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Comprehensive State of the Art of Bio-Inspired Routing in Mobile Ad-Hoc Networks

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***Abstract*— In this paper we discuss different biologically inspired routing protocols for Mobile Ad-hoc NETworks (MANETs) and the influence it has on the Quality of Service (QoS) in the system. Bio-inspired routing protocols have made the main focus of the contributions to the field of mobile ad-hoc NETworks. Routing problem in MANETs is due to their unpredictable and dynamic nature and also with few resources (speed and autonomy), that's why bio-inspired algorithms are widely used to design adaptive routing strategies for MANETs. In this article, we present a comprehensive state of the art of bio-inspired routing protocols for MANETs. Besides, we propose some future research directions in this area.**

***Keywords*— Mobile Ad-hoc Networks, Bio-inspired routing, QoS.**

I. Introduction

Mobile ad hoc network (MANET) is a collection of wireless mobile nodes dynamically forming a temporary network without the use of any centralized administration. the challenge in MANETs is to find a path between communicating nodes. Such type of networks are characterized by the absence of centralized infrastructure, dynamic topology, the constraint of energy, routing, the heterogeneity of nodes, multi-hop, limited bandwidth.
Routing in MANET is extremely challenging because of MANETs dynamic features, its limited bandwidth, frequent topology changes caused by node mobility and power energy consumption. In order to efficiently transmit data to destinations, the applicable routing algorithms must be implemented in mobile ad-hoc networks. Thus we can increase the efficiency of the routing by satisfying the Quality of Service (QoS) parameters by developing routing algorithms for MANETs. The algorithms that are inspired by the principles of natural biological evolution and distributed collective behavior of social colonies have shown excellence in dealing with complex optimization problems and are becoming more popular.

This paper presents a survey on few meta-heuristic algorithms and naturally-inspired algorithms. The objective of routing in MANETs is to find a path between the source and destination over which packets can be forwarded. A MANET routing algorithm should not only find the shortest path between the source and destination, but it should also be adaptive, in terms of the changing state of the nodes, the changing load conditions of the network and the changing state of the environment.

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The rest of the paper is organized as follows. Section II discusses the Routing in Mobile Ad-hoc Networks. Section III introduces the Bio-inspired Routing in MANET. Section IV discusses Performance Analysis and discussion. Finally Section V represents the conclusion of this paper and some future directions.

II. Routing in Mobile Ad-hoc Networks

Routing in ad hoc networks is the most important problem .This problem is very complicated, and this is due to the properties that characterize such networks. So it seems very difficult to locate a destination at a moment, because of the mobility of the nodes that make up the network, the routing protocol is used in order to discover the paths between nodes, routing protocols can be separated into three main categories, proactive and reactive protocols and the third category called hybrid is the combination of the two protocols.

The routing strategy is fundamental for mobile ad hoc networks. It must be done in a rational manner, i.e. with minimal control and good conservation of bandwidth. Furthermore, the changes in topology must be taken into account. For this, a hundred routing protocols have been proposed

- Proactive protocols: control packets are constantly broadcast on the network to maintain the state of the link between each pair of nodes. At each node a table is constructed where each entry indicates the next hop to a certain destination. The most important routing protocols of this class are: Destination Sequence Distance Vector (DSDV) and Optimized Link State Routing (OLSR).
- Reactive protocols, (or on demand), that create and maintain the paths as needed. When a node needs a route, a global discovery procedure of paths is launched to obtain a valid path to the destination. The most important routing protocols of this class are: Ad hoc On demand distance Vector (AODV) and Dynamic Source Routing (DSR). The main limits of this category are: Delay caused by a search before transmission, Path expiration after a certain time.
- Hybrid protocols combine the two approaches. They use a proactive protocol, to learn the close neighborhood (on two or three hops), and they have the paths in the immediate neighborhood. Beyond the predefined area, the hybrid protocol uses the techniques of reactive protocols to look for routes between non-neighboring nodes (more than two or three hops). The most important routing protocol of this class is Zone Routing Protocol (ZRP).

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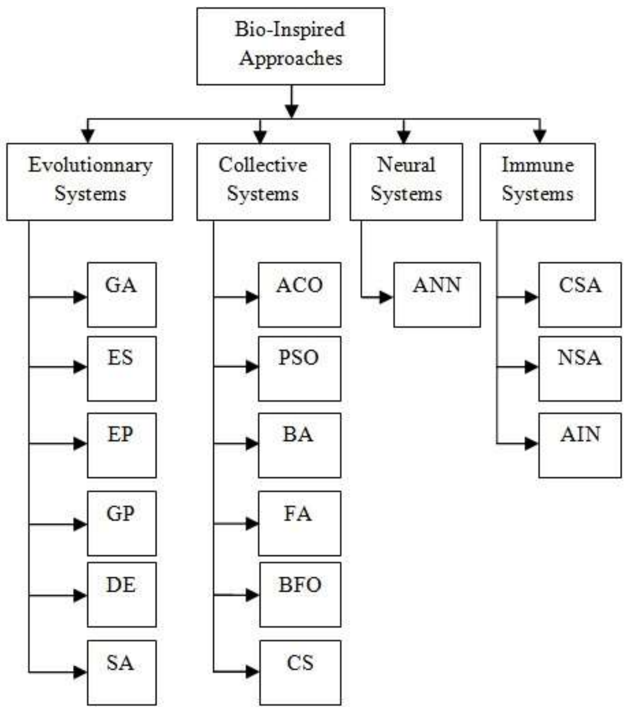
III. Bio-inspired Routing in MANET

Bio-inspired (biologically-inspired) computing is a field of study related to the topics of social behaviour, emergence and connectionism. It is also closely related to the field of AI (artificial intellegence). It depends on the fields of biology, computer science and mathematics. Bio inspired computing is a major subset of natural computation. Figure 1. and Figure2. presents Bio-inspired Approaches :



GA: Genetic Algorithm
ES: Evolutionary Algorithm
EP: Evolutionary Programming
GP: Genetic Programming
DE: Differential Evolution
ACO: Ant colony Optimization
PSO:Particle Swarm optimization
ABC : Artificial Bee Colony
FA: Firefly Algorithm
BFO:Bacterial Foraging Optimization
CS : Cuckoo Search
ANN:Artificial Neural Networks
NSA: Negative Selection Algorithm
AIN: Artificial Immune Networks

Figure 1. Bio-inspired algorithms classification

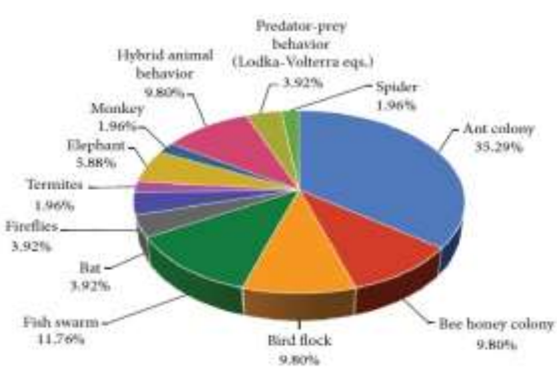


Figure 2. Bioinspired mechanism based on animal's behavior.

✓ *Swarm Intelligence based Routing in MANET*

Swarm Intelligence indicates a computational and behavioral metaphor that originally took its inspiration from the biological examples provided by social insects (ants, bees, birds, fish) and by swarming, which aim to find solutions for difficult combinatorial optimization and distributed problems. These approaches are adequate for ad hoc and wireless sensor networks due to the following prominent aspects i.e. [29]:

- Locality of interactions
- Availability of multiple paths,
- Self-organizing behaviors
- Failure backup,
- Ability to adapt in a robust way to topological and traffic changes and component failures,
- Easiness of design and tuning.

SI addresses the study of the collective behavior of individuals in a population who interact locally and coordinate using decentralized controls and self-organization. The aim is to design effective algorithms for distributed optimization. These algorithms, like their natural systems of inspiration, are adaptive, scalable, and robust. Collective Intelligence emerges through the cooperation of large numbers of homogeneous agents in the environment. Examples include schools of fish, flocks of birds, and colonies of ants. The main Properties of SI are: Agents are assumed to be simple, Indirect agent communication, Global behavior may be emergent, Behaviors are robust, required in unpredictable environments and, Individuals are not important. the reasons that make SI more efficient are: Positive Feedback : reinforces good solutions, Negative Feedback removes bad or old solutions from the collective memory, Randomness allows new solutions to arise, Multiple Interactions: No individual can solve a given problem. Only through the interaction of many can a solution be found.

A. Ant Colony Optimization (ACO)

1) Ants in Nature

The original idea comes from observing the exploitation of food resources among ants. Indeed, these ants are able collectively to find the shortest path between a food source and their nest.

Biologists have thus observed in a series of experiments conducted from 1989 a colony of ants with a choice between two paths of unequal length leading to a source of food tended to use the shortest path.

A model explaining this behavior is as follows :

1. ant runs randomly around the environment of the colony ;
2. if it discovers a food source, it returns more or less directly to the nest, leaving in its path a trail of pheromones (Pheromones are chemicals released by ants) ;
3. pheromones are attractive ; ants passing nearby will tend to follow more or less directly, the track ;

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4. returning to the nest, these ants will reinforce the runway ;
5. if two tracks are available to achieve the same food source, the shorter will be, at the same time, traveled by the ants over long track ;
6. short track will be increasingly reinforced, and therefore more attractive ;
7. long track will eventually disappear, pheromones will be volatile ;
8. eventually, all ants therefore determined and "chosen" the shortest track.

2) *Ants applied to Routing in MANET*

The main idea behind using Ant Colony Optimization based Routing in MANETs is that nodes in the network periodically send out artificial ants towards possible destination nodes. These ants are small control packets, which have the task to find a path towards their destination. Like ants in nature, artificial ants follow and drop pheromone. This pheromone takes the form of routing tables maintained locally by all the nodes of the network. They indicate the relative quality of different routes from the current node towards possible destination nodes. Often, the tasks of following and updating pheromone are split between a forward and backward ant (FANT and BANT), whereby the forward ant finds a path towards the destination and the backward ant travels back over the path to update pheromone tables. This can again be done probabilistically or deterministically following the path with the highest pheromone level (see Figure 3.). [30]

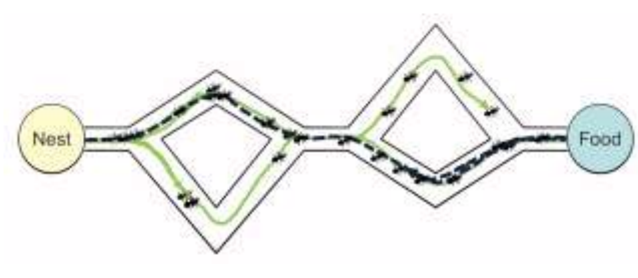

Figure 3. Collective Foraging by Ants

3) Ant-based protocols

ANTNET [20] is a proactive ACO routing algorithm. The operating principle of this algorithm is as follows, a forward ant FANT is initiated from the source node at regular intervals. A FANT at each intermediate node chooses the next hop via the information of the routing table of that node. The next node is selected with a probability proportional to the goodness of that node ; it is measured by the amount of pheromone deposited on the link to that node. When a FANT reaches the destination, it generates a backward ant BANT which takes the same path as the corresponding forward ant but in opposite direction. The backward ant updates pheromone values as it moves on its way to the source node.

Günes et al. proposed ARA [16] (Ant-Colony-Based Routing Algorithm) a reactive implementation of ACO for routing in MANETs. ARA has two phases : route discovery, and route maintenance. In route discovery phase, the sender broadcasts a FANT which is relayed by each intermediate node until arrives to the destination. After receiving a FANT in the destination, the ant is destroyed and a BANT is sent back to the sender. The BANT increases the pheromone value corresponding to the destination in each intermediary node until it reaches the sender. When the sender receives the BANT, the route maintenance phase starts by sending data packets. Since the pheromone track is already established by the forward and backward ants, subsequent data packets will perform the route maintenance by adjusting the pheromone values. As an on-demand algorithm, routing overhead in ARA is minimized. Also, the authors claim that ARA allows node to go into sleep mode to save their energies. ARA is shown to have higher data packet delivery ratio and lower routing overhead in comparison to DSDV and AODV protocols. DSR and ARA have marked very close results in terms of data packet delivery ratio. However, ARA generates less routing overhead than DSR.

Then in 2004, Di-Caro et al. [17] proposed AntHocNet a hybrid and multipath routing algorithm for MANETs. In AntHocNet, routes are reactively established and proactively maintained during communication sessions. When there is a demand for a route, the algorithm first checks the routing table of the source node to see if there is any information about the destination. If there is no routing information for the destination, it will broadcast a forward ant. Due to this broadcasting, each neighbor receives a copy of the ant and checks its routing table. Again, the ant will be broadcasted if there is no routing information for the destination, otherwise it will be sent to the next hop using a stochastic decision. Each forward ant keeps a list of the visited nodes and when reaches the destination, uses it to take the same path back to source and update the pheromone values deposited in the links. To avoid generating a huge number of ants of the same generation, a limit a on the length of a path is defined and when the length of the traveled path by an ant exceeds a, the ant is discarded. Whenever an intermediate node receives two ants of the same generation, it checks the length of the traveled path of both ants and discards the ant with longer traveled path. AntHocNet was shown to be more efficient than AODV in terms of packet delivery ratio, average end-to-end delay and average jitter. Unfortunately, this efficiency is achieved at the cost of an increased routing overhead. As a result ARA and AntHocNet are not scalable.

POSANT, reactive routing algorithm for MANETs proposed by Kamali and Opatrny [18]. POSANT reduces both route establishment time and control-packets amount in ant-routing by exploiting position-based routing. In comparison to conventional position-based routing algorithms, POSANT is multipath and succeeds in approximating shortest paths. POSANT achieves a higher delivery rate with a shorter average packet delay than GPSR [19]. Also, it converges faster than ANTNET.

In HOPNET, Wang et al. [21] combine the concepts of ACO routing with Zone based routing. Proactive mode is

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used for intra-zone routing and reactive mode for inter-zone routing. The authors have shown through simulation, that HOPNET is more scalable than AntHocNet and that is more stable under high and low mobility. Moreover, HOPNET outperforms AODV in terms of end to end delay and delivery ratio.

Then the Energy-Aware Ant-Based Routing (EAAR) protocol is proposed in [29]. To deal with energy issue, EAAR uses the hop count and minimum battery cost of nodes as metrics for evaluating paths quality. Moreover, the multipath feature of ant routing is exploited to balance energy expenditure among nodes. It was shown through simulation that energy consumed per packet in EAAR is 60% less in comparison to MMBCR (Min-Max Battery Cost Routing) [22]. Moreover, packets-lost in EAAR is only 12% less of what is marked in AODV.

Recently, Singh et al. [28] propose ANTALG a new ACO based routing protocol for MANETs. In comparison to previous works, ANTALG includes two main innovative ideas. First, source and destination nodes are randomly selected for ANTs exchange. This minimizes the generated overhead during the route discovery phase. Second, to enhance protocol adaptivity, the evaporation mechanism is invoked for the whole system at the end of Ant's trip. Simulation study has shown that ANTALG outperforms AODV, ADSR and HOPNET protocols in terms of throughput, packet drop, Average End-to-End delay, average Jitter and window size with TCP traffic.

B. Artificial Bee Colony (ABC)

1) ABC applied to Routing in Manet

The Bee Colony Optimization (BCO) [1, 2] is a nature-inspired meta-heuristic, Once the problem is defined, the forward operation starts by artificial bees looking a partial solution to the problem. After finding enough information, they return to the hive where the partial solutions they have collected are shared between the searchers. Each artificial bee has to make a decision based on a certain probability, whether it will continue searching following its own path, or switch to a fellow searcher's solution. The final step is to decide which solution is the best, based on certain criteria.

2) Bee-based protocols

BeeAdHoc [3] is an energy efficient source routing protocol for MANETs which is mainly based on the foraging principles of honey bees. BeeAdHoc uses scout agents to discover routing paths between sources and destinations. Reactively, when a route is required at destination node, a scout agent is broadcasted in the network just like a forward ant in ant-inspired protocols. When a scout returns to its source, it recruits foragers using a bee-dance metaphor. A forager is the bee agent that receives data packets from a packer and delivers them to their destination [4, 5]. The authors show that BeeAdHoc consumes significantly less energy in comparison to DSR, AODV and DSDV [6].

While BeeSensor [7] focuses on minimizing the energy costs using bee agents (packers, scouts and foragers) in wireless sensor networks. The sensor nodes's purpose is to receive data from the transport layer and load them to an appropriate forager. At the sinks, packers recover data from the incoming foragers and deliver them to the transport layer. Route discovery is achieved by forward scouts (FS) and backward scouts (BS). This protocol is found to be more energy efficient than Energy optimized version of AODV [8].

Recently, Giagkos et Al. proposed a new honeybee-inspired Adaptive Routing Protocol based on the Collaborative behaviors of honeybee foragers [9], this work shows the ability of honeybees to perform foraging and to communicate with each other within the hive, in order to achieve efficient and productive recruitment. The results obtained show that BeeIP outperforms the other protocols AODV, DSR, DSDV in term of the average end-to-end delay and packet delivery ratio.

C. Particle Swarm Optimization (PSO)

1) PSO applied to Routing in MANET

Particle Swarm Optimization PSO is a population based optimization technique that simulates the social behavior of organisms such as bird flocking in order to describe an automatically evolving system [31]. PSO optimizes a problem by having a population of candidate solutions called particles and moving these particles around inside the search-space via simple mathematical operation over the rate and position of the particle. The action of every particle is under the impact of its local best known position however, is also guided toward the most effective known positions in the search-space, that are updated as better positions known by other particles. This is expected to move the swarm toward the effective (optimal) solutions. In PSO, every solution represents a bird of the flock; particle in the search space. Every particle makes use of its own knowledge gained by the swarm in order the find the best solution. Firstly population of random solutions is initialized then searches for optimum solution by updating the generations. By the end of the simulation, the route formed will be the optimized route [31].

2) PSO-based protocols

In response to dynamic routing requirement in Mobile Ad-hoc networks, Garcia [12] proposed the Rational Swarm Routing Protocol. The key novelty of this work is the combination of stigmergie concept of ant colony with PSO Metaheuristic. In 2011 Mala et al. [13] addressed to solve Quality of Service (QoS) multicast routing problem using Particle Swarm Optimization (PSO) technique. They used a fitness function to implement the constraints specified by the QoS conditions. They also include extra

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parameters in the fitness function which resulted in efficient convergence with minimal computational cost. In addition, Rehab and al. [14] proposed also PSO-GA hybrid multicast routing algorithm which combines PSO with genetic operators and mixes the strengths of PSO and GA to appreciate the balance between natural selection and sensible data sharing for supplying robust and efficient search of the solution space. Results show that the combination of GA and PSO does outperform both the quality PSO and GA models. Recently, as the last work, Kaur et al. [15] used a hybrid of genetic algorithm (GA) and particle swarm optimization (PSO) to consider only the mobile nodes in the routing which have less distance from destination and thus have high energy (based on their fitness function).

IV. Performance Analysis And Discsussion

The performance metrics used in this paper are : Packet Delivery Ratio (PDR), End to End Delay (E2ED) and the Routing Overhead (RO).

A. *Packet Delivery Ratio*

The PDR measures the efficiency of routing protocol: if it is high, then the packet loss rate is low and as a result, the routing protocol provides valid routes between source and destination. The causes of packet loss are many, we cite for example the collision, overloading queues, interference, lack of roads to the destination, inactive roads, etc.

B. *End to End Delay*

The DM enriches the evaluation of the protocol because the time is a very important constraint especially for real-time and multimedia applications. The average time includes any delays caused by buffering during route discovery latency, queuing at the interface queue, retransmission delays at the MAC layer, the spread and transfer time. This is important to understand the delay introduced by the discovery of the way.

C. *Routing Overhead*

The ratio of the bandwidth occupied by the routing/control packets and the total available bandwidth in the network. This parameter shows the control overhead of the routing algorithm.

From the number of papers that we have reviewed it is clear that, so far, significant efforts have been addressed to exploit Bio-Inspired techniques to design effective routing protocols for MANETs. Table 1. gives the performance of the routing protocols studied in this paper.

TABLE I. performance of bio-inspired protocols studied in this paper

Bio-inspired protocols	**Performance metrics**				
	Packets delivery ratio	***Mobile agents***	***End-to-end delay***	***Lost packet ratio***	***Overhead***
AntNet	Low	FANT, BANT	Average	Average	High
ARA	High	FANT, BANT	Average	Average	Average
AntHocNet	High	(R,P)FANT, (R,P)BANT	low	low	High
HopNet	High	FANT, BANT, Notification, error Ant	low	low	High
AntAlg	High	FANT, BANT, Notification, error Ant	low	low	Average
BeeAdHoc	High	Scout, Forager, Packer agents	Average	Average	High
BeeSensor	Average	Forager, (R,P) Scout agents	Average	Average	Average
BeeIP	High	Scout, Forager, Packer agents	low	low	Average

As conclusion, the most efficient routing protocols are those based on SI principles, and, more specifically, taking inspiration from foraging behaviors of ant and bee colonies.

V. Conclusion

The design of effective, robust, and scalable routing protocols in Mobile Ad-hoc Networks is a challenging task. The algorithms that are inspired by the principles of natural

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biological evolution and distributed collective behavior of social colonies have shown best results in comparing with other optimization problems.

In this paper, we have presented a comprehensive state of the art of Bio-inspired Routing in Mobile Ad-hoc Networks and we outlined that the routing protocols taking inspiration from foraging behaviors of ant and bee colonies are more efficient in term of performance. So It can be concluded that Swarm Intelligence based approach offers to be a powerful means to solve routing problems in Mobile Ad hoc Networks.

To conclude, we want to sketch some future directions for the field:

- Introduce others bio-inspired algorithms such as: Cuckoo search.
- Increase the proposed algorithms performance (fast convergence).
- Introduce hybrid approaches.

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