

Ant Inspired Adaptive Routing: MANET Routing Protocols- A Survey

S.Nagalakshmi¹, Dr.Rakesh Poonia²Research Scholar, Dept. of Information Science and Engineering, Dr AIT, Bangalore, India¹Asst. Professor. Dept. of Computer Application, Govt. Engineering, College, Bikaner, India²

ABSTRACT: A class of routing algorithms based on swarm intelligence and inspired by nature's own self-organizing systems like ants in colonies and ant like mobile agents has been designed by researchers for routing in Mobile Ad Hoc Networks (MANETs). These algorithms, derived from a biological phenomena which when adapted to wireless networks provides intrinsic characteristics like increased self-organization capability, adaptation to the changing conditions, self healing, providing nodes in the network an increased scope for decision making, and thus making for a more efficient network by improving the latency of the network. These extrinsic Agents provide an advantage in finding more optimal routes for delivering the data in a mobile ad hoc network. Ant Colony Optimization and Antlike mobile agents are used in MANET for devices like cell phones, laptops etc. forming an infrastructure-independent network communicating through a wireless connection. In this paper a survey on the routing protocols based on nature inspired routing algorithms for mobile ad hoc is done to bring out their main merits and demerits.

KEYWORDS: MANETs, ACO, Pheromone, AntNet, ARA, PERA, AntHocNet.

I. INTRODUCTION

In this paper a survey of routing protocols based on ant-inspired mobile agents deployed into MANETs is done. Ants are mobile agents which provide an advantage in MANET routing [1 2 3] aid the discovery of routes and disseminate topological information to the nodes in the ad-hoc network. In frequently changing topologies like MANETs ants are an effective means to path efficiently [4]. Ant algorithms adapt to the situational requirement, they are robust and have a decentralized nature, as needed for routing in MANETs. Frequent routing table updates are not required when the routing uses ant agents and when the network traffic increases the ant agents becomes more effective. Ant-like agents are a known means to mitigate congestion [5].

Biological systems have the ability to self-organize which inspires us to apply their principles to mobile ad hoc networks. Stigmergy is the basic principle used in the ant nests, here the insects use a form of indirect communication in which traces are left in the environment that can be understood by other ants. The ant nest is a complex structure within which communication is efficiently managed through pheromone. Ants roam around and on finding food return back to the nest and while returning back lay pheromone trails. Ants determine the shortest route between the nest and the food source by pheromone on the path that has been traversed [6 7]. The trails left behind direct the other ants in the direction of food and they are likely not to wander around. For every shortest path found by an ant to a food source there is a high probability that other ants follow that path leaving more pheromone and make the path more attractive for more ants to follow that path. The stigmergy seen in the ant network system can be used in our networks for defining new routing protocols for MANETs. The MANETs may be compared to the colonies of ants or termites, where these insects work independently like the nodes in a MANET. The trails laid down by the ants reduce in strength over the time thereby avoiding sticking to the same optimal solution for a long period when there could be more efficient dynamic solution discovery. The evaporation of pheromone sees that the solution space is not restricted by the path found by the first ants and its excessive usage.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

II. OVERVIEW OF ANT COLONY OPTIMIZATION (ACO)

Colony Optimization (ACO) was first put forward by Dorigo M. in the early 1990's, and it was designed to simulate the foraging behavior of real ant colonies [8 9]. There have been a class of algorithms which are inspired on the behavior of foraging ants. Ants when looking for food, explore the space surrounding their nest. Ants perform random search while looking for food. The path taken is marked by the ant by releasing a chemical substance called Pheromone.

Pheromone triggers social response in its own species. It acts outside the body of an individual which secretes the substance. When any of the ants find the food source it collects sample of food and returns back to the nest following their own pheromone trail. Initially, the ants walk randomly when multiple paths are available from nest to food. These trails are used for efficient foraging. During their return to nest, ants extensively mark the trail towards the food source [10]. The amount of pheromone deposited by the visiting ants depends upon the quality and quantity of food [11], which guides other ants towards food source. The deposited pheromone gets evaporated after a short interval of time. When the rate of pheromone deposition by ants is faster than the rate of evaporation, pheromone accumulates [12].

As multiple ants start from the nest in search of food following different paths, some of them return to nest after successful exploration of food source, thus evolving multiple paths. During the course of exploration, ants follow the paths where pheromone is deposited at maximum. Further, ants also mark the traversal path they choose by releasing pheromone. Thus over a short duration of time the shortest path is explored with maximum pheromone deposition. Ants communicate indirectly based on environmental changes (pheromone diffusion) i.e. based on stigmergic communication Stigmergy is an indirect communication followed by agents. Trails are left by some ants form the source of action for other ant agents. Although initial exploration results in longest paths, over course of time shortest path dominates.

The principle of ACO algorithms is to get information about the routes through repeated sampling, ants which are nothing but some control packets are sent for this purpose [13 14]. Ants are generated by a source node and released to test paths for acquiring information like end-to end delay, no. of hops etc. to the destination it wants to send data. These ants after acquiring this information, update the intermediate nodes on their way back to the source node. Ants always sample complete paths from one source node to the destination node [15].

Individual tables contain for each destination a vector of real valued entries called the pheromone variables, one for each known neighbor node. The pheromone entries at each node represent the how good it is to take that path, of which this node is a part on the way to the destination. The pheromone variables are frequently updated according to path quality values as calculated by the ants. Each node has a list of frequently used and available paths along with an estimated measure of quality, as a result of the repeated and concurrent generation of path-sampling ants. The routing tables at each node provide information to the ants as to which path they need to take at each node to reach their destination. Random hops are taken in a probabilistic manner, based on higher pheromone values. The collective learning behavior is achieved through the individual ants. Each of these artificial ants is a not too complex entity, which is autonomous, and updating the pheromone entries thereby participating in stigmergic communication in the network.

The data packets choose those routes used by ants for reaching the destination, along the paths having nodes with higher pheromone values. The data for a same destination may be spread over multiple paths however most of the packets go over the best paths which result in load balancing. While sending the data packets, the routing mechanisms usually do not choose low quality paths. However virtual ants are more exploring they choose the less travelled paths to sample and retain these paths as a backup in case of congestion or link failure. These alternatives provide us with parallel sample solutions for the problem at hand.

Ants which live in colonies discover optimal paths over time between their nest and sources of food laying along pheromone [16] which principle has been reverse-engineered and used in the general optimization framework of the Ant Colony Optimization [17, 18, 19].

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

Ant algorithms are self learning, robust having a decentralized structure making them adaptable for routing in MANETs. The characteristics of ant based algorithm which make them suitable for MANET routing is they can adapt to the current topology of the network, based only on local information. There is an evaporation process imbibed into the network which integrates the quality of connection into the computation of the pheromone concentration, providing support for multi-path [20].

III. ANT-BASED CONTROL ALGORITHM (ABC)

One of the earliest work in routing of networks, Ant Based Control (ABC) algorithm [Schoonderwoerd et al.,1996] used the idea of swarm intelligence . ABC was primarily designed for wired circuit switched networks like say telephony networks. It is a adaptive algorithm and exhibits robustness under various network conditions. Ant Based Control is implemented by using simple agents, called ants, which alter the routing policy at every node in a telephone network by depositing a virtual pheromone trail on the entries in the routing table. It assumes symmetric path costs between nodes, The goal of an ant is to build routing tables, and adapt them to load changes in the network so that performance is optimized. An ant is a mobile routing agent, randomly exploring the network and updating the routing tables according to the current network state. The routing tasks associated with ABC is to make probabilistic decisions through exploratory ants, and route the actual calls, making deterministic decisions[21]. If the optimal route is congested, ants could change the probability distribution to make changes in the routes. Here nodes periodically send out ants to randomly chosen destinations. Every ant has an associated age, which is increased proportionally to the load of each visited node. While travelling from a source to its destination, the ant updates the pheromone for the path backward, based on its age.

IV. ANTNET

DiCaro, Dorigo et al,1997 introduced a scalable, distributed, routing algorithm used for routing in packet-switching wired networks. It was based on the adaptive learning through ant colonies was called the AntNet,. AntNet was later improved upon by Barán and Sosa, 2000. AntNet was based on the ants exploring the network with an intention of building and rebuilding routing tables, hence keeping them always ready to the traffic conditions.

Routing in AntNet is associated with sets of complex interactions between exploration agents called ants. Ants are of two types the forward and backward ants. Ants are mobile agents having the same data structure but behave differently in the network. The entire network is explored proactively through the forward ants.

The nodes in the network launch forward ants, asynchronously toward randomly selected destination nodes. The launching of forward ants happens in parallel with the data traffic at regular intervals. Each forward mobile agent searches for a minimum cost path between source and destination nodes [22 23 24]. The routing information gathered by the forward ants on their trip from source to destination is inherited by the backward ants from the forward ants, and is used to update the routing table of nodes in the path from destination to source travelled by the backward ant. Routing tables of Nodes are not updated for paths between nodes by the forward ants, but by the backward ants. The sole purpose of a forward ant is to report network delay conditions and traffic statistics to the backward ants.

In AntNet, every node maintains two data-structures viz. routing table and local traffic statistics table. Routing tables hold artificial pheromone values and is also called as pheromone table. Towards every destination, pheromone table contains a vector with single entry per outgoing link. Node i 's pheromone table T_i contains an entry T_{ij}^d which holds the pheromone value T_{ij}^d indicating the relative goodness of taking the path across j on the way to d [25]. An ant, upon reaching its destination turns around and becomes backward ant. It then returns to source node s . Backward ants follow the exact reverse path of their forward ant and do not take probabilistic routing decisions. A backward ant during its traversal towards from source node s updates the destination d 's entries in all the intermediary nodes say i 's routing tables.

Since the main purpose of AntNet is to investigate how data packets travel along a certain route, the forward ants and data packets share the same queue in the intermediate nodes. Thus the advantage is that the forward ants can measure

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

the estimated travelling time that the actual data packets would experience. The problem, however, is that the forward ants may take a significantly lengthy travelling time to reach their destinations causing extra overhead thereby reducing the available traffic capacity for actual data communication.

V. ANT-COLONY BASED ROUTING ALGORITHM (ARA)

ARA is reactive, MANET routing algorithm based on mobile agents called the ants [26]. One of its notable characteristics is that it does not use the hello packet to explicitly find its neighbors [27]. Instead, ARA uses a flooding technique. ARA has three phases associated with its working, the route discovery, route maintenance and handling of route failure during communication. Here the route discovery happens through mobile agents called as ants. There are three phases of this routing algorithm are as follows.

A. Route Discovery Phase

In this phase routes are formed through the concept of mobile agents called ants. Two types of these mobile agents are used and they are the forward ant (FANT) and backward ants (BANT) [28]. FANT has the responsibility of laying the pheromone track to the source node and the BANT has the responsibility of laying of the pheromone track to the destination node. FANTs are packets broadcast and relayed through the network. Duplicate FANTs which may arrive at any node are destroyed as every FANT has a source address and a unique sequence number associated with it [28]. Unique sequence numbers are used to identify duplicate FANTs which are destroyed by the receiving nodes. A node on receiving a FANT for the first time adds a record to its routing table the data like the destination address, next hop, and pheromone value. However the node interprets data from the arrived FANT as - Destination address: the source address of the FANT, Next hop: the address of the previous node, pheromone value: computes based on the number of hops the FANT needed to reach that particular node [28]. After interpretation the FANT is relayed to its neighbors.

After the FANT reaches the destination for which it is intended, the destination node extracts the data from the FANT and subsequently destroys it. The data which has been extracted helps in initializing the newly created BANT by the destination node. The BANT is now sent to the source node. The responsibility of the BANT is to create a track back to the source node. As the BANT reaches the source node from the destination a path is established using which the data packets can be sent [28]. ARA supports multi-path routing.

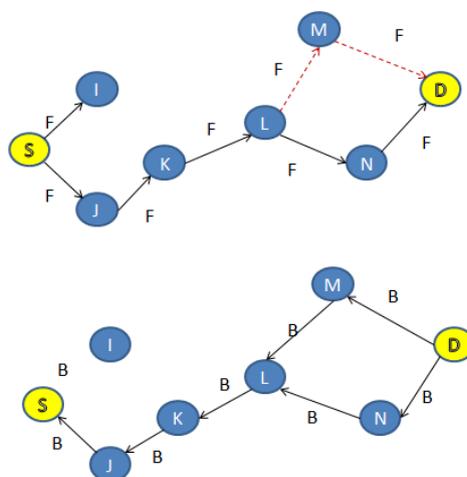


Fig: Route discovery in ARA

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

B. Route Maintenance

Route maintenance uses no special packets in ARA. Here after the FANT and BANT establish the pheromone tracks between the source and destination nodes, the data packets are used to maintain the path and also the path has an increase in the pheromone value. Pheromone values keep on changing. As nodes relay a data packet toward destination through a neighbor node, an increase in the pheromone value is made for that entry. However in the opposite direction there is a regular decrease of the pheromone values which are similar to nature allowing for evaporation [28].

C. Route Failure Handling

Route failure handling phase of ARA handles routing failures, which are caused through node mobility in mobile ad-hoc networks. A route failure is determined when there is a missing acknowledgement. When a node gets a ROUTE_ERROR message for a certain link, the link is deactivated by the node by setting the pheromone value to 0. The node now searches for an alternate link in its routing table, as multiple routes have been determined in the route discovery phase. In case if there exists an alternative second link, it sends the data packets via that path. If there is no alternative path the node informs its neighbors, with the intention that they can relay these packets. If the packets couldn't be sent to the destination node successfully then the backtracking continues towards the source node in search of more alternative paths. If the data packets are not able to reach the destination, the source has to re-initiate a new route discovery.

VI. PROBABILISTIC EMERGENT ROUTING ALGORITHM (PERA)

Baras and Mehta (2003) [30] have introduced Probabilistic Emergent Routing Algorithm PERA for MANETs. This algorithm works in an on-demand way, with the ants being broadcast towards the destination at the start of a data session [31]. Here multiple routes are discovered by the mobile agent packets forward ant and the backward ant. For the transmission of data packets the route with the highest pheromone value is chosen, with the other paths made available for backup [31].

Neighbors are discovered through HELLO messages being broadcast. Routing table is initialized by adding all the neighbors (having initial equal probability value) in the table. The ant agents create and adjust probability distribution at each node for that node's neighbors. The probability associated with a neighbor reflects the chances of that neighbor forwarding and hence the packet being delivered. The routing tables are also modified to attach a higher probability to that node through which the backward ant just came from, establishing a path to the destination. To discover a route the node broadcasts Forward ants after pushing its own IP address and creation time of the forward ant on to the stack of the forward ant. Subsequent nodes (which are not the destination) add their own address and the receiving time of the ant on that node in forward ant stack and decrement the hop count field of that forward ant.

Duplicate forward ants are avoided by discarding all the ants with the sequence numbers less than the number already stored in the nodes routing table for forward ants from that same previous node. Only sequence numbers which are greater than that previously recorded by the node, is received is accepted by the node and updating happens. As the forward ant reaches the destination, the information it is storing is extracted, a backward ant is created, and then the forward ant is killed. The backward ant retraces the path of the forward ant which was responsible for its creation. The backward ant travels in unicast fashion on high priority queues back to the correct next hop.

VII. ANTHOCNET

Gianni Di Caro, Frederick Ducatelle et all proposed AntHocNet which is a hybrid adaptive routing algorithm [32] based on Ant Colony Optimization. AntHocNet combines a reactive route setup along with constant proactive route probing, maintenance and providing for improvement. Given the dynamic topology of the network, communication is restored quickly through a new route discovery process. The algorithm reactively determines multiple paths which may

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

be used to set up communication between the source and destination of a data session; however the path characterized by minimal number of hops, low congestion and good signal quality between adjacent nodes is used. As communication session is in progress, ants proactively test existing paths and explore new ones. This algorithm mainly concentrates on path exploration resulting in large control overhead as it needs to find path frequently and for which it broadcasts forward ants.

Every node has two tables associated with it, one is the Neighbor table and the other is the Pheromone table. Routing information is stored in the pheromone table which is used for forwarding the control and data packets. The routing is done in a stochastic way. Pheromone table has information like regular pheromone value, virtual pheromone value and average hop count for the destination over that neighbor. The neighbor table stores information about neighbor nodes. For data to be sent from a source node to a destination node, the source node checks its routing table for information about the destination, if the information is current and is updated, routing starts else route discovery process begins.

A. Reactive Route Setup

When a node receives a data packet that was locally generated, to move towards a destination for which no routing information is available, the reactive route establishment process is triggered [24].

1. Reactive Forward Ant

When there is no routing information between a source to the destination node, the source node initializes a communication session by generating reactive forward ants towards destination. Forward ant only has addresses of the source nodes and destination node. After its creation, the ant is broadcasted by the source to its neighbors. At subsequent nodes, the ant could be unicasted or broadcasted based on whether a node currently holding forward ant has routing information about destination or not [25].

If routing information is available the node chooses next hop as associated with a path with the highest probability. When no routing information is available, ants are broadcasted to their neighbors by nodes. Due to broadcasting, ants quickly proliferate over the network following different paths to the destination causing heavy network traffic. To reduce the induced network instability, when a node receives several ants of the same class, chooses the first forward ant which reaches the destination to become the backward ant. Copies of forward ants later received are discarded to reduce overhead. The backward ant traces back towards source, following the list of nodes \mathcal{P} visited by forward ant. By the end of reactive route setup phase, a single path from source to destination is established [25].

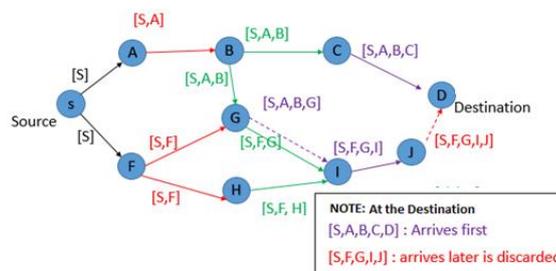


Fig : First ant arriving at the destination gives the best path

2. Reactive Backward Ant

Backward ants traverse the best path in reverse. The first forward ant that has been received from the source is used to make reactive backward ant. This reactive backward ant holds the addresses of the forward ant's source, destination

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

nodes along with the list of nodes \mathcal{P} the forward ant has visited. Reactive backward ant is unicasted from destination to the source along the list of nodes \mathcal{P} passed by the forward ant [25]. All the intermediate nodes a backward ant visits, it updates the routing information of the intermediary nodes. This phase ends with a single path being established between the source and the destination.

B. Proactive route maintenance

As paths are established through the reactive route setup process, proactive path probing and maintenance processes begin and update the available routing information across nodes involved in communication. The rate at which proactive ants are forwarded is in synchrony with data packets forwarded during the data session [33]. Proactive ants follow the pheromone values in the same way as the data does and serve dual purpose; if proactive forward ants are unicasted and choose their next hop accordance to the pheromone values available across nodes, it means that existing paths are sampled, gather up-to-date quality estimates of that path, and an updating of the pheromone values of the nodes along that path from source to destination takes place. A backward ant does the same in the direction from the destination back to the source. If on the other hand the proactive ants get broadcasted at any point, it will leave the currently known pheromone trails, and explore new paths. After being broadcast to the neighbors of the broadcasting node, it is possible that this neighbor it does not find pheromone pointing towards the destination, so that the proactive ant needs to be broadcasted again. The proactive ants will then quickly proliferate and flood the network like reactive forward ants. It is necessary to limit the number of broadcasts, if the proactive ant does not find routing information within two hops; it will be deleted [25]. The effect of this mechanism serves the purpose of exploring new paths which are concentrated around current paths, identifying path variations and improvements.

Route maintenance has the responsibility divided into the following two sub-processes.

1. Pheromone Diffusion

This sub-phase uses periodic update messages and information. Pheromone diffusion is executed by all nodes throughout their lifetime, is not bound to just running sessions. In order to give a better guidance to the forward ants in the reactive route setup, each node in the network will broadcast periodic “Hello” messages to its immediate neighbors. This is to get to know them better and spread pheromone information of their neighbors.

A neighboring node on receiving a “Hello” message uses the pheromone information it receives through the message and enter the details into its pheromone table through an update of its virtual pheromone value. The bootstrapped pheromone, a combination of regular pheromone from a node’s pheromone table and locally estimated cost function is called as virtual pheromone. It acts as an alternative to regular pheromone deposited by ants in the reactive route setup phase. When no routing information is available about destination in regular pheromone table, the bootstrapped values are used to establish new route to destination. If neither of regular pheromone nor virtual pheromone tables have routing information about destination then the proactive forward ant is discarded. When proactive forward ant reaches destination it changes to proactive backward ant.

This way the pheromone deposited on the ground diffuses, and can also be detected by ants further away. Once virtual pheromone entries are updated and stored, proactive ants sample in the proactive route setup phase leading to that path being used to forward the data packets. Hello messages also serve another purpose which is to detect broken links, allowing nodes to clean up stale pheromone entries from their routing tables. The link failures are notified to all nodes by flooding. Alternate path to the destination are determined by repair ants in case of failure during transmission.

2. Proactive Ant Sampling

The process of Proactive ant sampling aims to gather routing information for ongoing sessions using ant-based sampling [25]. Proactive forward ants follow either of regular or virtual pheromone. Following regular pheromone

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

helps in updating goodness estimate of existing routes while following virtual pheromone leads to establish new routes. Proactive backward ants exhibit same behavior as reactive backward ants. When a proactive forward ant reach destination by following virtual pheromone, it becomes proactive backward ant. As it exhibits same behavior as reactive backward ant, it follows through the list of nodes \mathcal{P} it has visited and dumps pheromone on its way back. Through this mechanism, path with virtual pheromone is now diffused with regular pheromone and a new path is established. The process repeats which evolves into a full mesh. Therefore proactive ants ensure reliability of new paths established through pheromone diffusion.

VIII. CONCLUSION

In this paper we have presented a comparison of various ACO based routing algorithms for routing in MANETs. ACO algorithms are robust, adaptive and help in dealing with the challenges of routing in MANETs. The agents in ACO routing algorithms which are the ants communicate indirectly through the stigmergy and provide a positive feedback through laying of pheromone on the links. Moreover, there is negative feedback through evaporation and aging mechanisms, to avoid stagnation. ACO routing algorithms allow for direct agent-to-agent communication which makes them more suitable for MANETs.

REFERENCES

- [1] N. Minar, K.H. Kramer and P. Maw, "Cooperating Mobile Agents for Dynamic Network Routing", Software Agents for Future Communications Systems, 1999, Ch. 12, Springer Verlag Publishers.
- [2] R.R. Chaudhary, S. Bhandhopadhyay, K. Paul, "A Distributed Mechanism for topology discovery in Ad Hoc Wireless Networks Using Mobile Agents". In Proceedings of Mobicom 2000, pp. 145-146.
- [3] L. Carilo, J.L. Marzo, P. Vilà, C.A. Mantila, "MAntSHoc: A Multi-agent Ant-based System for Routing in Mobile Ad Hoc Networks". Proc. of "Congrés Català d'Intel·ligència Artificial" (Spain) 004.
- [4] Choudhury, R.R.; Bandyopadhyay, S.; Paul, K. A Distributed Mechanism for Topology Discovery in Ad Hoc Wireless Networks Using Mobile-Agents. In Proceedings of the 1st ACM International Symposium on Mobile Ad Hoc Networking & Computing, Boston, MA, USA, 11 August 2000; pp. 145–146.
- [5] Schoonderwoed, R.; Holland, O.; Bruten, J. Ant-Like Agents for Local Balancing in Telecommunications Networks. In Proceedings of the First International Conference on Autonomous Agents, Marina del Rey, CA, USA, 5–8 February 1997; pp. 209–216.
- [6] Vincensius LR, Indrarini Dyah I, Istikmal. "Performance Analysis DSDV and ZRP based Ant algorithm at Mobile Adhoc network". Telecommunications Journal of Research and Development, December 2010 volume 15 - number 2, pp. 99-107.
- [7] Leksono, Agus. "Ant Colony Optimization (ACO) Algorithm to Completed Traveling Salesman Problem (TSP). Faculty of Mathematics and natural Sciences, University of Dipengoro, 2009.
- [8] Mohammad Towhidul Islam, "A Parallel Ant Colony Optimization Algorithm For All-Pair Routing In MANET's", Proceedings Of The International Parallel And Distributed Processing Symposium (IPDPS'03) 0-7695-1926-1/03@2003 IEEE
- [9] G.A. Di Caro, F. Ducatelle, and L.M. Gambardella. "AntHocNet: an ant-based hybrid routing algorithm for mobile ad hoc networks." In Proceedings of PPSNVIII, volume 3242 of LNCS, pages 461–470. Springer, 2004.
- [10] Falko Dressler, Ozgur B. Akan, "A survey on bio-inspired networking". In Computer Networks, 2010 Elsevier
- [11] S'ergio Luis O. B. Correia, Joaquim Celestino J'unior, Omar Cherkaoui, "Mobility-aware Ant Colony Optimization Routing for Vehicular Ad Hoc Networks". In Proceedings of IEEE WCNC 2000, 2000.
- [12] Yasushi Kambayashi, "A Review of Routing Protocols Based on Ant-Like Mobile Agents". In Algorithms, 6 August 2013, pp. 442-456
- [13] S. Corson and J. Macker. RFC 2501: Mobile Ad Hoc Networking (MANET): Routing Protocol Performance Issues and Evaluation Considerations, January 1999."
- [14] J.S. Baras, H. Mehta, "A probabilistic emergent routing algorithm for mobile ad hoc networks" , In Proceedings of WiOpt03: Modeling And Optimization in Mobile Ad Hoc and Wireless Networks, 2003.
- [15] R.S. Sutton and A.G. Barto. Reinforcement Learning: An Introduction. MIT Press, 1998.
- [16] S. Goss, S. Aron, J. L. Deneubourg, and J. M. Pasteels. Self-organized shortcuts in the Argentine ant. *Naturwissenschaften* , 76:579–581, 1989.
- [17] M. Dorigo, G.A. Di Caro, and L. M. Gambardella. Ant algorithms for discrete optimization. *Artificial Life* , 5(2):137–172, 1999.
- [18] M. Dorigo and G.A. Di Caro. The ant colony optimization meta-heuristic. In D. Corne, M. Dorigo, and F. Glover, editors, *New Ideas in Optimization*, pages 11–32. McGraw-Hill, 1999.
- [19] M. Dorigo and T. Stützle. *Ant Colony Optimization* . MIT Press, Cambridge, MA, 2004.
- [20] B. Kalaavathi, S. Madhavi, S. VijayaRagavan & K. Duraiswamy, (2008) "Review of Ant based Routing Protocols for MANET", in Proceedings of the International Conference on Computing, Communication and Networking, IEEE.
- [21] S.A. Ladhake, Shradha A Thakare, "A Review: Ant Based Ad hoc Routing Protocols", International Journal of Emerging Technology and Advanced Engineering, Volume 2, Issue 1, pages 373–375, January 2012
- [22] Di Caro, G.; Dorigo, M. AntNet: A Mobile Agent Approach to Adaptive Routing; Technical Report IRIDIA 97–12; Université Libre de Bruxelles, Brussels, Belgium, December 1997.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 12, December 2015

- [23] Di Caro, G.; Dorigo, M. An Adaptive Multi-agent Routing Algorithm Inspired by Ants Behaviour. In Proceedings of Fifth Annual Australasian Conference on Parallel and Real-Time Systems, Adelaide, Australia, 28–29 September 1998.
- [24] Di Caro, G.; Dorigo, M. AntNet: Distributed stigmergetic control for communications networks. *J. Artif. Intell. Res.* 1998, 9, 317–365.
- [25] Frederick Ducatelle, “Adaptive Routing in Ad Hoc Wireless Multi-hop Networks”. PhD thesis. Faculty of Informatics. Università della Svizzera Italiana. Lugano, Switzerland, May 2007
- [26] Bouazizi, I. ARA–The Ant-Colony Based Routing Algorithm for MANETs. In Proceedings of the 2002 International Conference on Parallel Processing Workshops, Vancouver, BC, Canada, 21 August 2002; pp. 79–85.
- [27] Roth, M.; Wicker, S. Asymptotic Pheromone Behavior in Swarm Intelligent MANETs. In Proceedings of the Conference on Mobile and Wireless Communication Networks, Paris, France, 25-27 October 2004; pp. 335–346.
- [28] Mesut Güneş, Martin Kahmer, Imed Bouazizi, “Ant-Routing-Algorithm (ARA) for mobile multi-hop ad-hoc networks – New features and Results”, Proceedings of the Ad-Hoc Net 2003 Workshop Mahdia, Tunisia 25-27 June, 2003
- [29] Mesut Güneş, Otto Spaniol, “Routing Algorithms for Mobile Multi-Hop Ad-Hoc Networks”, International Workshop NGNT
- [30] J. S. Baras and H. Mehta. “A probabilistic emergent routing algorithm (PERA) for mobile ad hoc networks”. In Proceedings of WiOpt, 2003.
- [31] J. Baras and H. Mehta 2003. A Probabilistic Emergent Routing Algorithm for Mobile Ad hoc Networks (PERA).
- [32] G.A. Di Caro, F. Ducatelle, and L.M. Gambardella. “AntHocNet: an ant-based hybrid routing algorithm for mobile ad hoc networks.” In Proceedings of PPSNVIII, volume 3242 of LNCS, pages 461–470. Springer, 2004.
- [33] Di Caro, G., Ducatelle, F., Gambardella, “AntHocNet: an adaptive nature inspired algorithm for routing in mobile Ad Hoc networks”. In European Transactions on Telecommunications, Special Issue on Self Organization in Mobile Networking 16(5) (2005) 443 - 455