SWARM INTELLIGENCE BASED COMPARATIVE SCRUTINY OF DIFFERENT ROUTING ALGORITHMS IN MANETs

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ABSTRACT

A Mobile Ad-Hoc Network (MANET)[Sen, 2006, 1-43] is a group of wireless movable nodes forming an impermanent network without using centralized access points, infrastructure, or centralized administration. Routing algorithms such as Dynamic Source Routing(DSR), Zone Routing Protocol(ZRP), Temporally Ordered Routing Algorithm(TORA) and Ad Hoc On Demand Distance Vector(AODV) etc are examples of basic algorithms for MANETs that has been developed by researchers and these basic algorithms are classified under three categories i.e. proactive, reactive and hybrid algorithms for MANETs. Dynamic Source Routing(DSR) and Ad Hoc On Demand Distance Vector(AODV) Routing are reactive algorithms setting up paths only when they are required. When data is required to be transferred over the wireless network in order to provide communication between two nodes, the sender node searches for a route by flooding the network with route request messages. Their propagation introduces some stoppage before data packets can be sent and reactive routing algorithms are inefficient when there is much continuous but irregular traffic in the network. On the contrary, Destination Sequenced Distance Vector(DSDV) routing comes under the category of proactive routing algorithms. It maintain a fresh list of routes between all node pairs all the time by periodically broadcasting the routing information to keep the routing table up-to-date at each node. This approach requires a network to carry a lot of control traffic into a network. Zone Routing Protocol(ZRP) is a hybrid protocol in which whole network is divided into zones such that routes within a zone are maintained proactively and routes among different zones are maintained reactively. The term Swarm Intelligence[Prasad, Singh & Rai, 2007, 153-158] refers to the communal performance of self-organized and distributed systems. Ant Colony Optimization is admired along with other swarm intelligent techniques. Ants-based routing algorithms have fascinated the awareness of researchers because they are more tough, consistent, and scalable than other usual routing algorithms. Since they do not need extra direct communication to maintain paths when network topology changes, they are appropriate for mobile ad-hoc networks where *nodes shift dynamically and topology changes often. In this paper a comprehensive comparison of various Ant based algorithms is presented. The algorithms discussed here are Ant Colony based Routing Algorithm Routing(ARA), Probabilistic Emergent Routing Algorithm(PERA), AntHocNet, HopNet.*

Keywords: *MANET, Ant Based Routing Algorithms, Ant Colony Optimization, Swarm Intelligence.*

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1. INTRODUCTION

1.1 Routing in MANET

Routing is a Dynamic Optimization Problem in MANET as the search space varies over time. The routing policy identifies what node to take next at each decision node to reach the destination node. Because of the instantly changeable nature of the topology of MANETs, conventional routing techniques such as distance-vector and link-state algorithms that are used in fixed networks cannot be straightforwardly applied to mobile ad hoc networks. The limitations of MANETs require the need of dedicated routing algorithms that can work in a distributed and self-organizing way. The routing protocol of a MANET must dynamically acclimatize to the changes in the network topology. With the development of next generation of wireless communication systems, development in personal computing devices and wide use of mobile and other handheld devices are increasing population of Mobile Ad Hoc Network (MANET)[Kalaavathi, Madhavi, VijayaRahavan and Duraiswamy, 1-6].

The routing scheme in a MANET can be broadly classified into three major categories – Proactive, Reactive and Hybrid[Asadinia, Rafsanjani, Saied, 2010, 77-82]. The proactive or table driven routing protocols maintains a fresh list of routes between all node pairs all the time by periodically broadcasting the routing information to keep the routing table up-to-date at each node. So in this technique, each node in the network will have the complete knowledge of the topology of the network irrespective of its requirement. This approach suffers from tribulations like reduced scalability, need of flexibility and amplified overhead to respond to dynamic changes.[Dhillon, Arbona, Mieghem, 2007, 1-8]

The reactive or on-demand approach is driven by the event occurrence and the routing information is communicated only when the requirement arises. These protocols search the path on demand by flooding the network with Route Request packets. This approach suffers from tribulations like high latency time in finding paths and network clogging due to excessive flooding.

Hybrid approaches merge the facets of both proactive and reactive approaches. It initially establishes few proactively prospected routes and then serves the demand from additionally activated nodes. Its performance is impacted by the number of nodes taken initially which are to be maintained by proactive routing[Rosati, Berioli, Reali, 2008, 827-859]. Destination Sequence Distance Vector (DSDV) and Open Link State Routing (OLSR) are examples of flat proactive or table driven routing protocols whereas Dynamic Source Routing (DSR), Temporally Ordered Routing Algorithm (TORA) and AdHoc On-Demand Distance Vector

(AODV) routing are examples of flat reactive or on demand protocols. The enlarged latency in searching routes on demand may make the on-demand protocols inappropriate for time-critical traffic. Zone Routing Protocol (ZRP), Two Zone Routing Protocol (TZRP) and Zone Based Hierarchical Link State Routing Protocol (ZHLS) are examples of hybrid protocols.

1.2 Ant Colony Optimization

The biological insects like ants in the ant colony form a collective behavior. Their collective behavior is studied and applied to solve the complex engineering problems[Kumar, Singh, 2011, 2231-4334]. The Ant colony optimization is inspired by the foraging activity of ants [Caro, Ducatelle and Gambardella, 2005, 1-10]. While ants seek out for food, they roam arbitrarily and upon discovering foodstuff they return to their camp leaving behind a chemical stuff called pheromone. Many ants may follow different paths to the same food source. The ants, which follow the shortest route, reinforce the route by extra pheromone that assists other ants to go after that shortest path. Consequently more ants are fascinated by this shortest path which is having the maximum pheromone concentration, which further reinforces the shortest route even more. As with the case of any scent which if not reapplied, the perfume evaporates. Similarly as the ants move, the longer routes lose their pheromone concentration guiding ants to choose the shortest path. This autocatalytic action quickly identifies the shortest route and the main catalyst in this action of ants for finding the shortest route is the use of chemical volatile element called as pheromone. Ants are independent and self-directed agents that work together via indirect communication called as stigmergy. Biological insects have the ability to self-organize and it relies on four principles that is, Positive Feedback, Negative Feedback, Randomness and Multiple Interactions. A fifth principle, stigmergy, arises as a product of the other four (Bonabeau et al., 1999). Such self-organizing ability of biological insects is known as Swarm Intelligence[Singh, Singh and Kumar, 2010, 147-153]. Stigmergy is an indirect way of communication where individual working agents leave behind kind of indications in the environment and other working agents sense those indications to make their own action. This way of communication is local in which individual agents communicate locally without possessing any universal information. Swarm intelligence is emerged with communal intelligent behavior of groups of simple agents. This strategy emphasizes on distributed, robust, flexible and direct or indirect communication among relatively simple agents [Marwaha, Indulska and Portmann, 2009, 1-10]. Swarm Intelligence (SI) is the local interaction of many simple agents to achieve a global goal[Cauvery, and Viswanatha, 2008]. Ant Colony Optimization (ACO) is perhaps the best analyzed branch of swarm intelligence based algorithms [Dressler, Akan, 2010, 881-900].

2. ANT BASED ALGORITHMS

2.1 Ant Colony Based Routing Algorithm

Ant Colony Based Routing Algorithm (ARA) [G¨unes¸ Sorges, Bouazizi, 2002, 1-7] works on the principle of reactive routing technique in an on-demand way. Here forward ants i.e. FANTs and backward i.e. BANTs ants both set up ***multiple*** paths between source and destination at the start of a data session. Here FANT agent is responsible for establishing the pheromone path to the source node. However BANT agent is responsible for establishing the pheromone path to the destination node. FANTs are broadcasted by the sender to all its immediate neighbors in the network. Each FANT uses an exclusive and distinctive sequence number to avoid duplicates. During the journey of FANT from source to destination, when the FANT is received at the intermediate nodes for the very first time, the recipient node getting a FANT for the very first time builds a record of three parameters i.e. ***[destination address, next hop, pheromone value]*** in its routing table. The node understands the source address available within FANT as destination address, the address of the previous node as next hop, and figures out the pheromone value depending on the number of hops the FANT required, reaching the node. Then the node relays the FANT to all of its immediate neighbors. Now, when the FANT reaches at the destination node, it is processed in a special manner. The destination node extracts the information from the FANT and then destroys the FANT. After that a BANT is created at the destination node and sent towards the source node on the reverse path that was followed by the FANT. In this manner, the route is established between source and destination and data packets can be sent. Data packets are also utilized to maintain the established route, so no overhead is introduced. Here artificial pheromone concentration is varying similarly in a manner as we see in case of original pheromone[G¨Unes¸, K¨Ahmer, Bouazizi, 2003, 1-12].

Let us consider $G = (V, E)$ be a connected graph with $n = |V|$ nodes. The amount of pheromone i.e. $\Phi i,j$ is a clue of the frequent usage of the link i, j. An ant positioned at node vi make use of pheromone value $\Phi i,j$ of node vj and Ni to calculate the probability of node vj as next hop. Ni is the set of one-step neighbors of node vi.

$$P_{i,j} = \begin{cases} (\Psi(i,j))/(\sum_{j\in N(i)} \psi(i,j)) & \text{if } j \in N(i) \\ 0 & \text{if } j \notin N(i) \end{cases} \quad \text{.....(i)}$$

The transition probabilities $p(i,j)$ of a node v_i satisfies the constraint:

$$\sum_{j\in N(i)} p(i,j) = 1, i \in [1, N] \quad \text{..................(ii)}$$

When an ant moves from node v_i to node v_j it changes the pheromone concentration of the edge $e(v_i, v_j)$ by increasing the pheromone concentration as follows:

$$\psi(i,j) = \psi(i,j) + \Delta\psi \quad \text{.............................(iii)}$$

Similar to the case of original pheromone, the artificial pheromone value decreases with time to slow down a fast transformation of pheromone on the links and the value decreases according to the equation shown below:

$$\psi(i,j) = (1-q) \times \psi(i,j), q \in [0,1] \quad \text{...........(iv)}$$

2.2 Probabilistic Emergent Routing Algorithm (PERA)

This algorithm [Baras and Mehta, 2003, 1-10] also works on the principle of reactive routing technique in an on-demand way. Here FANTs are broadcasted towards the destination at the start of a data session using flooding technique. So the route discovery and maintenance is done by flooding the network with ants and multiple paths between source and destination are discovered. As the forward ants are flooded, the PERA algorithm uses sequence numbers to avoid duplicate packets. Only the greater sequence number from the same previous hop is taken into account. Forward ants with a lower sequence number are dropped. This approach is similar to AODV Route Request packets, but discovers a set of routes instead of one. Data packets can be routed according to the highest probability in the routing table for the next hop.

The routing table at each node n is initiated by incorporating all the neighbors of node n in the routing table and each neighbor node of node n is assigned a probability equal to 1/N where N is the number of immediate neighbors of node n in the network. HELLO messages are used to discover all neighbors at the beginning. These equi-probable probabilities are then altered or increased by the BANTS i.e. backward ants on their arrival, establishing the route to the destination. This implies that here forward ants are travelled in broadcast fashion. However, backward ants are travelled in unicast fashion on the reverse path followed by their corresponding forward ants. So, multiple routes are set up, but only the one with the highest pheromone value or probability is used by data and the other routes are available for backup [Baras and Mehta, 2003, 1-10]. Both forward and backward ants are used to alter the routing tables with probabilities. These probabilities reveal the likelihood that a neighbor will forward a packet to the given destination.

The ant structure in PERA is extended from that of ARA in order to include the stack in ant structure which records the NODE ID and NODE TRAVERSAL TIME of each node it visits on its way to the destination node. This stack is used in both forward and backward ants. In forward ants, it resembles the path to the source node which is used by backward ants afterwards when they travel from destination node to source node on the reverse path. Means stack of forward ant is always pushed with the address (i.e. NODE ID and NODE TRAVERSAL TIME) of the current intermediate node. However, stack of backward ant is always popped to find the next hop on the path for the backward ant. Also point to be noted here is that forward ants are broadcasted in the network, however backwards ants travel in a unicast manner on their way back to the destination.

This algorithm maintains traffic statistics at each node by recording mean, variance and best value of trip time form the current to all destinations. This will help in determining the alternative best routes to the destination which can be used when the original best route is busy.

2.3 AntHocNet

AntHocNet[Caro, Ducatelle and Gambardella, 2005, 443-455] algorithm falls under the category of multipath routing algorithms for mobile ad-hoc networks. It has both proactive and reactive components means it is hybrid in nature. This implies that it has forward and backward ants for both proactive and reactive components. Therefore, there exist four types of ants in this algorithm i.e. forward reactive ants, forward proactive ants, backward reactive ants and backward proactive ants. At the beginning of data session, when the route setup phase is required. This AntHocNet algorithm searches for new paths between source and destination in an on demand way. This is done in a *Reactive Route Setup phase,* where reactive forward ants are broadcasted by the source node to find out multiple paths towards the destination node[Caro, Ducatelle and Gambardella, 2005, 1-10]. Backward ants are used to actually setup the route and hence they travel in a unicast manner. Now, once multiple routes are setup reactively after that data routing is done stochastically by randomly choosing any path for data transfer that lies in the category of acceptable quality. The probabilistic routing approach guides to data load spreading according to the estimated quality of paths which indirectly leads to automatic load balancing. When a route is evidently worse than others, it will be rejected, and its congestion will be relieved. Other paths will get more traffic, leading to higher congestion, which will make their end-to-end delay increase. By continuously adapting the data traffic, the nodes try to spread the data load evenly over the network. While the data session is open, paths are monitored, maintained and improved proactively using different agents, called proactive forward ants. Means it maintains routes only for the open data sessions. ANTHOCNET is a reactive routing algorithm. They have a very high delivery rate and the route that they find is either a shortest path or is very close to the shortest path. A big disadvantage of ANTHOCNET is the number of routing messages that needs to be sent in the network for establishing routes to the destination. [Kamali, Opatmy, 2007, 1-6]

2.4 HOPNET Algorithm

HOPNET is a hybrid routing algorithm for MANETs which involves Swarm Intelligence to solve routing problems[Okazaki and Froehlich, 2009, 30-35]. The HOPNET algorithm is a hybrid ant based routing algorithm. It uses both reactive and proactive techniques. It is based on hybrid protocol ZRP[Osagie , Thulasiraman and Thulasiram, 2009, 690-705]. In this algorithm the whole network is divided into zones which are the node's local neighborhood. Within a zone the routes are created, maintained and improved proactively i.e HOPNET algorithm uses local proactive path discovery within a node's neighborhood. However, the communications between different zones are created maintained and improved in an on demand way i.e. reactive communication is there between the neighborhoods. The dimension of the zone is not determined locally but by the radius length calculated in hops. Therefore, a routing zone consists of the nodes and all other nodes within the specified radius length. A node may be within multiple overlapping zones and zones could vary in size. The nodes can be classified as exterior, interior and boundary (or peripheral) nodes. Boundary nodes are at distance equal to radius from the central node. All those nodes which are at distance less than the radius from the central node are interior nodes and all those nodes that are at distance greater than the radius from the central node are considered as exterior nodes. In this algorithm, each node maintains two routing tables namely Intrazone Routing Table i.e. IntraRT and Interzone Routing Table i.e. InterRT. Here, IntraRT is maintained proactively so that routes within the zone can be identified rapidly and InterRT is configured reactively which stores the routes to the exterior nodes. So similar to AntHocNet this algorithm also uses four type of ants i.e. reactive forward ants, reactive backward ants, proactive forward ants and proactive backward ants. Here, reactive forward ants and reactive backward ants are used by InterRT routing table and proactive forward ants and proactive backward ants are used by IntraRT routing table. HOPNET algorithm is capable of finding multiple routes between source and destination.

Let us consider proactive ants as internal ants and reactive ants as external ants because proactive ants are used internally within a zone and reactive ants are used for communication among different zones. A node broadcasts internal forward ants periodically to all its neighbors to maintain the IntraRT. The size of the IntraRT table is calculated as the degree of the node multiplied by all the nodes within its zone. The rows of the table designate the neighbors of nodes which are one hop away and the column specifies all the nodes in the zone. There are four elements in the routing table for a particular (row, column) pair: pheromone, visited times, hops, SeqNO. Pheromone is the concentration of pheromone deposited on the link, visited times represents the number of times the link has been visited by the ants, hops is used to specify the number of hops between the node and all the nodes within its zone. Note that the hops field helps to distinguish between a peripheral node and an internal node. That is, if hops is less than zone's radius, then the node in the column is an internal node, if hops is greater than zone's radius, then the node in the column is an external node otherwise it is a peripheral or boundary node.

3. COMPARISON OF DIFFERENT ANT BASED ROUTING ALGORITHMS

In ARA both forward ants and backward ants are broadcasted. Forward ants are broadcasted from source to destination and backward ants are broadcasted from destination to source. So, it is not necessary for the backward ant to follow the exact reverse of the path followed by its corresponding forward ant. Means backward ant may follow different route from the one that was followed by forward ant. However, In PERA only forward ants are broadcasted from source to destination whereas backward ants are unicast from destination to source and backward ant follow exactly the reverse of a path followed by its corresponding forward ant.

In ARA, ants have the following structure: [source ip address, destination ip address, sequence number, hop count] whereas in PERA, ants have the following structure: [source ip address, destination ip address, stack[node id, node traversal time], sequence number, hop count]. This implies that in PERA ant structure is extended to have stack field associated with it which makes backward ant capable of determining the exact reverse of path followed by the forward ant. This ant structure of PERA is further extended to have the next hop ip address field in it in AntHocNet. So the ant structure in AntHocNet has following fields: [source ip address, destination ip address, next hop ip address, stack[node id, node traversal time], sequence number, hop count].

In ARA, data packets also update pheromone, so that routes which are in use are also reinforced while the data session is going on. This comes down to repeated path sampling, so that ARA keeps more of the original ACO characteristics than PERA.

In ARA, a routing table entry for each node is created when a forward ant reaches at that node. Pheromone value is the number of hops required by the forward ant to reach the current node from the destination.ARA is quite similar to PERA. One difference is that both forward and backward ants leave pheromone behind: forward ants update pheromone about the path to the source, while backward ants update pheromone about the path to the destination.

ARA uses routing table which has the following structure: [Destination, Next Hop, Pheromone Value] and PERA uses routing table which has the following structure: [Destination, Next Hop, Probability]. Means in PERA, probability is used as a pheromone value instead of considering number of hops required by forward ants to reach current node from the source node. Initially probability value each node from source to destination is initialized with uniform probabilities (1/N) where N is the number of neighbors for each node. Each node periodically sends forward ant to randomly chosen destination, whereas next node is chosen according to some probability of data flow.

ARA doesn't use any kind of extra traffic statistics except the routing table at each node in the network. However, PERA and AntHocNet also use these extra traffic statistics in addition to the routing table at each node in order to maintain the traffic more effectively. These traffic statistics may include mean, variance, best value of trip time etc.

In Anthocnet and HOPNET both require more number of resources as compared to other ant based algorithms. This is because there are two forward ants [Proactive and Reactive] and two backward ants [Proactive and Reactive]. Structure of ant is approximately similar to the ants used in previously used algorithms such as ARA or PERA but number of ants generated varies with other ant based algorithms. Amount of control traffic generated due to ants is more than other ant based algorithms.

Anthocnet is most efficient in maintaining paths. It has greater chance of exploring new paths due to proactive nature with a hint of probability. This is due to the fact that proactive ants are normally unicast to sample the existing path found by reactive forward ants but also have a small probability at each node of being broadcast. Therefore even though Anthocnet maintains paths between nodes and explores new routes it is costly and requires more resources.

In AntHocNet routes in the whole network are first reactively searched and then after route discovery phase they are proactively maintained. Means here reactive or proactive routing is concerned with the whole network but in HOPNET the whole network is divided into number of zones and in each zone routes are maintained proactively whereas routes among the zones are maintained reactively. Means here reactive or proactive terms are not concerned with the whole network at any instant.

In HOPNET, as we know that each node in the network will belong to some specific zone or some multiple overlapping zones. Each node maintains two routing tables here. One is for the routes belonging to the destinations which lie within its zone i.e IntraRT and second is for the destinations which lie outside its zones i.e. InterRT. Whereas in other ant based algorithms i.e. ARA, PERA and AntHocNet only one routing tables is used at each node for all the destinations in the network.

ARA and PERA are reactive ant based algorithms whereas HOPNET and AntHocNet are hybrid ant based algorithms. Out of which HOPNET is based on ZRP i.e. Zone Routing Protocol whereas AntHocNet is not.

Table 1 gives the comparison of different ant based routing algorithms based on resources used by them.

Table 1. Comparison of different Ant based Algorithms

Characteristics	Resource And Cost Comparision				
	ARA	PERA	AntHocNet	HOPNET	
Type Of Ants	Forward Ant, Backward Ant	Forward Ant, Backward Ant	Reactive Forward Ant and Backward Ant, Proactive Forward Ant and Backward Ant	Intra-zone Forward Ant and Intra-zone Backward Ant, Inter-zone Forward Ant and Inter-zone Backward Ant	
Routing Table Structure	Destination address, Next hop, Pheromone value	Destination address, Next hop, Probability	Goodness of next hop, Destination address, Next hop	IntraRT has: pheromone, visited times, hops, SeqNO	InterRT has: Destination, SeqNo, Path and Expire
Amount Of Control Overhead Used	More than PERA but less than others	Least	Less than HOPNET but more than others	Most	
Nature Of Algorithm	Reactive	Reactive	Reactive in beginning and later transforms into proactive	Truly hybrid	

4. CONCLUSION

For the wireless networks HOPNET and Anthocnet are more efficient among all the considered ant based algorithms because they have greater chance of exploring new paths based on probability but they is more expensive and need more resources for implementing them. This is due to the fact that there is lot of control traffic generated. Among the two hybrid algorithms considered i.e. HOPNET and AntHocNet, HOPNET is more scalable then

AntHocNet because by nature, in beginning AntHocNet is not hybrid at an instant. Means, at start AntHocNet is a completely reactive protocol and once, the new route has been found it becomes a proactive protocol for all known routes and we know that proactive protocols are not good for large networks or not scalable. However, HOPNET does not change its state for inter-zone routing or for intra-zone routing. PERA is better in terms of less cost and also efficient in maintaining and exploring new paths. ARA is similar to PERA but in ARA both forward and backward ants update pheromone value. Also in ARA even the data packets also update pheromone, so that routes which are in use are also reinforced while the data session is going on. This comes down to repeated path sampling, so that ARA keeps more of the original ACO characteristics than PERA.

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6. REFERENCES

1. Anandamoy Sen 2006. Swarm Intelligence based optimization Of MANET cluster formation, pages 1-43.
2. Alexandre Massayuki Okazaki and Antˆonio Augusto Fr¨ohlich, “Adapting HOPNET algorithm for Wireless Sensor Networks”, i2ts 2009, pp 30-35.
3. Arun Kumar, Rajeshwar Singh, “Mobile Ad Hoc Networks Routing Optimization Techniques Using Swarm Intelligence” International Journal of Research in IT & Management, Aug 2011, pp 2231-4334.
4. Cauvery N. K., and K. V. Viswanatha, “Enhanced Ant Colony Based Algorithm for Routing in Mobile Ad Hoc Network”, World Academy of Science, Engineering and Technology 46 2008, pp 30-35.
5. Falko Dressler, Ozgur B. Akan, “A Survey on Bio-inspired Networking”, Article published in Elsevier Computer Networks 54(6) (2010) 881-900.
6. Frederick Ducatelle, Gianni Di Caro and Luca Maria Gambardella, “Ant Agents for Hybrid Multipath Routing in Mobile Ad Hoc Networks”, 2005, pages 1-10.
7. Gianni Di Caro*, Frederick Ducatelle and Luca Maria Gambardella 2005. AntHocNet: an adaptive nature-inspired algorithm for routing in mobile ad hoc networks, pp. 443-455.
8. Gianni Di Caro, Frederick Ducatelle and Luca Maria Gambardella 2005. AntHocNet: an Ant-Based Hybrid Routing Algorithm for Mobile Ad Hoc Networks, pp 1-10.

9. J. Baras and H. Mehta 2003. A Probabilistic Emergent Routing Algorithm for Mobile Ad hoc Networks (PERA), pp 1-10.
10. Jianping Wang , Eseosa Osagie , Parimala Thulasiraman and Ruppa K . Thulasiram 2009. HOPNET: A hybrid ant colony optimization routing algorithm for mobile adhoc networks, pp. 690-705.
11. Kalaavathi B, Madhavi S, VijayaRahavan and Duraiswamy K, "Review of Ant Based Routing Protocols for MANET" International Conference on Computing, Communication and Networking, Dec 2008, pp 1-6.
12. Laura Rosati, Matteo Berioli, Gianluca Reali,"On Ant Routing Algorithms In Ad Hoc Networks With Critical Connectivity", Adhoc Networks6 (2008), pp 827-859.
13. Mesut G¨Unes¸, Martin K¨Ahmer, Imed Bouazizi, "Ant-Routing-Algorithm (Ara) For Mobile Multi-Hop Ad-Hoc Networks - New Features And Results ", Med-Hoc Net 2003 Workshop, pp 1-12.
14. Mesut G¨unes¸, Udo Sorges, Imed Bouazizi 2002, 1py. ARA – The Ant-Colony Based Routing Algorithm for MANETs, pp 1-7.
15. Rajeshwar Singh1*, D. K. Singh2 and Lalan Kumar3, "Swarm intelligence based approach for routing in mobile Ad Hoc networks ", International Journal of Science and Technology Education Research Vol. 1(7), December 2010, pp. 147 – 153.
16. S. Prasad, Y.P.Singh, and C.S.Rai 2009. Swarm Based Intelligent Routing for MANETs, pages 153-158.
17. S. S. Dhillon, X. Arbona and P. Van Mieghem. "Ant Routing in Mobile AdHoc Networks", Third International Conference on Wireless and Mobile Communications. IEEE(2007), pp 1-8.
18. Sanaz Asadinia, Marjan kuchaki Rafsanjani, Arsham Borumand Saeid. "A Novel Routing Algorithm Based-on Ant Colony in Mobile Ad hoc Networks", IEEE(2010), pp 77-82.
19. Shahab kamali, Jaroslav Opatrny, "POSANT: A Position Based Ant Colony Routing Algorithm for Mobile Ad-hoc Networks", Third International Conference on Wireless and Mobile Communications. IEEE(2007), pp 1-6.
20. Shivanajay Marwaha Jadwiga Indulska Marius Portmann "Biologically Inspired Ant-Based Routing In Mobile Ad hoc Networks (MANET): A Survey" Symposia and Workshops on Ubiquitous, Autonomic and Trusted Computing, 2009, pp 1-10.