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A Study on Swarm Artificial Intelligence

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Abstract— ***This paper presents a survey on an emerging subfield of Artificial Intelligence which is inspired by the collective behaviour of swarms and is termed as swarm intelligence .The term swarm is used to represent an aggregation of the animals or insects which work collectively to accomplish their day to day tasks in an intelligent and efficient manner. Swarms are capable of performing tasks which are complex enough to be performed by an individual animal or insect. This fascinating intelligent behaviour of swarms has been used by researchers for solving various complex problems in computer science computer science, robotics, telecommunication and in other technical fields. Several complex problem solving algorithms have been proposed which are inspired by swarm intelligence. This paper covers a brief description of some of algorithms based on the behaviour of the swarms.***

Keywords—swarm, swarm intelligence, stigmergy, optimization, pheromone

I. INTRODUCTION

In various areas like computer science applications, robotics etc there always arise a need to design an intelligent system capable of performing complex tasks with the help of multiple self organizing autonomous nodes which are distributed in nature and have no central control. Many researchers were inspired by collective behaviour of groups of animals like school of fishes, flocks of birds and social insects like ants, bees etc while designing such systems. Various algorithms were designed for distributed problem solving devices based on the intelligent behaviour of swarms. This way of problem solving which was inspired by the intelligent collective behaviour of swarms was defined as swarm intelligence. In nature swarms (ants, bees, termites etc) consists of simple creatures as individuals which have limited intellectual capabilities still the swarm as a whole presents an intelligent and efficient solution for complex problems such as shortest path finding , predator evasion. If we take the example of ants and bees they both search for their food but using somewhat different strategies. Ants are capable of finding the shortest path for their food and they do it by communicating through their environment using a chemical substance called pheromones as they can't communicate directly. This indirect communication through the environment is known as stigmergy. Honey bee swarms are capable of finding good quality food sources. They do it by sending their scout bees to search for food sources and then after searching good quality food source scout bees perform a kind of dance which encodes some information by which conveys the direction and quality of the food source. The location for which enough number of scouts vote is chosen. Thus based on such intelligent behaviour of swarms various algorithms have been designed. Some of the strategies used by various swarms and algorithms based on those strategies are summarized in this paper.

II. ANT SWARMS

Ants are simple creatures which have limited intellectual capabilities. Thus we can say that ants as individuals are not smart enough to perform their day to day tasks like finding best food source and the shortest path for the food source ,dividing work in smaller tasks and assigning those tasks to various workers, defending a territory from neighbor and predator evasion. But all these tasks can be performed by ant colonies in an intelligent and efficient manner. Although as individual ants are just simple and small creatures which can be seen as tiny dummies but as colonies they are capable of responding quickly and efficiently to the changes in their environment. This is something called swarm intelligence. Foraging in ants can be a good example for explaining capabilities of ant colonies. Ant colonies perform foraging as follows:

(a) We can see individual ants as tiny agents searching for food. Thus these agents keep wandering randomly around the colonies in search for food.
(b) If an agent finds a food source it immediately returns to its nest either less or more directly. On its way back to nest it leaves a chemical substance on the path which is known as pheromone.
(c) The pheromones are volatile as well as attractive. Ants are capable of sensing it hence they are inclined to follow the track with pheromone.
(d) As ants start following the same track and each ant leaves pheromone on the track, thus strength of the route will keep on increasing as more and more number of ants pass through that path.
(e) If agents have found to different paths for the same food source then the shorter path will be travelled by more number of ants in the same amount of time. Thus the shorter path will be becoming more and more attractive with the passage of time as the concentration of pheromone on the path will increase.

(f) The longer route will be disappeared after some time and as the pheromone is volatile in nature.
(g) Thus finally all the ants will be able to determine or we can say choose the shorter route for the food source.

A. Routing Algorithm For MANET Based On Foraging In Ant Colony

By mimicking the foraging in ants an algorithm for routing in MANETs has been devised. The algorithm consists of three phases which are described below:

1) *Route Discovery Phase*

In this phase new routes are discovered. To discover new routes two types of agents are used named as Forward ants (FANT) and Backward ants (BANT). The agent FANT is used to establish a pheromone track to the source node while agent BANT establishes the same for the destination node.

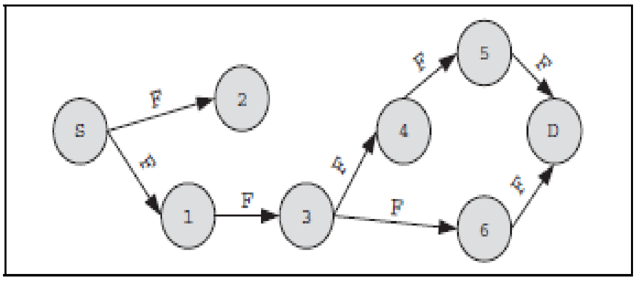

Figure 1: Route discovery phase with FANT(F) packets being forwarded from source towards destination

FANT is nothing but tiny packet having a unique sequence number. If a node receives a duplicate packet then it can identify that packet as duplicate with the help of unique sequence number and source address of FANT. A FANT is broadcasted by sources which is further forwarded by the nieghbor of the sender. After receiving FANt for the first time each node creates a new entry in the routing table. Each record in the routing table is a triplet i.e consists of three fields which are destination address (V_D), next hop (V_J) and pheromone value (ϕ). The node cosiders the source address of the FANT as the destination address, the next hop adddress is the address of the previous node which has forwarded the FANT and the number of hops that the FANT needes to reach the current dnode is used to compute the pheromone value. After storing this information the node relays the FANT to the neighbors. When the destination node receives the FANT, it extracts the information of FANT and and then FANT is destroyed by the destination node. Now destination node creates a BANT packet which is then sent to source node. BANT serves the same purpose as that of FANT i.e establishing route but to the destinaion node.

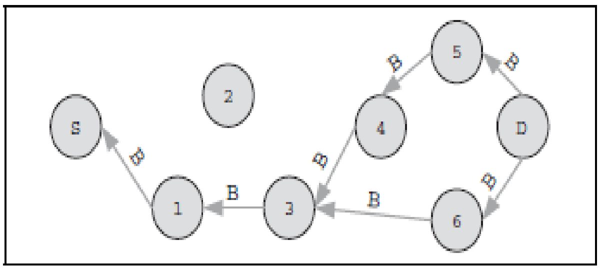

Figure 2: Route discovery phase with BANT(B) packets being forwarded from destination towards source

Once the BANT is received by the source node a path is established between between source and destination and now data packets can be sent from the source to destination and acknowledgement from the destination to source.

2) *Route Maintenance Phase*

Once the pheromone tracks for the source and destination nodes are established, it is required that these nodes should be improved as more and more packets pass through it. This is done in route maintenance phase. In ant routing algotithm, route maintenance does not require any special packet. Routes are maintained with the help of data packets transmitted over the established routes. As in natural foraging the pheromone keeps on evaporating or if more and more ants pass through the track the concentration of pheromone keeps on increasing in the same way the phromone value on the established path can not be same forever. Each time a node V_I forwards a packet to a neighbor node V_J, the pheromone value ϕ in the entry (V_D,V_J,ϕ) is increased by $\Delta\phi$. Thus as more and more number of data packets pass through the same path, that path will be strengthned by increasing the pheromone value in the entry for V_D in each node of that path. Similarly the pheromone value in the entry (V_D,V_I, ϕ) is also increased by the node V_J, to strengthen the route to the source node. The voltile nature of the pheromone is achieved by regularly decreasing the pheromone values after a predifined interval of time. Using this method of route maintenance may generate loops but Ant Routing Algorithm prevents loops by the same method which was used in route discovery phase. Duplicate packets can be identified by the nodes with the help of source address and sequence number. Whenever a duplicate packet is received by a node a Duplicate Error flag is set by that node and the packet is sent back to previous node. As a result the previous node deactivates the lint to this node, consequently no data packets can be sent to this direction any more.

3) *Route Failure Handeling*

As here we are talking about mobile ad hoc networks in which nodes are mobile in nature which causes frequent route failure. In this phase broken links are identified and handeled . Route failures are identified using missing acknowledgement. Whenever a node receives Route Error message for a particular link, at first that link is deactivated by that node. This can be done simply by setting pheromone value for that link as zero. After this the node looks its routing table for an alternate link. If an alternate link is found, the node sends the packet through that link.otherwise the node informs the neighbor about that the route failure so that packet can be relayes by them if possible. Thus either the packet is relayed to the destination by passing forwarding from one node to another or the packet reaches back to source node by continuous backtracking.

This algorithm inspired by the ant swarms helps reducing the exchange of control packets and only small amount of information is needed to be stored in the routing table. There is no need to broadcast the whole routing table in the network. It provides an energy efficient algorithm for routing in the network

III. HONEY BEE SWARMS

Another interesting swarm in nature which has been used as an inspiration for an efficient and intelligent distributed system is honey bee swarm. Honey bee swarms are capable of dividing various tasks among bees in the swarm dynamically in an intelligent manner. Bees perform their various day to day tasks like foraging, storing, retrieving and distributing honey and pollen, communication, predator evasion and adapting themselves to the changes in the environment in a collective manner but without any central control. Various algorithms have been by using intelligent behaviour of bees to model distributed systems with autonomous nodes. Foraging in bee swarms is different than that in ant swarms. An algorithm serving the same purpose as that of Ant Routing Algorithm i.e. finding best path between source and destination in an ad hoc network is designed using food foraging in bee swarms.

A. Foraging In Bees

In a hive there are thousands of worker bees which perform all the maintenance and management activities like collecting and storing food, removing the dead bees and debris, keeping proper ventilation in the hive, guarding the hive etc. in the foraging process there are two types of worker bees which are named as scouts and foragers. At first the scout bees are sent out in search for promising food source. Scout bees move randomly from one flower patch to another and keep exploring the flower patches in order to find the best food source until they are tired. The scout bees which have found a flower patch whose quality is rated above a predefined quality threshold deposit their nectar or pollen and then they move to the dance floor and perform a dance to communicate the information regarding the flower patch to the other bees. The nature of the dance performed by a scout bee represents the quality and the proximity of the food source. This dance performed by the scout bees named as waggle dance conveys three pieces of information to the hive which direction of the patch, distance of the patch from the hive and the quality rating. After getting this information forager bees are sent to the various patches by the colony. The number of forager bees sent to a patch is directly proportional to the quality of the patch. i.e. higher the quality of the food source, more will be the number of foragers sent to it. With this strategy the bee colony is able to gather good quality food quickly and efficiently.

B. Bee Ad Hoc Model Based On Bee Hive

A model has been designed for MANET based on the foraging in bee hive. According to this model every node contains a hive which comprises three floors: Packing floor, entrance floor and dance floor. At each floor in the hive a specific task is performed.

1) *Packing Floor*

It acts as an interface to the transport layer. A packer is created on the packing floor whenever a packet is received from the transport layer. The task of the packer is to find a suitable forager from the dance floor which can carry the packet to the destination. If the packer finds a forager then it gives the packet to forger. After it has handed over the packet to the forager, its task is over and it dies. But if it does not find a forager then it waits for a particular time hoping that there may be a returning forager on its way to the hive. If in that waiting period no forager is found by the packer then the packer creates a scout which discovers a new route to destination for the data packet

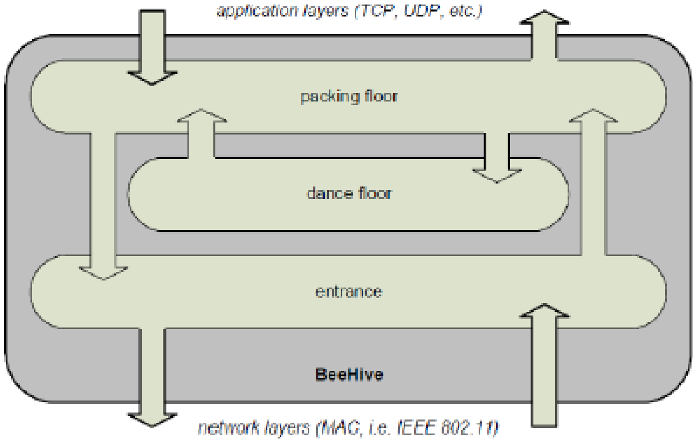

Figure 3: *Architecture of BeeAdHoc*

2) *Entrance Floor*

This is an interface to the Mac layer. The entrance floor deals with all incoming and outgoing data packets. Its task is to broadcast all the scouts that it receives. If it's TTL timer is not expired. Scouts are broadcasted by the entrance floor until they reach their destination. A table is maintained to store the id and the source node of the scout which helps in detecting the duplicate scouts so that the replicas can be killed. If the scout finds a forager with same destination at the dance floor then the route to the destination in the forager is appended to the current route of scout. Forager is forwarded by every node to MAC interface of the next hop until reaches the destination node. At the destination the forager is forwarded to the packing floor.

3) *Dance Floor*

The crucial routing decisions are taken by the dance floor. After completing its journey when a forager returns, its task is to recruit new foragers which it does by creating a number of clones of itself. A lifetime forager clones itself in to cases: if the route of the forager is a good route (a good route has nodes with enough battery capacity. Secondly, if there are so many packers which are waiting for foragers with the same destination then the forager may create its clones even though the route is not a good route. However if there are no packers waiting for the forager then the forager even with a good route may not create more forager as the other foragers are doing well in transferring data packets. Whenever a packet requests, a matching forager is sent by the dance floor. If there are many foragers at the dance floor for the same destination and satisfying the matching criteria then one of them is chosen randomly. The packets are sent over multiple paths which help avoiding congestion as well as keeps the rate of depletion of battery same at different nodes. Thus the load is balanced among different nodes when the last forager leaves the hive then the hive is left with no route to that destination. It is supposed that the forager will return within a specific time period if the route to that destination actually exists. Otherwise the node has lost the route to the destination. Using this strategy the need for exchanging hello packets for monitoring the validity of routes can be avoided. Thus energy expenditure is reduced as the number of control packets is reduced.

IV . PARTICLE SWARM OPTIMIZATION

It is a metaheuristic for stochastic optimization of continuous functions which is based on the foraging behaviour of flocks of birds. This technique is inspired by the way the swarms of birds search for their food. In this technique it is imagined that a flock of birds is searching for their food in a particular area and in that defined area there is a single piece of food. Now to reach to the exact location where the food is laying, the flock of birds will flew in a way that each bird will follow the bird in the flock which is nearest to the food. The algorithm works by assuming that each virtual bird knows its personal best position X_{pbest} and globally best personal value X_{gbest}.The velocity and position of birds are modified in each iteration using following equation:

$$V' = V + C_1.\ R_1.\ (P_{best} - X) + C_2.\ R_2.\ (G_{best} - X) \qquad \text{----(i)}$$

$$X' = X + V' \qquad \text{----(ii)}$$

In above equations V and V' are current and new velocities respectively and X and X' are current and new positions respectively while C_1 and C_2 are the acceleration coefficients and R_1 and R_2 are distributed random variables. Inspired by the behaviour of birds, takes particles at random positions as that of birds and every particle is a solution in the search space for the problem. The algorithm takes following steps:

(a) Each particle is initialized with a random velocity and position.
(b) The cost is computed for every particle and if the current cost is less than the best value till now then it is remembered as the P_{best}.
(c) The position of the particles with lowest cost of all particles is considered as G_{best}.
(d) New velocity and position is calculated for every particle and using above equations.

Steps (b) to (d) are repeated until maximum iteration or minimum error criteria are not attained. The algorithm is used for minimizing functions and while training neural networks. Thus swarm intelligence is also used in stochastic comparisons.

V. TERMITE SWARMS

Another swarm which provides an idea to generate efficient algorithm for an adaptive distributed system is termite swarm. Termites are known for building hill from pebbles. They do it using the chemical substance pheromone. Each termite follow some simple rules to build a hill and these rules are as follows:

(a) Each termite is attracted toward pheromone and if there are no pheromone traces yet then it may move randomly in search of pebble.
(b) While moving randomly whenever the termite agent encounters a pebble it will pick it up if it is not carrying any pebble at that time.
(c) A termite can have only one pebble at a time.
(d) If the termite agent along with a pebble encounters another pebble then it drops the pebble that it was carrying with it right there and also infuse it with pheromone so that other termite agents can sense the pheromone and leave their pebbles there to build a hill.

In analogy with this action of termites an algorithm for routing have been generated which considers each network node as the termite hill. The data packets are considered as a termite agent with a pebble while a control packet is considered is a termite agent without a pebble. More number of packets will pass thorough the link containing strong concentration of pheromone which is laid by the packets while they pass thorough that link. Thus this concept is helpful in developing an efficient routing algorithm.

VI. A GENERALIZATION OF SWARM INTELLIGENCE

Thus various algorithms have been discussed so far based on the intelligence of different swarms i.e. ants, bees, termites and birds. But instead of limiting the scope of swarm intelligence to a specific swarm a general frame work for problem solving technique based on swarm intelligence can be designed. This common framework includes all the characteristics of swarms. It is considered as a multiagent system in which agents communicate through the environment for solving the given problem. This general framework follows the following principles:

Principle 1: This principle says that swarm artificial intelligence uses a multiagent system in which the problem is divided into various subtasks and different agents perform the subtask given to it. All the agents are autonomous in nature i.e. there is no central control on any agent. It is the task of the designer to divide the problem into various subproblems in a logical manner.

Principle 2: This principle says that an agent in swarm artificial intelligence has to be fast in processing, simple in working and should be of limited perspective. However an agent can receive any kind of sensory information but to be simple in working it should consider only that information which is needed to perform the task given to it. Thus only small amount of information will be processed by it as an agent is responsible for the subtask given to it not for the whole problem. Also the processing will be faster as small amount of information is processed by it.

Principle 3: If we consider the first two principles alone then it looks like Swarm AI takes into account the locally important data only and neglects the globally important data. But the third principle does away with this concern by providing a way to the system to act globally. The third crucial characteristic of Swarm AI is that its agents are capable of communicating with each other indirectly and in a simple manner. More concisely we can say that this communication can take place in two ways. First way of communicating information is by altering the environment in a manner such that the other agents can take crucial decisions by noticing the change in the environment and this way of communication is known as stigmergy. In the second method an agent communicate the information to the other agents by changing its own state such as its location or velocity so that other agents can act differently depending upon the information conveyed to them.

VII. CONCLUSIONS

With the advances in technologies, new approaches and techniques are required for solving various optimization problems in areas like computer science, robotics, MANATs etc. Nature inspired problem solving techniques have been found to be an intelligent and efficient way for this. The paper surveys that researcher's work has shown that nature inspired routing algorithms for MANETs (which are distributed and autonomous in nature) have provided a solution for various challenges in MANETs. These algorithms provide a solution to problems like energy consumption, scalability, maintainability etc. Swarm intelligence has also been used for minimizing functions and for training in neural networks efficiently. Swarm intelligence is used in various other areas like in digital circuits, data mining and telecommunication.

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