is similar to seeking a vehicle destination. The roaming behavior can be contributive to VANET routing equally since it can ameliorate local solutions and provide more effective stochastic intensification search for route moving in clause areas. The defense behavior seen detection reflexes that lions show among themselves can be exploited equally for secured routing in VANETs to block attacks targeting forwarded packets or nodes. It can also provide recent routing information which ensures more routing reliability. The migration which can offer a good diversification search for global solutions.

For VANETs, only one found LOA-based work is the modified lion-inspired QoS routing algorithm for route discovery assistance fin VANETs is suggested by Wagh and Gomathi (2018b) which exploits the leading characteristic of lion in pride and the moving from local pride to a stronger pride to optimize the QoS route discovery in VANETs. The proposed solution gets ride of the original LOA weaknesses residing in crossover and mutation operators. The fitness evaluation considers the congestion cost, travel cost, QoS awareness cost and collision cost as parameters for evaluating each lion packet before passing fertility evaluation and mating operator which decide its direction after territorial defense and takeover steps. The proposed model surpasses both GA and LOA in collision and travels costs.

No further LOA-inspired routing protocols have been realized for vehicular ad-hoc routing according to our research, but the window is open to exploit the variety of LOA algorithm which offers very performant intensification-and diversification balance which is needed for ad-hoc routing optimization.

6.6 Human social-modeled behaviors

Social phenomena that we can notice in our daily life are the context of a wide research for exploiting classic daily activities of human living being for performing intelligent ad-hoc routing specifically for VANETs such as pedestrian behaviors as walking in roads or streets (Frohnwieser et al. 2013), marrying traditions and tendencies, organization of peoples' communities, leadership styles in groups, communities and professional life, friendship mechanism (Khokhar et al. 2011), social leadership styles (Ramezani and Lotfi 2013) human driving behaviors, and so on. Other social-originated practices cited in Hung (2012) which proposed a Social Behavior Algorithm (SBA) extended from GA and inspired from few family-related behaviors.

Social behaviors can be approached to different sorts of routing tasks in VANETs. In our opinion, leadership can be exploited for heading routing nodes like CH role in CBR. Friendship helps to forward packets with less beaconing and more accurate delivery. The same context for walking behaviors and citizen social practices. Social-based algorithms have tendencies towards proactive routing in which several opportunities are open like providing an effective restricted beaconing seen the similarity in the distribution of both human individuals and vehicles in cities. The case is identical for intersection-based routing with use of GPS.

Social-behavior intelligence has been tried for VANET routing, driving behavior of humans in roads inspired the Fuzzy-Assisted Social-based rouTing (FAST) protocol realized by Khokhar et al. (2011), a geography-based routing protocol for urban environments that leverages the friendship mechanism for optimal and secured routing decisions exploiting prior global knowledge of real-time traffic. FAST's friendship mechanism is differentiated into three categories: direct friends, indirect friends (friends-of-friends) and non-friends. In the first, vehicular relationships are based on personal judgment in daily life experiences. In the second, such relationships are based on the positive reputation of other vehicles, while in the third new nodes can be added to the current node's list after creating mutual trust with friends or friends-of-friends. FAST gives higher PDR, less average delay and less hop count, comparing with GPCR, GPSR, RBVT-R and GyTAR (Jerbi et al. 2006) following different packet rates.

Sharma and Kad (2018) described the notable human social-based protocols for VANETs which are conceived for DTN routing recently the Social Routing protocol proposed by Schoeneich and Surgiewicz (2016) which reflect the friendship human behavior in canalizing message forwarding exploiting the number of friends and their social ranking.

Another human-inspired work is the social-based Epidemic (EpSoc) proposed by Lenando and Alrfaay (2018) suggesting the control of overheads in ER by setting two mechanisms: the first considers the node's popularity whereas the second sets a message blocking mechanism to avoid receiving replicated surpassed TTL bundles.

Not all social-inspired behaviors are modelled so far which opens a large area for extending social-based optimization algorithms and deepening their utilization on VANET routing, especially seen the effectiveness of already tried techniques like friendship mechanism and SBA model on the above-described protocols.

6.7 Cuckoo search algorithm (CSA)

The cuckoo search optimization metaheuristic has been proposed by Yang and Deb (2009) modelling the aggressive reproduction behavior of particular bird species called cuckoo which show other abilities like increasing the hatching expectation of its eggs. The intelligent movement from worse to better nest characterizes the convergence quality of CS which leads the optimization of combinatorial problems.

For VANET, few CSA-inspired schemes have been realized lately, we mention:

The CSA-based adaptive routing (ARP-CS) for secured VANET proposed by Ramakrishnan et al. (2015) suggesting a hybrid topology and geography-based protocol where a GA-assisted geographic routing is applied for low network density levels while a CSA-based topologic routing is performed for high density as the case in urban areas, CSA with Lévy flights intervene in the route discovery process to produce less congested routes by considering the distance as the fitness evaluation parameters for each nest (solution) and the Lévy flight searches arbitrarily for novel solution exploiting its huge coverage range. ARP-CS's performances surpasses existing method as AODV and GPSR in AE2ED and NRL.

Second work is the Cuckoo-HyBR protocol (Kaur and Devgan 2018), described previously in this paper which improves the performance of HyBR (Bitam et al. 2013b) by involving CSA in the route optimization process.

CSA is a promising nature-inspired metaphor for VANET routing optimization bringing the convergence abilities of swarm-inspired metaheuristics like ACO, IWD and BFOA, and the reproduction-based characteristics noted in the EA-based metaheuristics like GA and BOA. That's moreover to the hybridization capabilities with other swarm-inspired metaphors thanks to its local search advantages which incites for spreading on further VANET-related routing problems.

6.8 Other nature-inspired metaheuristics

We expose in this subsection a few emerging bio-inspired metaheuristics that can contribute the described VANET-related routing problems:

6.8.1 Bull optimization algorithm (BOA)

BOA metaheuristic is a new EA proposed by Findik (2015) to solve continuous optimization problems. BOA is a GA-modified algorithm which uses classic genetic operators, namely crossover and mutation. The difference resides in exploiting the best individual found up to ongoing iteration, for producing offsprings to next generations contrarily to GA. BOA removes selection operator seen it entails decreasing searching ability due to filtration of best individuals since early stages and, the fact that clause partial fitness values don't permit to improve solutions due to random selection. Furthermore, BOA modifies the GA-based mutation using values of the gene to get rid of local minima by increasing randomization factor. BOA proved positive results using unimodal, multimodal, separable, non-separable, regular, and irregular test functions, compared to classic metaheuristics.

BOA has been proposed lately in the BVRRP scheme (Azzoug and Boukra 2019), described previously in this paper, for assisting the reactive topology-based routing. BOA intervenes in generating optimized paths for both regular and recovery forwarding considering the specific fitness evaluation parameters that serve the characteristics of routing of each type.

BOA seen its nature can perform better than classic EAs like GA and DE in solving several VANET-based routing issues like routing parameters tuning, congestion control and routing path shortening. Especially, BOA is positively tested in benchmark test functions and gave better results comparing to GA, DE and PSO.

6.8.2 Glowworm swarm optimization (GSO)

A swarm-inspired metaphor approach proposed by Krishnanand and Ghose (2006) the grouped movement of glowworm particles controlled by a luminescent quantity named luciferin. GSO is a variant of the ACO that offers solutions to continuous functions. GSO proved positive convergence results in multimodal functions seen its ability to detect multiple local optima.

Lately, GSO metaheuristic began to take part in swarm-inspired VANET routing with few contributions notably:

The fractional GSO-assisted TAR routing (FGWSO-TAR), described previously in this survey, improving the performance of TAR using a modified version of GSO to avoid convergence toward local minima.

A GSO-inspired position-based routing algorithm suggested by Yarinezhad and Sarab (2019) which establishes routing paths by propagating glowworm routing packets. GSO algorithm uses the updating mechanism of luciferin on request packets based on vehicles position when selecting each next-hop toward the destination. The luciferin is updated on each reached hop after calculating the fitness value which is based on the number of vehicles plus the ED between the source and current hop. The proposed GSO routing scheme is compared to OSTD (Mirjazaee and Moghim 2015) and SAMQ (Eiza et al. 2015) protocols, the simulation results showed a higher average PDR and lower lost packet ratio.

The GSO has been the context of enhancement the case of (Wu et al. 2012) which opens for spreading its application for diverse VANET-related routing problems. GSO offers the characteristic of grouping which can be exploited, moreover to intersection-based routing, in the cluster-based routing in which numerous similar, metaheuristics proved its efficiency like GWO (Mirjalili et al. 2014) and FA.

6.8.3 Whale optimization algorithm (WOA)

A swarm-inspired metaphor approach proposed by Mirjalili and Lewis (2016) inspired from the hunting strategy of humpback whales and their ability to localize prey's position, and the bubble-net attacking behavior which considers the exploitation phase, while the search for prey reflects the exploration phase. WOA search agents update their position toward the best agent.

Few realizations of VANET routing have been realized using WOA the very last few years, we mention:

The adaptive autoregressive WOA for traffic aware routing for urban networks (Adaptive-ARW) proposed by Rewadkar and Doye (2018) consisting of applying the Exponential Weighed Moving Average (EWMA) fore traffic prediction considering the average nodes velocity and network density. The WOA intervenes in optimizing the generated paths from the EWMA by adjusting whale agents' positions based on three factors namely, fitness value, distance to the best agent and the number of passed iterations. The proposed solution gave better E2ED comparing to other schemes like GSO approach and SCRP (Togou et al. 2016).

An improved WOA for vehicular communication (AWCP-EWOA) proposed by Kittusamy et al. (2019) suggesting an adaptive weighted clustering protocol (AWCP) for improving cluster stability measured by CM longevity and optimum CH election through grouping randomly-distributed vehicles, and using a modified WOA (EWO). Vehicle's position and velocity moreover to distance between trusted vehicles and RSUs are used in the cluster formation process. The proposed EWO avoid tracking best local solution since early stages of the algorithm, this is shown in its CH updating with aid of shrinking encircling and spiral update mechanisms, and the dynamic set stopping criteria. The proposed AWCP-EWOA gets better cluster stability comparing to AWCP and AWCP-WOA.

6.8.4 Artificial fish swarm algorithm (AFSA)

AFSA is a nature-based metaheuristic proposed by Neshat et al. (2012) inspired from the grouped movement of fish and its various social behaviors. AFSA can furnish an effective global stochastic search for optimal solutions, besides elevated tracking accuracy, high convergence speed and performant flexibility for vehicular routing seen its similarities with classic metaheuristics like ACO and ABC.

One found AFSA-inspired protocol for VANETs is a geography-based routing algorithm with hybrid TS-AFSA route links optimization proposed by Sataraddi et al. (2017)

the protocol combines the V2V and V2I communication and uses GPS-collected vehicles position. This solution exploits the fast convergence of AFSA with the global optimization abilities of TS used for route discovery optimization providing more stable routes. The implementation of AFSA showed progress in basic QoS metrics.

6.8.5 Grasshopper optimisation algorithm (GOA)

The GOA swarm approach is proposed by Saremi et al. (2017) modelling and mimicking the swarm behavior of particular insecticide species called grasshopper reflecting the evolution of its lifecycle notably the migration and food seeking. The latter is characterized by two major interactive behaviors between grasshoppers which are attraction and repulsion, where the first incites for exploiting promising regions while the second incites for exploring the search space. The GOA models the balance between exploitation and exploration of this operation using an adaptive coefficient for limiting the concentration of grasshoppers in their comfort areas.

Very few GOA-based works on VANET routing started appearing lately with the GOA-based parameter tuning of AODV for VANETs (Tabar and Farazkish 2019), described previously in this survey, which seeks finding the best combination of parameters for optimal functioning of AODV and showed better result than GA in some QoS metrics.

GOA has the balance stochastic searching depth in term of intensification and diversification to optimize numerous types of VANET routing problems which opens a wide perspective for GOA bio-inspired routing contributions.

6.8.6 Grey wolf optimization (GWO)

The GWO metaheuristic is a nature-inspired metaphor proposed by Mirjalili et al. (2014) inspired from two behaviors of grey wolves, a Canidae family species, namely the leadership hierarchy and hunting mechanism. Grey wolf shows exploitation and exploration abilities in all hunting behaviors as searching, tracking, encircling and attacking preys. The hierarchical ranking is another modelled phenomenon in the GWO reflecting the intelligent selection of fittest solutions. GWO proved promising ability in quick convergence and local optimum avoidance when test with multimodal benchmark functions.

GWOCNETs clustering algorithm (Fahad et al. 2018), described previously in this survey, is one of the very recent and first works conceived for VANET routing on the basis of GWO algorithm, GWOCNET showed the abilities of GWO in improving cluster stability on VANETs. Another GWO-inspired intelligent clustering algorithm (ICGWO) proposed also by Khan et al. (2018), likewise GWOCNET, ICGWO exploits the hierarchical system of wolf swarm to rank routing search agents seen numerous factors namely, the ED between nodes, speeds, directions and transmission ranges.

The GWO can be spread to further VANET routing problems, seen its research methods variety, particularly on route optimization within different categories of vehicular routing, swarm-inspired routing optimization and VDTN routing.

6.8.7 Water wave optimization (WWO)

A nature-inspired metaheuristic proposed by Zheng (2015) inspired from the movement of water waves in seas and oceans modelling its basic operations namely the propagation, refraction and breaking. The WWO algorithm models the interactive behavior of waves in the three operations where the ability to escape from search stagnation in refraction, intensive search in breaking, and size variation in area exploration in propagation show the adaptive balance of WWO between intensification and diversification.

Lately, a WWO-based routing protocol for VANETs has been suggested by Wagh and Gomathi (2018a) simulating the water wave features for optimal route selection on the basis of three factors namely, congestion, QoS and collision. The costs of the three evaluated factors gave better results for WWO comparing to GA and LOA.

6.8.8 Elephant herding optimization (EHO)

EHO algorithm is proposed by Wang et al. (2015b) for solving global optimization tasks. EHO got inspiration from the herding behavior of grouped families of elephants. EHO gave better optimization tendencies than DE, GA and Biogeography-based optimization (BBO) (Simon 2008) in numerous benchmark problems, which encourages to introduce it for numerous VANET routing problems, notably:

- Clustering optimization for VANET CBR assistance seen the possibility for exploiting the grouping behaviors of elephant under the leading of the matriarch.
- The latter property can serve to the reactive routing as well.

6.8.9 Earthworm optimization algorithm (EWA)

Metaheuristic-based studies focused on life-phenomena of particles living in the soil, the case of earthworms. Earthworms have numerous particularities like breathing through its skin, absorbing nutrients from live and corpse organic substances and possessing a solid digestive system that functions through its full body. These properties gave birth to EWA metaheuristic proposed by Wang et al. (2015a), an evolutionary algorithm which reflects the reproduction behavior of earthworms. EWA can contend for solving numerous VANET routing challenges seen its similarities with common nature-inspired metaheuristics.

6.9 Synthesis

We conclude this section by regrouping all treated VANET-related routing problems for each spread bio-inspired approach as shown in Table 6. We seek recapitulating in an entirety of the tendencies of involved bio-inspired optimization algorithms in VANET routing including an opinion about likely routing problems to treat in the future for each bio-inspired approach.

7 A taxonomy of different combinations of bio-inspired approaches proposed for VANET routing

In this section, we spread the main used combinations of metaheuristics and different implementations according to the heterogeneity of VANET routing problems, metaheuristic categories and optimization tendencies:

Table 6 Major emerging nature-inspired metaheuristics for VANET routing

Bio-inspired approach	Treated routing problems	Emerging routing problems
BFOA metaheuristic	Security mechanism for VANET routing	VANET-originated protocols
	Swarm-inspired routing tasks	VDTN routing
	Conventional ad-hoc routing	
Human Social-based algorithms	Geography routing-related tasks	Clustering optimization
	Secured routing for VANET	
IWD algorithm	Reactive routing-related tasks	Geography routing-related tasks
AIS algorithms	VANET security issues	VDTN routing
	Conventional ad-hoc routing	
BOA metaheuristic	Routing-related tasks	Parameters tuning
FA metaheuristic	Routing-related tasks	VDTN routing
	Clustering optimization	
AFSA metaheuristic	Position-based routing	Routing-related tasks
		Conventional ad-hoc routing
LOA metaheuristic	Routing-related tasks	VANET-originated protocols
		Conventional ad-hoc routing
CSA algorithm	Bio-inspired ad-hoc protocols	VANET-originated protocols
	Secured routing for VANET	Conventional ad-hoc routing
GSO algorithm	Geography-based routing	Intersection-based routing
		Cluster-based routing
WOA metaheuristic	Route optimization	
	Clustering optimization	
GOA metaheuristic	Parameters tuning	Route optimization
		Bio-inspired ad-hoc protocols
GWO algorithm	Clustering optimization	Swarm-inspired route optimization
		VDTN routing
WWO algorithm	Route optimization	
EHO algorithm		Routing-related tasks
		Security-related routing
		Clustering optimization
EWA metaheuristic		Routing-related tasks

7.1 Swarm-inspired metaheuristics

Swarm-based approaches are metaphor-inspired approaches that treats great part of VANET routing protocol's tasks, starting by optimizing route paths and reducing packet loss. Numerous well-known behaviors are ant-colonies seeking for food nests, water-drops way to settle in final destinations like lakes or seas, reproduction process of numerous particles like bees or bacteria, immigration of birds, human social living and among other behaviors. Swarm-based metaheuristics are evolving either with modified versions like EBFOA in Sonia and Kaur (2016), or newer realized metaheuristics like IWD, LOA described above in this paper.

The great amount of realized routing works reflect the implication degree of swarm-inspired approaches, especially in QoS and naturally-imitated routing. Notable works started with a BCO-inspired routing algorithms (MQBV) proposed by Bitam et al. (2013a) assisting QoS multicast and multipath routing protocol to find and maintain robust routes between source and all multicast group members. Bee Life Algorithm (BLA) for resolving QoS in MRP (QoS-MRP) in VANETs (Bitam and Mellouk 2013). Also, QoS Bee Swarm (Bitam and Mellouk 2011), a new QoS multipath routing protocol inspired by the automatic bee communication.

Recent research tendencies merged to younger swarm-based algorithms, initially for MANETs like FBFOZBR protocol using BFOA, then passed to VANETs such as FAST, described above in this paper, a social-inspired protocol inspired from friendship mechanism, which tries to imitate social behaviors from human daily mobility in roads to make optimal and secure routing decisions.

Swarm-inspired optimization algorithms are used to solve numerous other problems of VANET routing further to QoS routing like:

- VDTN routing, like the Human behavior-based Message Routing in VDTN (de Andrade et al. 2016).
- Parameters tuning, like the PSO-based optimal configuration of DSDV (Sharma et al. 2014) and AOMDV (Lobiyal et al. 2015).
- Clustering optimization, like CACONET algorithm using ACO.

Recently founded algorithms can be more interesting to use for VANET routing like IWD, EWA, LOA and others. Further details of future swarm-based metaheuristics are spread previously in this survey. Swarm-based metaheuristics are all-round optimization techniques for routing context in VANETs and can contribute with different direct or indirect ways by their ability to solve multiple VANET-originated routing issues.

7.2 Hybrid bio-inspired optimization approaches

Regrouping the advantages of different bio-inspired metaheuristics seen their varieties and characteristics, is being more interesting in VANET routing. The principle combines advantages of two or more different metaheuristic parts where certain approaches privileges local search while others give quicker global convergence. Such example we cite the chemotaxis behavior of BFOA, mutation operator in DE and GA, food foraging in ACO and so on. Such hybridization can provide better balances between intensification and diversification methods (Lozano and García-Martínez 2010) and gives quicker searching convergence to solve hard problems, hence getting less responding time. Different types of metaheuristic-based combinations exist like:

- Combining two full metaheuristics like in Kim et al. (2007) which offers a GA-BFOA algorithm for global optimization.
- Combining a metaheuristic with a functionality of another metaheuristic like in Zhong et al. (2011) suggesting a hybrid ABC with BFOA's Chemotaxis behavior.
- Combining enhanced versions of a metaheuristic with another metaheuristic or a functionality of it like in Cao et al. (2015) associating an improved Brain Storm Optimization (BSO) (Shi 2011) version with DE algorithm.

Several combinations of two metaheuristics have been realized in the framework of VANET routing like hybrid ACO-PSO based algorithm for the QoS MRP (Patel et al. 2014) using a swarming agent based on a hybrid ACO-PSO algorithm. Hybridization of Meta-heuristics for Optimizing Routing protocol in VANETs (Gautami et al. 2016) using a combination of GA and SA (Kirkpatrick et al. 1983). Lately, a hybrid PSO-Leapfrog approach for multipath routing for VANETs is proposed by Bhagyavathi and Saritha (2016) using PSO for path construction and Leapfrog algorithm for predicting vehicles position and speed and route updating.

Hybrid metaheuristics have been used to solve QoS routing of VANET so far. Meanwhile, such metaheuristics are as performant as to solve different VANET routing problems like parameters tuning, security and clustering optimization. Hybrid nature-inspired metaheuristics still a wide research area for contributing to bio-inspired routing in VANETs seen the emergence of new nature-inspired algorithms like LOA, EWA or FA and the variety of vehicular routing problems that can be approached to NP-Hard problems solvable by bio-inspired optimization algorithms.

7.3 Combined bio-inspired approaches and conventional ad-hoc routing solution

This field is spread initially on MANET-originated protocols in the framework of VANET-destined routing, since MANET protocols gave typical examples how to combine conventional routing techniques of well-known protocols, notably the topology-based schemes such as AODV and OLSR besides geography-based and CBR techniques, with nature-inspired optimization metaheuristics.

Notable contributions within this field are: HyBR, combining geography-based routing with ABC for vehicular sparse networks. A hybrid optimization algorithm for geographic routing in VANET (Tamizhselvi and Banu 2014) by combining PSO with Broyden-Fletcher-Goldfarb-Shanno (Head and Zerner 1985). G-NET, described previously in this survey, which implies a DSR-based route discovery with a GA-inspired route maintenance. To conclude, MAZACORNET, described above in this paper, a hybrid Zone-based ACO-inspired multi-path routing algorithm among others.

That kind of optimization has been spread also on VANET-originated protocols, as discussed above in this paper. Since there exist VANET-originated routing protocols that are the context of hybridization with bio-inspired optimization algorithms. The case notably of GeoDTN+Nav with GA in Bitaghsir and Hendessi (2011), setting a GA-based routing in DTN mode to select the optimal carry-and-forward vehicle. Lately, a combined ACO-inspired RSU-assisted routing protocol for VANETs by Melaouene and Romadi (2019) using both V2V and V2I communication paradigms for improved intersection-based routing performing an ACO-like path exploration.

This field is still productive for more contributions, especially for VANET-originated protocols like VADD (Zhao and Cao 2008), RIVER (Bernsen and Manivannan 2012), TFOR (Abbasi et al. 2014) among others. Where there is the opportunity to produce bio-inspired versions on the basis on such protocols.

7.4 Parallel multi-objective optimization

Appeared in the framework of routing parameters tuning. Where sorts of parallel optimization metaheuristics have been proposed to surpass classic metaheuristics performances. Parallel algorithms consist of simultaneous execution of the same metaheuristic algorithm or a combination of numerous metaheuristics on numerous iterations.

Few metaheuristic-based parallel optimization algorithms destined for MOPs have been realized. We expose few existing use cases, namely:

Toutouh and Alba (2012b) proposed the parallel PSO (pPSO) optimization algorithm, a PSO-based algorithm, where the swarm evaluation is split into several processing elements executed simultaneously, permitting parallel fitness computations by setting a master-slave model.

Atashpendar et al. (2016) proposed the parallel Cooperative Coevolutionary SMPSO Algorithm for Multi-objective Optimization (CCSMPSO), a variant of Speed-constrained Multi-objective PSO (SMPSO) in a cooperative coevolutionary framework.

Few works have been initiated using parallel optimization algorithms for vehicular ad-hoc routing, particularly for parameters tuning, the case of the Implication of a Parallel Swarm Intelligence algorithm for VANETs Optimization proposed by Toutouh Toutouh and Alba (2012a), which suggests the pPSO algorithm for AODV routing optimization. pPSO executes n multi-objective parallel tunes of AODV routing parameters using the NS2 simulator. Simulation results show a better QoS metrics returns (PDR, NRL, and E2ED) comparing to original PSO.

Fast energy-aware OLSR routing in VANETs using parallel EA (pEA) proposed by Toutouh et al. (2013) a parallel GA (pGA) for tuning OLSR protocol's eight-sized routing parameters set with the intermediate of MALLBA library (Alba et al. 2007).

Toutouh and Alba (2017) proposed a parallel multi-objective metaheuristics (pMOAs) for smart communications in VANETs, composed from two schemes, pNSGA-II and pSMPSO, used for tuning routing parameters of AODV under urban scenarios. pNSGA-II is a parallel version of NSGA-II (Deb et al. 2002), a GA-variety well-known multi-objective evolutionary algorithm (MOEA) which applies genetic operators during regeneration process on population's individuals and saves best individuals regarding an evaluating metric called the crowding distance, while pSMPSO is a parallel version of SMPSO (Nebro et al. 2009) which imposes a velocity constriction mechanism to reduce the swarm explosion problem found usually in multi-objective PSO-based algorithms. pSMPSO and pNSGA-II parallelize the evaluation operator of SMPSO and NSGA-II respectively.

Toutouh and Alba (2015) suggested a parallel running of numerous EAs, namely: PSO, DE, GA, ES and SA to find the optimal configuration for OLSR's routing parameters.

Parallel metaheuristics represent effective stochastic approaches for parameters tuning, better than classic EAs and can be a good solution for other VANET routing problems which tend for evolutionary metaheuristics like congestion control. The parallel solution can contribute better to QoS routing as well.

7.5 Enhanced bio-metaheuristic techniques

Another conceived type of optimization technique appeared last few years is being used for optimizing different of the discussed routing problems is based on original bio-inspired optimization algorithms such as GA, FA among others. This sort of modified version to improve the performances of the classic versions by either adding particular aspect that allow deepening research depth and improving intensification-diversification effectiveness, or deleting other aspects that deteriorate the quality of stochastic search in different stages of running optimization process and forces quick convergence to local optima. Particularly for VANET routing, numerous techniques have been introduced on this type of optimization, in this case:

- Conventional modification on original bio-inspired approaches, we cite: fractional GSO (FGWSO) in Rewadkar and Doye (2017), chaotic Krill Herd Optimization (KHO) (Gandomi and Alavi 2012) proposed in Amudhavel et al. (2015b), etc.,
- A generated metaheuristic taking basis from a classic approach, the case of BOA approach, an enhanced version of the GA implemented in BVRRP (Azzoug and Boukra 2019),
- New emerging approaches with similar feature of older metaheuristic, we mention for instance GSO metaheuristic, a variant of ACO, implemented in the intersection-based routing,
- Using one or few features of particular metaheuristic for enhancing the main approach, we illustrate this type with the ANN-improved WOA case proposed in Yadav et al. (2017),
- Among others.

Numerous examples illustrate such modified metaheuristic, we mention notably:

- An improved GA-based route optimization scheme (IGAROT) proposed by Bello-Salau et al. (2019) introducing a V2I protocol for urban VANETs featuring an enhanced GA with k-means clustering approach to increase GA's global convergence speed.
- The modified LOA for route discovery optimization (Wagh and Gomathi 2018b) described previously in this paper.
- The EWOA-based clustering implemented in AWCP (Kittusamy et al. 2019) described previously in this paper.
- The ANN-improved WOA for VANET routing optimization (Yadav et al. 2017) described previously in this paper.

8 Conclusion and future perspectives

In this survey, we exposed the major routing problems found in vehicular ad-hoc routing and their related protocols, with details of origins and evolution of each problem. A progressive description of realized VANET routing contributions from classic to bio-inspired works is presented increasingly with the attained solutions realized using nature-inspired metaheuristics, moreover with clearing the major remaining challenges of improving existing bio-inspired works for each spread problem.

This paper exposed as well, an overview and perspective of new emerging nature metaheuristics, which can contribute to the VANET-originated routing according to several criteria and assumptions. This paper can provide a referential classification of routing problems in VANETs by clarifying the current realizations made using bio-inspired approaches which split those problems into two categories in our opinion based on the advancement state made, namely existing treated problems and emerging developed problems.

A taxonomy of different combinations of bio-inspired optimization algorithms is exposed to analyze the variety of exploitation of metaheuristics to offer better routing in VANETs than using classic metaheuristics. A typical use case is the hybridized metaheuristics and parallel optimization algorithms.

This survey spread as well, a wide window of potential nature-based metaheuristics that can provide an effective support to solve different mentioned VANET routing problems, either EAs like BOA or swarm-based metaheuristics like LOA.

This contribution presents a global guide to contribute to VANET routing quality using nature-inspired optimization approaches, by offering a historic evolution of what has been already realized to expose remaining challenges to fulfil in the framework of bio-inspired vehicular routing development.

References

Aadil F, Bajwa KB, Khan S, Chaudary NM, Akram A (2016) CACONET: Ant colony optimization (ACO) based clustering algorithm for VANET. PLOS ONE 11(5):e0154080

Ababou M, Elkouch R, Bellafkih M, Ababou N (2014a) AntProPHET: a new routing protocol for delay tolerant networks. In: Proceedings of the 14*th* Mediterranean microwave symposium, Marrakech. IEEE

Ababou M, Elkouch R, Bellafkih M, Ababou N (2014b) BeeAntDTN: a nature inspired routing protocol for delay tolerant networks. In: Proceedings of the 14*th* Mediterranean microwave symposium, Marrakech. IEEE

Abbasi IA, Nazir B, Abbasi A, Bilal SM, Madani SA (2014) A traffic flow oriented routing protocol for vANET. EURASIP J Wirel Commun Netw 121:1–14

Agarwal RK, Mathuria M, Sharma M (2017) Study of routing algorithms in DTN enabled vehicular ad-hoc network. Int J Comput Appl 159(7):1–6

Ahmadi S-A (2016) Human behavior-based optimization: a novel metaheuristic approach to solve complex optimization problems. Neural Comput Appl 28(1):233–244

Ahmed B, Malik AW, Hafeez T (2019) Ahmed N (2019) Services and simulation frameworks for vehicular cloud computing: a contemporary survey. EURASIP J Wirel Commun Netw 4:1–21

Ahmed SH, Kang H, Kim D (2015) Vehicular delay tolerant network (VDTN): routing perspectives. In Proceedings of IEEE 12*th* Consumer communications and networking conference, pp 898–903, Las Vegas. IEEE

Alba E, Luque G, Garcia-Nieto J, Ordonez G, Leguizamón G (2007) MALLBA: a software library to design efficient optimisation algorithms. Int J Innovative Comput Appl 1(1):74–85

Ali AF, Hassanien A-E (2016) A survey of metaheuristics methods for bioinformatics applications. In: Hassanien A-E, Grosan C, Tolba MF (eds) Applications of intelligent optimization in biology and medicine, chapter 2. Springer, Switzerland, pp 23–46

Alijla BO, Wong L-P, Lim CP, Khader AT, Al-Betar MA (2014) A modified intelligent water drops algorithm and its application to optimization problems. Expert Syst Appl 41(15):6555–6569

Allal S, Boudjit S (2013) Geocast routing protocols for VANETs: survey and geometry-driven scheme proposal. J Internet Serv and Inform Secur 3(1–2):20–36

Aloise D, Deshpande A, Hansen P, Popat P (2009) Np-hardness of Euclidean sum-of-squares clustering. Mach Learn 75(2):245–248

Alouache L, Nguyen N, Aliouat M, Chelouah R (2018) Survey on IoV routing protocols: security and network architecture. Wiley, Hoboken

Amudhavel J, Kumar KP, Narmatha T, Sampathkumar S, Jaiganesh S, Vengattaraman T (2015a) Multi-objective clustering methodologies and its applications in VANET. In: International conference on advanced research in computer science engineering & technology (ICARCSET '15), Unnao. ACM, pp 1083–1092

Amudhavel, J., Rajaguru, D., Kumar, S. S. (2015b). A chaotic krill herd optimization approach in VANET for congestion free effective multi hop communication. In: Proceedings of the (2015) international conference on advanced research in computer science engineering & technology (ICARCSET 2015). Unnao, ACM, India

Arthur D, Vassilvitskii S (2007) k-means++: the advantages of careful seeding. In: Proceedings of the 18*th* annual ACM-society for industrial and applied mathematics symposium on discrete algorithms, New Orleans, Louisiana. ACM, pp 1027–1035

Atashpendar A, Dorronsoro B, Danoy G, Bouvry P (2016) A parallel cooperative coevolutionary SMPSO algorithm for multi-objective optimization. In: International conference on high performance computing & simulation, Innsbruck. IEEE, pp 714–720

Azzoug Y, Boukra A (2019) Reactive topology-based routing for VANETs: a new bio-inspired solution. In 8*th* international conference on advances in vehicular systems, technologies and applications, Roma

Balaji S, Sureshkumar S, Saravanan G (2013) Cluster based ant colony optimization routing for vehicular ad-hoc networks. Int J Sci Eng Res 4(6):26–30

Bello-Salau H, Aibinu A, Wang Z, Onumanyi A, Onwuka E, Dukiya J (2019) An optimized routing algorithm for vehicle ad-hoc networks. Eng Sci Technol Int J 22(3):754–766
Benamar N, Singh KD, Benamar M, Ouadghiri DE, Bonnin J-M (2014) Routing protocols in vehicular delay tolerant networks: a comprehensive survey. Comput Commun 48:141–158
Bernsen J, Manivannan D (2012) RIVER: a reliable inter-vehicular routing protocol for vehicular ad hoc networks. Comput Netw 56(17):3795–3807
Bhagyavathi M, Saritha V (2016) Leapfrog and particle swarm optimization based multipath routing for VANETs. Contemp Eng Sci 9(31):1525–1533
Binitha S, Sathya SS (2012) A survey of bio inspired optimization algorithms. Int J Soft Comput Eng 2(2):137–151
Bitaghsir SA, Hendessi F (2011) An intelligent routing protocol for delay tolerant networks using genetic algorithm. In Balandin S, Koucheryavy Y, Hu H (eds), Proceedings of the 2004 11*th* international conference on next generation wired/wireless networking and the 4*th* conference on smart spaces. Lecture Notes in Computer Science book series, vol 6869. Springer, St. Petersburg., pp 335–347
Bitam S, Mellouk A (2011) QoS swarm bee routing protocol for vehicular ad-hoc networks. In: Proceedigs of IEEE International Conference on Communications, Kyoto
Bitam S, Mellouk A (2013) Bee life-based multi constraints multicast routing optimization for vehicular Ad-hoc networks. J Netw Comput Appl 36(3):981–991
Bitam S, Mellouk A (2015) Cloud computing-based message dissemination protocol for vehicular ad hoc networks. international conference on wired/wireless internet communication. Springer, Cham, pp 32–45
Bitam S, Mellouk A, Fowler S (2013a) MQBV: multicast quality of service swarm bee routing for vehicular Ad-hoc networks. Wirel Commun Mob Comput 15(9):1391–1404
Bitam S, Mellouk A, Zeadally S (2013b) HyBR: a hybrid bio-inspired bee swarm routing protocol for safety applications in Vehicular Ad-hoc NETworks. J Syst Architect 59(10–B):953–967
Bitam S, Mellouk A, Zeadally S (2014) Bio-inspired routing algorithms survey for vehicular ad-hoc networks. IEEE Commun Surv Tutor 17(2):843–867
Bitam S, Mellouk A, Zeadally S (2015) VANET-cloud: a generic cloud computing model for vehicular Ad hoc networks. IEEE Wirel Commun 22(1):96–102
Boussaïd I, Lepagnot J, Siarry P (2013) A survey on optimization metaheuristics. Inf Sci Int J 237:82–117
Cao Z, Hei X, Wang L, Shi Y, Rong X (2015) An improved brain storm optimization with differential evolution strategy for applications of ANNs. Math Prob Eng. https://doi.org/10.1155/2015/923698
Cañas DR, Orozco ALS, Villalba LJG, Hoon Kim T (2017) A family of ACO routing protocols for mobile ad-hoc networks. Sensors 17(5):1179
Chawla SK, Kamboj S (2014) Geocast routing in vehicular ad-hoc networks: a survey. Int J Comput Sci Inf Technol 5(4):5365–5370
Chen C, Liu L, Zhang N, Wang S (2016) A Bio-inspired Geographic Routing in VANETs. In: IEEE international conference on intelligent transportation engineering. Singapore, pp162–166
Chen Y-M, Wei Y-C (2013) A beacon-based trust management system for enhancing user centric location privacy in VANETs. J Commun Netw 15(2):153–163
Cheng P-C, Lee KC, Gerla M, Härri J (2010) GeoDTN+Nav: geographic DTN routing with navigator prediction for urban vehicular environments. Mob Netw Appl 15(1):61–82
Cherif AH, Boussetta K, Diaz G, Fedoua D (2017) Improving the performances of geographic VDTN routing protocols. In: Proceedings of the 16*th* annual mediterranean ad-hoc networking workshop (Med-Hoc-Net), Budva. IEEE
Chhabra S (2016) Efficient routing in vehicular ad-hoc networks using firefly optimization. Master's thesis, Thapar University
Chou L-D, Yang J-Y, Hsieh Y-C, Tung C-F (2010) Intersection-based routing protocol for VANET. 2*nd* international conference on ubiquitous and future networks (ICUFN). Jeju, South Korea. IEEE, pp 268–272
Chouhan P, Kaushal G, Prajapati U (2016) Comparative study MANET and VANET. Int J Adv Trends Comput Sci Eng 5(4):16079–16083
Chowdhary N, Kaur PD (2017) Dynamic route optimization using nature-inspired algorithms in IoV. In: Proceedings of 1*st* international conference on smart system, innovations and computing, Jaipur, India. Springer, pp 495–504
Clausen T, Jacquet P (2003) Optimized link state routing protocol (OLSR). https://tools.ietf.org/rfc/rfc3626.txt. RFC 3626
Corson S, Macker J (1999) Mobile ad-hoc networking (MANET): routing protocol performance issues and evaluation considerations. https://tools.ietf.org/rfc/rfc2501.txt

Darwish T, Bakar KA (2015) Traffic aware routing in vehicular ad hoc networks: characteristics and challenges. Telecommun Syst 61(3):489–513
de Andrade GE, de Paula Lima LA, Calsavara A, de Oliveira JA, Michelon G (2016) Message routing in vehicular delay-tolerant networks based on human behavior. In: Proceedings of the 10*th* international symposium on communication systems, networks and digital signal processing, Prague. IEEE
Deb K, Pratap A, Agarwal S, Meyarivan T (2002) A fast and elitist multi-objective genetic algorithm: NSGA-II. IEEE Trans Evol Comput 6(2):182–197
Devi M, Kumar R, Bhatla N (2017) Secure and enhanced vehicular ad-hoc networks using DSR protocol and BFOA algorithm. Int J Comput Sci Eng 9(8):506–516
Dhawale S, Deshmukh A, Dorle SS (2016) Heterogeneous approaches for cluster based routing protocol in vehicular ad-hoc network (VANET). Int J Comput Appl 134(12):201–213
Dorigo M (1992) Learning and natural algorithms. PhD thesis, Politecnico di Milano, Milano
Dorronsoro B, Ruiz P, Danoy G, Pigné Y, Bouvry P (2014) Evolutionary algorithms for mobile ad hoc networks. Wiley Inc, Hoboken
Ebadinezhad S, Dereboylu Z, Ever E (2019) Clustering-based modified ant colony optimizer for internet of vehicles (CACOIOV). Sustainability 11(9):1–22
Eiza MH, Owens T, Ni Q, Shi Q (2015) Situation-aware QoS routing algorithm for vehicular ad hoc networks. IEEE Trans Veh Technol 64(12):5520–5535
Eltahir AA, Saeed RA (2018) V2V communication protocols in cloud-assisted vehicular networks. In: Jyoti Grover P, Vinod, CL (eds) Vehicular cloud computing for traffic management and systems, chapter 6. IGI Global, pp 125–150
Eurocom V (2007) VanetMobiSim. http://vanet.eurecom.fr/
Fahad M, Aadil F, Rehman Z, Khan S, Shah PA, Muhammad K, Lloret J, Wang H, Lee JW, Mehmood I (2018) Grey wolf optimization based clustering algorithm for vehicular ad-hoc networks. Comput Electr Eng 70:853–87
Fathian M, Jafarian-Moghaddam AR (2015) New clustering algorithms for vehicular ad-hoc network in a highway communication environment. Wirel Netw 21(8):2765–2780
Findik O (2015) Bull optimization algorithm based on genetic operators for continuous optimization problems. Turk J Electr Eng Comput Sci 23:2225–2239
Forrest S, Perelson AS, Allen L, Cherukuri R (1994) Self-nonself discrimination in a computer. In Proceedings of IEEE symposium on security and privacy, Oakland, pp 202–212
Frohnwieser A, Hopf R, Oberzaucher E (2013) Human walking behavior: the effect of pedestrian flow and personal space invasions on walking speed and direction. Hum Ethol Bull 28(3):20–28
Gadkari MY, Sambre NB (2012) VANET: routing protocols, security issues and simulation tools. IOSR J Comput Eng 3(3):28–38
Gandomi AH, Alavi AH (2012) Krill Herd: a new bio-inspired optimization algorithm. Commun Nonlinear Sci Numer Simul 17(12):4831–4845
Gao XZ, Govindasamy V, Xu H, Wang X, Zenger K (2015) Harmony search method: theory applications. Comput Intell Neurosci 2:1–10
Garg C, Wadhwa B (2016) G-AODV: a novel approach to improve AODV by using genetic algorithm in VANET. Int J Innov Res Comput Commun Eng 4(6):11328–11334
Gautami R, Sedamkar RR, Patil H (2016) Hybridization of meta-heuristics for optimizing routing protocol in VANETs. Int J Eng Res Appl 6(2):24–28
Gayathri S, Nithya S, Shanthini G, Janani R, Ramachandiran R, Shanmugam M, Kalaipriyan T, Raghav R, Rao GSN (2018) ACO-ECDSA based secure routing in VANET: a bio-inspired approach. Int J Pure Appl Math 119(14):395–406
Gazdar T, Benslimane A, Rachedi A, Belghith A (2012) A trust-based architecture for managing certificates in vehicular Ad-hoc networks. In: Proceedings of the 2*nd* international conference on communications and information technology, Hammamet. IEEE, pp 180–185
Ghafoor KZ, Lloret J, Bakar KA, Sadiq AS, Mussa SAB (2013) Beaconing approaches in vehicular ad-hoc networks: a survey. Wirel Pers Commun 73(3):885–912
Golden BL, Raghavan S, Wasil EA (2008) The vehicle routing problem: latest advances and new challenges. Springer, Washington DC
Gu L, Zeng D, Guo S, (2013). Vehicular cloud computing: a survey. In: 2013 IEEE Globecom workshops (GC Wkshps). Atlanta, GA, IEEE
Gunasekar M, Hinduja S (2014) Automatic Tuning Of OLSR Routing Protocol Using IWD in VANET. International Journal of Innovative Research in Computer and Communication Engineering 2(1):3455–3461
Haas ZJ, Pearlman MR, Samar P (2002) The zone routing protocol (ZRP) for ad-hoc networks. https://tools.ietf.org/id/draft-ietf-manet-zone-zrp-04.txt

Hammoodi MR, Muniyand RC (2018) An improved harmony search algorithm for optimized link state routing protocol in vehicular ad hoc network. Int J Eng Technol 7(2):177–181

Harrabi S, Jaffar IB, Ghedira K (2016) Novel optimized routing scheme for VANETs. Proc Comput Sci 98:32–39

Head JD, Zerner MC (1985) Broyden-Fletcher-Goldfarb-Shanno. Chem Phys Lett 122(3):264–270

Hofmeyr SA, Forrest S (2000) Architecture for an artificial immune system. Evol Comput 8(4):443–473

Holland JH (1975) Adaptation in natural and artificial systems, volume 4 of 10. University of Michigan Press, Ann Arbor

Hung W-Z (2012) Social behavior algorithm. In: International conference on fuzzy theory and its applications, Taichung. IEEE, pp 57–61

ITS (2011–2014). SUMO—Simulation of Urban MObility. http://sumo.dlr.de/

Jayachithra N, Sivakumar K, Chandrasekar DC (2017) Shortest path using ant colony optimization in VANET. Int J Eng Res Technol 5(17):1–6

Jerbi M, Meraihi R, Senouci S-M, Ghamri-Doudane Y (2006) Gy-TAR: Improved greedy traffic aware routing protocol for vehicular Ad-hoc networks in city environments. In Proceedigs of the 3*rd* international workshop on vehicular ad-hoc networks, Los Angeles. ACM, pp 88–89

Jiang M, Li J, Tay YC (1998) Cluster based routing protocol (CBRP) functional specification. https://tools.ietf.org/id/draft-ietf-manet-cbrp-spec-00.txt

Johnson DB, Maltz DA, Hu Y-C, Jetcheva JG (2001) The dynamic source routing protocol for mobile ad hoc networks. https://www.ietf.org/proceedings/50/I-D/manet-dsr-05.txt. Section 10 of RFC 2026

Joshi A, Sirola P, Purohit KC (2014) Comparative study of enhanced AODV routing protocols in VANET. Int J Comput Appl 96(18):22–27

Joshua CJ, Duraisamy R, Varadarajan V (2019) A reputation based weighted clustering protocol in VANET: a multi-objective firefly approach. Mobile Netw Appl 24(4):1199–1209

Kalia N, Kaur N (2015) Intrusion detection system for VANET based on BFO algorithm. Int J Adv Res Comput Sci 6(5):185–189

Karaboga D (2005) An idea based on honey bee swarm for numerical optimization (ABC). Technical Report 06, Erciyes University, Computer Engineering Department

Karimi R, Ithnin N, Razak SA, Najafzadeh S (2011) DTN routing protocols for VANETs: issues and approaches. Int J Comput Sci Issues 8(6):89–93

Karp B, Kung HT (2000) GPSR: greedy perimeter stateless routing for wireless networks. In: Proceedings of the 6*th* annual international conference on mobile computing and networking, Boston, Massachusetts. ACM, pp 243–254

Kaur N, Devgan M (2018) A hybrid routing protocol based on route optimization mechanism for VANET. Int J Comput Sci Eng 6(9):948–951

Kaur P, Kaur U (2017) Various techniques for secure routing in VANETs: a review. Int J Comput Appl 161(5):1–4

Kennedy J, Eberhart R (1995) Particle swarm optimization. In: IEEE international conference on neural networks, volume 4, Perth. Association for Computing Machinery, pp 1942–1948

Khakpour S (2015) Cluster-based target tracking in vehicular ad-hoc networks. Master's thesis, University of Ontario Institute of Technology, Oshawa

Khan I (2009) Performance evaluation of ad-hoc routing protocols for vehicular ad-hoc networks. Master's thesis, Mohammad Ali Jinnah University

Khan MF, Aadil F, Maqsood M, Khan S, Bukhari BH (2018) An Efficient optimization technique for node clustering in VANETs using gray wolf optimization. KSII Trans Internet Inf Syst 12(9):4228–4247

Khokhar RH, Noor RM, Ghafoor KZ, Ke C-H, Ngadi MA (2011) Fuzzy-assisted social-based routing for urban vehicular environments. In: EURASIP journal on wireless communications and networking, 2011

Kim DH, Abraham A, Cho JH (2007) A hybrid genetic algorithm and bacterial foraging approach for global optimization. Inf Sci 177(18):3918–3937

Kirkpatrick S, Gelatt CD, Vecchi MP (1983) Optimization by simulated annealing. Sci Mag 220(4598):671–680

Kittusamy V, Elhoseny M, Kathiresan S (2019) An enhanced whale optimization algorithm for vehicular communication networks. Wiley, Hoboken

Krishnanand K, Ghose D (2006) Glowworm swarm based optimization algorithm for multimodal functions with collective robotics applications. Int J Multiagent Grid Syst 2:209–222

Lee KC, Cheng P-C, Weng J-T, Tung L-C, Gerla M (2008) VCLCR: a practical geographic routing protocol in urban scenarios. Technical Report 080009, University of California, Los Angeles

Lee U, Magistretti E, Gerla M, Bellavista P, Lió P, Lee K-W (2009) Bio-inspired multi-agent data harvesting in a proactive urban monitoring environment. Ad-hoc Netw 7(4):725–741

Lenando H, Alrfaay M (2018) EpSoc: social-based epidemic-based routing protocol in opportunistic mobile social network. Hindawi Mobile Information Systems, London

Liang W, Li Z, Zhang H, Sun Y, Bie R (2014) Vehicular ad-hoc networks: architectures, research issues. In: Challenges and trends. Wireless algorithms, systems, applications, pp 102–113

Lin Y-W, Chen Y-S, Lee S-L (2010) Routing protocols in vehicular ad-hoc networks : a survey and future perspectives. J Inf Sci Eng 26(3):913–932

Liu F, Wang Q, Gao X (2006) Survey of artificial immune system. In Proceedings of the 1*st* international symposium on systems and control in aerospace and astronautics, Harbin. IEEE, pp 985–989

Lobiyal DK, Katti CP, Giri AK (2015) Parameter value optimization of ad-hoc on demand multipath distance vector routing using particle swarm optimization. Procedia Comput Sci 46:151–158

Lochert C, Hartenstein H, Tian J, Fubler H, Hermann D, Mauve M (2003) A routing strategy for vehicular ad hoc networks in city environments. In: Proceedings of the IEEE intelligent vehicles symposium (IVS), Columbus, Ohio, USA. IEEE, pp 156–161

Lochert C, Mauve M, Füßler H, Hartenstein H (2005) Geographic routing in city scenarios. ACM SIGMOBILE Mobile Comput Commun Rev 9(1):69–72

Lopez JGB (2010) A survey of geographic routing protocols for vehicular ad-hoc networks (VANETs). https://fr.slideshare.net/gabitobalderas/a-survey-of-geographic-routing-protocols-for-vehicular-ad-hoc-networks-vanets, New Mexico State University. Available via Technology

Lozano M, García-Martínez C (2010) Hybrid metaheuristics with evolutionary algorithms specializing in intensification and diversification: overview and progress report. Comput Oper Res 37(3):481–497

Łukasik S, Żak S (2009) Firefly algorithm for continuous constrained optimization tasks. Computational collective intelligence. In Nguyen NT, Kowalczyk R, Chen SM (eds), Proceedigs of the 1*st* international conference on computational collective intelligence. Semantic web, social networks and multiagent systems. Lecture Notes in Computer Science, vol 5796. Springer, Wrocław, pp 97–106

Mane U, Kulkarni SA (2013) QoS realization for routing protocol on VANETs using combinatorial optimization. In: Proceedings of the 4*th* international conference on computing, communications and networking technologies, Tiruchengode. IEEE, pp 1083–1092

Marina MK, Das SR (2002) Ad-hoc on-demand multipath distance vector routing. ACM SIGMOBILE Mobile Comput Commun Rev 6(3):92–93

Matai R, Singh SP, Mittal ML (2010) Traveling salesman problem: an overview of applications, formulations, and solution approaches. INTECH Open Access Publ 4(2):201–213

Mazhar N, Farooq M (2007a) BeeAIS: artificial immune system security for nature inspired, MANET routing protocol, BeeAdHoc. In de Castro LN, Zuben, FJV, Knidel H (eds), Proceedings of the 6*th* international conference on artificial immune systems. Lecture notes in computer science book series volume 4628. Springer, Santos, pp 370–381

Mazhar N, Farooq M (2007b) Vulnerability Analysis and Security Framework (BeeSec) for Nature Inspired MANET Routing Protocols. In Proceedings of the 9*th* annual conference on genetic and evolutionary computation, London. ACM, pp 102–109

Mazhar N, Farooq M (2011) A hybrid artificial immune system (AIS) model for power aware secure mobile ad-hoc networks (MANETs) routing protocols. Appl Soft Comput 11(8):5695–5714

Mehta K, Bajaj DPR, Bajaj DPR (2017) Nature inspired biological computing (NIBC) algorithm to provide quality of service in vehicular ad-hoc network (VANET). Int J Sci Eng Res 8(2):2456–2470

Mehta K, Bajaj RP, Malik LG (2016) Fuzzy bacterial foraging optimization zone-based routing (FBFOZBR) protocol for VANET. In: International conference on ICT in business industry & government, Indore. IEEE

Mekki T, Jabri I, Rachedi A, Ben Jemaa M (2016) Vehicular cloud networks: challenges, architectures, and future directions. Vehic Commun 9:268–280

Melaouene N, Romadi R (2018) An enhanced routing algorithm using ant colony optimization and VANET infrastructure. MATEC Web Conf 259(6)

Mirjalili S, Lewis A (2016) The whale optimization algorithm. Adv Eng Softw 95:51–67

Mirjalili S, Mirjalili SM, Lewis A (2014) Grey wolf optimizer. Adv Eng Softw 69:46–61

Mirjazaee N, Moghim N (2015) An opportunistic routing based on symmetrical traffic distribution in vehicular networks. Comput Electr Eng 47:1–12

Mo J, Huang B, Cheng X, Huang C, Wei F (2018) Improving security and stability of ad hoc on-demand distance vector with fuzzy neural network in vehicular ad hoc network. Int J Distrib Sensor Netw 14(10):1550147718806193

Montana D, Redi J (2005) Optimizing parameters of a mobile ad-hoc network protocol with a genetic algorithm. In Proceedings of the 7*th* annual conference on genetic and evolutionary computation, Washington DC. ACM, pp 1993–1998

Mottahedi M, Jabbehdari S, Adabi S (2013) IBCAV: intelligent based clustering algorithm in VANET. Int J Comput Sci Issues 10(1):538–543

Moustafa H, Senouci SM, Jerbi M (2009) Introduction to Vehicular Networks. In Moustafa H, Z. Y., editor, Vehicular Networks: Techniques, Standards, and Applications, chapter 1. Taylor & Francis Group, CRC Press, London, , Boca Raton, Florida

Naumov V, Gross TR (2007) Connectivity-aware routing (CAR) in vehicular ad-hoc networks. 26*th* IEEE international conference on computer communications (IEEE INFOCOM 2007). Spain. IEEE, Barcelona, pp 1919–1927

Nebro AJ, Durillo JJ, García-Nieto J, Coello CAC, Luna F, Alba E (2009) SMPSO: A New PSO Metaheuristic for Multi-objective Optimization. In Proceedings of the (2009) IEEE Symposium on Computational Intelligence in Multi-Criteria Decision-Making. Nashville, Tennessee, IEEE

Neshat M, Sepidnam G, Sargolzaei M, Toosi AN (2012) Artificial fish swarm algorithm: a survey of the state-of-the-art, hybridization, combinatorial and indicative applications. Artif Intell Rev 42(4):965–997

nsnam web pp (2018) The Network Simulator - ns-2. http://www.isi.edu/

Nzouonta-Domgang J (2009) Road-based procative routing protocols for vehicular networks. PhD thesis, New Jersey Institute of Technology

Omidvar A, Mohammadi K (2014) Particle swarm optimization in intelligent routing of delay-tolerant network routing. EURASIP J Wirel Commun Network 2014:1–2

Panda R, Naik MK (2012) A crossover bacterial foraging optimization algorithm. Appl Comput Intell Soft Comput. https://doi.org/10.1155/2012/907853

Passino KM (2002) Biomimicry of bacterial foraging for distributed optimization and control (BFOA). Control Syst Mag 22(3):52–67

Patel MK, Kabat MR, Tripathy CR (2014) A hybrid ACO/PSO based algorithm for QoS multicast routing problem. Ain Shams Eng J 5(1):113–120

Patel NJ, Jhaveri RH (2015) Trust based approaches for secure routing in VANET: a survey. Procedia Comput Sci 45:592–601

Perkins CE, Bhagwat P (1994) Highly dynamic destination-sequenced distance-vector routing (DSDV) for mobile computers. ACM SIGCOMM Comput Commun Rev 24(4):234–244

Perkins CE, Royer EM (1999) Ad-hoc On-Demand Distance Vector Routing. In Proceedings of the 2*nd* IEEE workshop on mobile computing systems and applications, New Orleans, Louisiana

Poonia RC, Raja L (2018) On-demand routing protocols for vehicular cloud computing. In Jyoti Grover P, Vinod, CL (eds) Vehicular cloud computing for traffic management and systems, chapter 7. IGI Global, pp 151–177

Punia S, Patial RK (2016) Clustering based routing protocols in vehicular ad-hoc networks: a review. Indian J Sci Technol 9(47):201–213

Qin Y, Huang D, Zhang X (2012) Vehicloud: Cloud computing facilitating routing in vehicular networks. In: 11th International conference on trust, security and privacy in computing and communications. IEEE

Qureshi KN, Abdullah H, Ullah F, Anwar RW (2015) Vehicular ad-hoc networks routing protocols: survey. Sci Int 27(5):4507–4525

Ramakrishnan DB, Sreedivya SR, Selvi M (2015) Adaptive routing protocol based on cuckoo search algorithm (ARP-CS) for secured vehicular ad hoc network (VANET). Int J Comput Netw Appl 2(4):173–178

Ramezani F, Lotfi S (2013) Social-based algorithm (SBA). Appl Soft Comput 13(5):2837–2856

Rana H, Thulasiraman P, Thulasiram RK (2013) MAZACORNET: mobility aware zone based ant colony optimization routing for VANET. In: IEEE congress on evolutionary computation, pp 2948–2955, Cancun

Rewadkar D, Doye D (2017) FGWO-TAR: fractional glowworm swarm optimization for traffic aware routing in urban VANET. Int J Commun Syst 2(5):1–22

Rewadkar D, Doye D (2018) Adaptive-ARW: adaptive autoregressive whale optimization algorithm for traffic-aware routing in urban VANET. Int J Comput Sci Eng 6(3):40–49

Sachdev A, Mehta K, Malik L (2016) Design of protocol for cluster based routing in VANET using fire fly algorithm. Int J Sci Res Develop 4(2):1565–1569

Saggi MK, Kaur R (2015) Isolation of Sybil attack in VANET using neighboring information. In: Proceedings of IEEE international advance computing conference, Banglore

Sahota RS, lal M (2016) Performance tuning of OLSR and GRP routing protocols in MANET's using OPNET. Int Res J Eng Technol 3(7):1635–1639

Saremi S, Mirjalili S, Lewis A (2017) Grasshopper optimisation algorithm: theory and application. Adv Eng Softw 105:30–47

Sari RF (2017) Bioinspired algorithms for internet of things network. URL: https://ieeexplore.ieee.org/document/8257662
Sataraddi MJ, Kakkasageri MS, Kori GS, Patil RV (2017) Intelligent routing for hybrid communication in VANETs. In 7*th* international advanced computing conference (IACC 2017), Hyderabad. IEEE
Sayad L, Bouallouche-Medjkoune L, Aissani D (2016) IWDRP: an intelligent water drops inspired routing protocol for mobile ad-hoc networks. Wireless Pers Commun 94(4):2561–2581
Schoeneich RO, Surgiewicz R (2016) SocialRouting: the social-based routing algorithm for delay tolerant networks. Int J Electr Telecommun 62(2):167–172
Shah YA, Habib HA, Aadil F, Khan MF, Maqsood M, Nawaz T, Pal AK (2018) Camonet: moth-flame optimization (MFO) based clustering algorithm for VANETs. IEEE Access 6:48611–48624
Shah-Hosseini H (2009) The intelligent water drops algorithm: a nature-inspired swarm-based optimization algorithm. Int J BioInspired Comput 1(1–2):71–79
Sharavanan S, Balajee RM (2016) Junction based urban scenario high speed node detection (JBUS-HSND) and alerting system on VANET. In: International conference on recent trends in information technology, Chennai. IEEE
Sharma S, Giri AK, Singhal N (2014) Finding optimal configuration of DSDV using particle swarm optimization. Int J Comput Appl 104(4):27–31
Sharma S, Kad S (2018) A review on social based routing schemes in vanets. Int J Eng Tech Res 8(12):14–18
Shi Y (2011) Brain storm optimization algorithm. In Tan Y, Shi Y, Chai Y, Wang G (eds), Proceedings of the 2nd international conference on advances in swarm intelligence. Lecture Notes in Computer Science, vol 6728. Springer, pp 303–309
Shrivastava N, Motwani A (2014) A modification to DSR using multipath technique. Int J Comput Appl 92(11):24–28
Simon D (2008) Biogeography-based optimization. IEEE Trans Evol Comput 12(6):702–713
Soares VNGJ, Rodrigues JJPC, Farahmand F (2014) GeoSpray: a geographic routing protocol for vehicular delay-tolerant networks. Inf Fus 15:102–113
Sonia Kaur (2016) Proficient and enhance the Mobile ad-hoc network using routing protocol and EBFOA (Enhanced Bacteria Foraging Optimization Algorithm). Int J Mod Comput Sci 4(6):88–94
Sood M, Kanwar S (2014) Clustering in MANET and VANET: a survey. In: International conference on circuits, systems, communication and information technology applications, Mumbai. IEEE, pp 375–380
Spyropoulos T, Psounis K, Raghavendra CS (2004) Single-copy routing in intermittently connected mobile networks. In: Proceedings of the (2004) 1st annual IEEE communications society conference on sensor and ad-hoc communications and networks. Santa Clara, California
Srinidhi N, Kumar SD, Venugopal K (2018) Network optimizations in the internet of things: a review. Eng Sci Technol Int J 22(1):1–21
Tabar AK, Farazkish R (2019) A new method for routing optimization in vehicular ad hoc networks (VANETs). Signal Process Renew Energy 37–45
Talbi E (2009) Single solution based metaheuristics. In: Talbi El-Ghazali (ed) Metaheuristics: from design to implementation. Wiley, New York, pp 87–189
Tamizhselvi A, Banu RSDW (2014) Hybrid optimization algorithm for geographic routing in VANET. J Theor Appl Inf Technol 65(2):320–326
Teodorović D (2009) Bee colony optimization (BCO). In: Lim CP, Jain LC, Dehuri S (eds) Innovations in swarm intelligence, 1st edn. Springer, Heidelberg, pp 39–60
Thenmozhi R, Govindarajan S (2017) A comparative study of collision avoidance techniques in VANET. Int J Pure Appl Math 117(16):19–26
Thorup RE (2007) Implementing and evaluating the DYMO routing protocol. Master's thesis, Aarhus University, Aarhus, Danemark
Tian D, Zheng K, Zhou J, Duan X, Wang Y, Sheng Z, Ni Q (2018) A microbial inspired routing protocol for VANETs. IEEE Internet-of-Things J 5(4):2293–2903
Tilahun SL, Ngnotchouye JMT (2017) Firefly algorithm for discrete optimization problems: a survey. KSCE J Civ Eng 21(2):535–545
Togou MA, Hafid A, Khoukhi L (2016) SCRP: stable CDS-based routing protocol for urban vehicular ad hoc networks. IEEE Trans Intell Transp Syst 17(5):1298–1307
Toutouh J, Alba E (2012a) Green OLSR in VANETs with differential evolution. In: Proceedings of the 14*th* annual conference companion on genetic and evolutionary computation (GECCO '12), Philadelphia. ACM, pp 11–18
Toutouh J, Alba E (2012b) Parallel swarm intelligence for VANETs optimization. In: P2P, parallel, grid, cloud and internet computing

Toutouh J, Alba E (2015) Metaheuristics for energy-efficient data routing in vehicular networks. Int J Metaheuristics 4(1):27–56
Toutouh J, Alba E (2017) Parallel multi-objective metaheuristics for smart communications in vehicular networks. Soft Comput 21(8):1949–1961
Toutouh J, Nesmachnow S, Alba E (2013) Fast energy-aware OLSR routing in VANETs by means of a parallel evolutionary algorithm. Cluster Comput 16(3):435–450
Vieira ASS, Filho JG, Jr, JC, Patel A (2013) VDTN-ToD: routing protocol VANET/DTN based on trend of delivery. In: Proceedings of the 9th advanced international conference on telecommunications (AICT 2013), Rome, pp 135–141
Wagh MB, Gomathi DN (2018a) Water wave optimization-based routing protocol for vehicular adhoc networks. Int J Model Simulat Sci Comput 9(5):1850047
Wagh MB, Gomathi N (2018b) Route discovery for vehicular ad hoc networks using modified lion algorithm. Alex Eng J 57(4):3075–3087
Wang G-G, Deb S, Coelho L (2015a) Earthworm optimization algorithm: a bio-inspired metaheuristic algorithm for global optimization problems. Int J Bio-Inspired Comput 12:1–22
Wang G-G, Deb S, dos S Coelho L (2015b) Elephant herding optimization. In Proceedigs of the 3rd international symposium on computational and business intelligence, Bali. IEEE, pp 1–5
Wang M, Zhang Y, Li C, Wang X, Zhu L (2014) A survey on intersection-based routing protocols in city scenario of VANETs. In international conference on connected vehicles and expo, Vienna. IEEE, pp 821–826
Whaiduzzaman M, Sookhak M, Gani A, Buyya R (2014) A survey on vehicular cloud computing. J Netw Comput Appl 40:325–344
Wille ECG, Monego HID, Coutinho BV, Basilio GG (2016) Routing protocols for VANETs: an approach based on genetic algorithms. KSII Trans Internet Inf Syst 10(2):542–558
Woeginger GJ (2003) Exact Algorithms for NP-hard problems: a survey. In: Jünger M, Reinelt G, Rinaldi G (eds) Combinatorial optimization—Eureka, you shrink!. Springer, New York. Papers Dedicated to Jack Edmonds 5*th* International Workshop Aussois, France, pp 185–207
Wu B, Qian C, Ni W, Fan S (2012) The improvement of glowworm swarm optimization for continuous optimization problems. Expert Syst Appl 39(7):6335–6342
Xiong-fa M, Ling L (2016) An enhanced bacterial foraging optimization with adaptive elimination-dispersal probability and PSO strategy. In: Proceedings of the 12*th* international conference on natural computation and 13*th* fuzzy systems and knowledge discovery, Changsha. IEEE
Yadav H, Lithore U, Agrawal N (2017) An enhancement of whale optimization algorithm using ANN for routing optimization in Ad-hoc network. Int J Adv Technol Eng Explor 4(36):161–167
Yahiabadi SR, Barekatain B (2019) Raahemifar K (2019) TIHOO: an enhanced hybrid routing protocol in vehicular ad-hoc networks. EURASIP J Wirel Commun Netw 192:1–19
Yang X-S (2009) Firefly algorithm for multimodal optimization. In: Watanabe O, Zeugmann T (eds), Proceedings of the 5*th* international symposium on stochastic algorithms, foundations and applications. Lecture notes in computer science, vol 5792. Springer, Sapporo, pp 169–178
Yang X-S (2012) Swarm-based metaheuristic algorithms and no-free-lunch theorems. In: Parpinelli R (ed) Theory and new applications of swarm intelligence. IntechOpen, London, pp 1–16
Yang X-S (2014) Firefly algorithms. In: Yang XS (ed) Nature-inspired optimization algorithms, chapter 8. Elsevier, Amsterdam, pp 111–127
Yang X-S, Deb S (2009) Cuckoo search via levy flights. In: World congress on nature & biologically inspired computing, Coimbatore. IEEE, pp 210–214
Yarinezhad R, Sarab A (2019) A new routing algorithm for vehicular ad-hoc networks based on glowworm swarm optimization algorithm. J AI Data Min 7(1):69–76
Yazdani M, Jolai F (2016) Lion optimization algorithm (LOA): a nature-inspired metaheuristic algorithm. J Comput Des Eng 3(1):24–36
Zhang G, Min Wu WD, Huang X (2018) Genetic algorithm based QoS perception routing protocol for VANETs. Hindawi Wirel Commun Mobile Comput 2018:1–10
Zhang H, Wang X, Memarmoshrefi P, Hogrefe D (2017) A survey of ant colony optimization based routing protocols for mobile ad-hoc networks. IEEE Access 5:24139–24161
Zhao J, Cao G (2008) VADD: vehicle-assisted data delivery in vehicular ad-hoc networks. IEEE Trans Veh Technol 57(3):1910–1922
Zheng J, Chen Y, Zhang W (2010) A survey of artificial immune applications. Artif Intell Rev 34(1):19–34
Zheng Y-J (2015) Water wave optimization: a new nature-inspired metaheuristic. Comput Oper Res 55:1–11
Zhong Y, Lin J, Ning J, Lin X (2011) Hybrid artificial bee colony algorithm with chemotaxis behavior of bacterial foraging optimization algorithm. In: Proceedings of the 7*th* international conference on natural computation, Shanghai. IEEE

Zhou T (2015) Data collection, dissemination, and security in vehicular ad-hoc network. PhD thesis, Duke University

Zukarnain ZA, Al-Kharasani NM, Subramaniam SK, Hanapi ZM (2014) Optimal configuration for urban VANET routing using particle swarm optimization. In: International conference on artificial intelligence and computer science, Bandung