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Swarm Intelligence for Routing in Mobile Ad Hoc Networks

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***Abstract*— In Mobile Ad Hoc Networks (MANETs), mobile nodes have changing locations with no centralized control, limited processing and memory for storage, lower bandwidth for communication and high bit error rate. This makes routing a complex problem in MANETs. Also, due to increase in traffic due to various format of data, problems such as packet losses, transmission delays, delay variations increases. An efficient network management solution is required that are scalable and can cope with large, and increasing, traffic volumes. The Adaptive and dynamic nature of Ants is finding its popularity as application in solving complex engineering problems. Swarm Intelligence (SI) based routing algorithms such as Ant Colony Optimization (ACO) is being used by researchers for solving the complexity of routing in MANETs. Each one based on different characteristics and properties. In this paper, we carry out an extensive review and introduce Mobile Ad Hoc Networks (MANETs) routing protocols based on biological insects like ants.**

Index terms - Mobile Ad Hoc Networks (MANETs), Swarm Intelligence (SI), Routing, Ant Colony Optimization (ACO).

I. Introduction

Mobile Ad Hoc Networks (MANETs) are built up from a number of nodes which have no fixed infrastructure. The nodes communicate through wireless network and there is no central control for the nodes in the network. Routing is the task of directing data packets from a source node i.e. transmitter. The packet is to reach its receiving end destination without any loss or delay of information contained in packets. It has become very challenging for the researchers to develop routing protocols with changing topology of Mobile Ad Hoc Networks.

Swarm intelligence (SI) based, more specially Ant Colony Optimization (ACO) [1-15] based routing algorithms are novel evolutionary algorithms, which have the characteristics such as positive feedback, negative feedback, distributing computing, stigmergy etc. Swarm Intelligence based techniques like ACO and PSO are inspired from real biological insects like ants, bees, bats, elephants, birds to and is being applied be researchers to solve complex engineering problems. They possess following characteristics:

- **Scalability –** The population changes by local and distributed agent interactions.
- **Fault tolerance**: - There is no centralized control for the agents, so they are able to sustain even in case of small failure in the links.
- **Adaptation**: - The agents change, reproduce or die as per requirement in the colony.
- **Speed**: - The agents communicate very fast through pheromone and others follow.
- **Modularity**: - Agents act independently.
- **Autonomy**: – No supervision is needed because each agent follow simple rule.
- **Parallelism**: – Agents perform the operations parallelly.

Further, in this research paper, Section II comprises of basic principle of Swarm Intelligence and Section III discuss Principle of self organizing ability in ACO Variants. In Section IV, we discuss various ANT based Algorithms/ACO Variants, and Section V is presented with Conclusion.

II. BASIC PRINCIPLE OF SWARM INTELLIGENCE - ANT COLONY OPTIMIZAION

Ant Colony Optimization (ACO), was discovered by M. Dorigo and colleagues for finding solutions to varied Hard CO problems in early 1990s. The basic foundation of ACO algorithms are real ant colonies. Ants roam randomly in the environment to determine food source and find the shortest path between food source and nest. In order to exchange information regarding which path to follow, ants communicate via use of chemical substance called Pheromone. As ants move from nest to food source, lay a trail of pheromone and other ants follow the same trail, creating a pheromone trail. The more ants follow a given trail, the more attractive that trail becomes to be followed by other ants. Using this mechanism, ants are able to transport the food from source to nest in an efficient way.

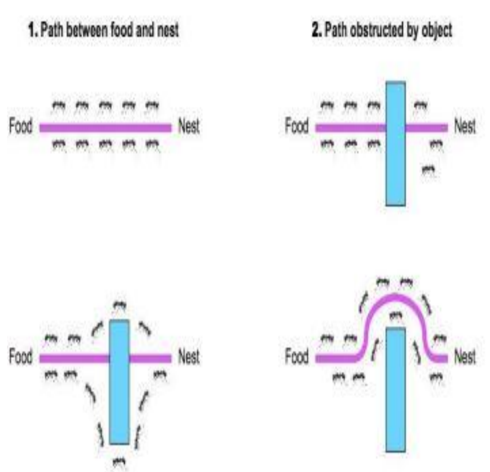

Fig.1. Basic Working of Ants in Real World

Algorithm explaining Ant Colony Optimization:

Initialize Parameters
Set pheromone trails
Create ants
***While** Stopping criteria is not reached do*
Let all ants construct their solution
Update Pheromone trails
Allow Daemon Actions
End While

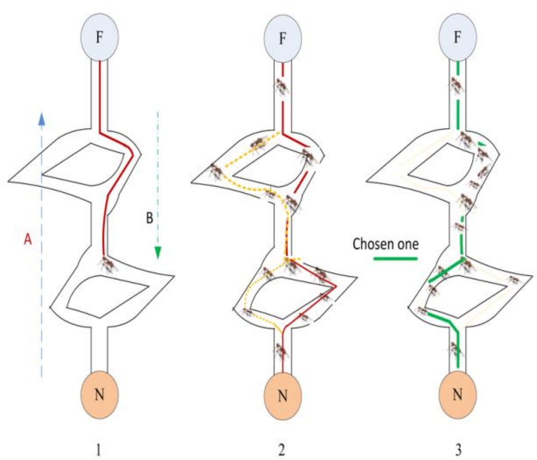

Fig. 2. Ant Colony Optimization- ACO Working

Ant Colony Optimization Algorithm

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input: An instance P of a CO problem model 𝒫 = (𝒮, f, Ω).
InitializePheromoneValues(𝒯)
s_bs ← NULL
while termination conditions not met do
   𝔖_iter ← ∅
   for j = 1, . . . , n_a do
      s ← ConstructSolution(𝒯)
      if s is a valid solution then
         s ← LocalSearch(s)          {optional}
         if (f(s) < f(s_bs)) or (s_bs = NULL) then s_bs ← s
         𝔖_iter ← 𝔖_iter ∪ {s}
      end if
   end for
   ApplyPheromoneUpdate(𝒯, 𝔖_iter, s_bs)
end while
output: The best-so-far solution s_bs
```

The following Table No: 1 highlights list of ACO based Algorithms in series of their development:

Algorithm Name	Name of Author	Year of Introduction
Ant System	Dorigo et al	1991
Elitist As	Dorigo et al	1992
Ant-Q	Cambardella & Dorigo	1995
Ant Colony System	Dorigo and Cambardella	1996
Max-Min As	Stutzle and Hoos	1996
Rank-Based As	Bullnheimer et al	1997
Ants	Maniezzo	1999
Bwas	Cordon et al	2000
Hyper-Cube As	Blum et al	2001
Ant Lion Optimizer	Seyedali Mirjalili	2015

Table No: 1 highlights list of ACO based Algorithms

III. THE PRINCIPLE OF SELF-ORGANIZING ABILITY

The biological insects follow five basic principle positive and negative feedback, randomness and multiple interactions and stigmergy to self organize. The self organizing ability of ants is called Swarm Intelligence. We will consider a surface upon which ants and foods are distributed. The ants would like to search the food and carry it to the nest that is; food should be collected in the nest. Each ant acts as individual but follow the basic principles. Ant is bound by the following rules: A biological insect like ant moves around for the search of food source by finding pheromone level on the paths. When no pheromone is found it keeps moving randomly. Once pheromone is found it starts following the path having highest gradient of pheromone. During their random roaming, if an ant finds food and not carrying then picks it up. When an ant is carrying food and find food, the ant will put the food down and start carrying the new food. The ant will also put certain amount of pheromone near the food, so that other ants roaming around can smell the pheromone and hence they also come to know about food source. The following characteristics describe the principle of Swarm Intelligence which is followed by ants for searching a food source and shortest path to the food source from an ant colony that is, nest.

Positive feedback: When ants find more deposits on a path it is followed by them. A general guideline for particular behavior is formed on the basis of Positive feedback. When an ant finds a food source and returns to its colony, it lays more pheromone on that path. Thereby the pheromone level on that path is increased. Increase in pheromone level in a particular path is a positive feedback for other ants.

Negative feedback: The chemical substance pheromone diffuses in the environment and evaporates over time. This reduces the level of deposit of pheromone in the path. Since the level of pheromone in the path diminishes with time and it does not exist where there is no food, so such paths are not being followed by other ants.

Randomness: A very important characteristic of Swarm Intelligence is randomness. The ants in the colony are not supervised. They do not have central control. They roam around randomly. A small change in pheromone level with lead to a large variations, so it is conveyed at very faster rate.

Multiple interactions: The entire ants keep finding a food source near their colony. They use multiple interactions to find the food source near their colony.

Stigmergy: The ability to communicate indirectly is called stigmergy. The ants in the colony do not communicate directly but they communicate through the deposit level of pheromone level in the path being followed by ants from nest to food source.

IV. REVIEW OF SWARM INTELLIGENCE BASED ALGORITHMS FOR MANETS

Ad hoc Networking with Swarm Intelligence (ANSI) is a reactive algorithm which finds out path only when demanded that is, when node has data to send to other nodes it finds out the path [16]. The Multicast for Ad hoc Network with Swarm Intelligence (MANSI) protocol provides multicast support for Ad hoc Networks. Within a multicast group, each member launches a forward ant in order to find an existing forwarding node where it can be used to establish connectivity to the group with lower cost [17]. The Multicast for Ad hoc Network with hybrid Swarm Intelligence (MANHSI) utilizes small control packets equivalent to ants in the physical world. These packets, traveling like biological ants, deposit control information at nodes they visit similar to the way ants laying pheromone trails on the path [18]. Ants Hybrid Routing (ACO-AHR) Hybrid routing algorithm [19]. It introduces the service agents to reduce expense of network. It uses two artificial ant agents that is, forward ant agent which travels from source to destination and find out information about quality of the path. Backward ant agent travels from destination to source and collect information about pheromone deposited. There are other types of agent that is called service agent (sagent). Improved Ant Colony Optimization algorithm for mobile ad hoc network (PACONET) is a reactive algorithm. It is a very dynamic algorithm which takes into account the mobility, route maintenance, Link Failure-Handling [20]. Position based on Ant colony routing algorithm for MANETS. (POSANT) is reactive that is, route is established only when there are some data to send. It is position based routing means each node has information about its own position, position of its neighbors, position of destination node [21]. Also, Swarm Intelligence: An emerging solution for Quality of Service (QoS) provisioning in Mobile Ad Hoc Networks is described in Singh et al.[22]. Probabilistic Ant Routing (PAR) is proposed for routing in MANET [23]. Each node maintains a list of neighbors according to HELLO MESSAGE received. Forward ant agents (FANT) are probabilistic and explore the network to collect network traffic information. They are routed on normal priority queue. If route to destination is available as present node, the FANT is uni-cast otherwise it is broadcasted. Saleem, Muhammad, Gianni A. Di Caro, and Muddassar Farooq in their paper Swarm Intelligence based routing protocol for wireless sensor networks: Survey and future directions [24], state extensive review of area of Swarm Intelligence especially with regard to Ant Colony Routing and Bee-Inspired routing protocols with regard to SI in WSN along with analysis of various issues surrounding SI based routing protocols and future directions to overcome these issues. Fatih, Ccedil; elik, Zengin Ahmet, and Tuncel Sinan in research paper - A survey on swarm intelligence based routing protocols in wireless sensor networks [25], mention various issues with regard to complexity, scalability and adaptability issues and comprehensive review of routing protocols being proposed to solve these issues. Babu, K. Ashok, D. Sreenivasa Rao, and S. Lakshminarayana, in the research paper titled, Swarm Intelligence based Energy Efficient Routing Protocol for Wireless Ad-hoc Networks [26], define various energy efficient routing protocols based on Swarm Intelligence network and propose Ant Colony Optimization meta heuristic to overcome routing issues and proposes Energy Efficient Ant Based Routing Protocol for finding optimal paths between sender and sink nodes. Zungeru, Adamu Murtala, Li-Minn Ang, and Kah Phooi Seng, in their paper - Classical and swarm intelligence based routing protocols: A survey and comparison [27], mention comprehensive review of classical to swarm intelligence based routing protocols based on complexity, structure and energy efficiency along with a proper comparison of protocols cum Simulation of these protocols on MATLAB based Simulator for determining performance metrics. Chandra Mohan, B., and R. Baskaran in a paper titled - A survey: Ant Colony Optimization based recent research and implementation on several engineering domain [28], present review of various research and implementations of ACO and proposed a modified ACO model which overcomes various routing issues as compared to other traditional ACO algorithms. Shtovba, S. D. in paper - Ant algorithms: theory and applications [29], explain theory and applications of ant algorithms and various new methods of discrete optimization on the simulation of self-organized colony of biologic ants; travelling salesman problem on basis of combinatorial optimization and various methods for improvising ant algorithms. Al Salami, Nada MA in their paper, Ant colony optimization algorithm [30] propose hybrid algorithm for solving various combinatorial optimization problem via usage of ant colony and genetic programming and to propose various effective solutions for organized networks.

Dorigo, Marco, Mauro Birattari, and Thomas Stutzle in paper, Ant colony optimization, [31] describe in detail the concept of ACO along with its variants, various theoretical results survey along with various other research issues. Yan, Jian-Feng, Yang Gao, and Lu Yang in research paper - Ant colony optimization for wireless sensor networks routing [32] state heuristic way for reducing energy consumption in routing and highlights three ACO Algorithms: Ant System, Ant Colony System and Improved AS and doing comparison among three via simulation to highlight reduction in energy consumption.

Dorigo, Marco, and Christian Blum in research paper, Ant colony optimization theory: A survey [33] describe in detail concept of ACO along with relations between ACO optimization algorithms and other approximation methods.

Monteiro, Marta SR, Dalila BMM Fontes, and Fernando ACC Fontes in research paper, Ant Colony Optimization: a literature survey [34], define ACO along with its various algorithms to determine the behavior of natural ants.

Rault, Tifenn, Abdelmadjid Bouabdallah, and Yacine Challal in research paper, Energy efficiency in wireless sensor networks: A top-down survey [35], highlight in detail the issue of energy efficiency in WSN along with survey of various energy conservation schemes to enhance network lifetime.

Ali, Zulfiqar, and Waseem Shahzad in research paper, Analysis of Routing Protocols in AD HOC and Sensor Wireless Networks Based on Swarm Intelligence [36], mention critical analysis of comparison of routing protocols of AdHoc and Swarm Intelligence in terms of routing overhead, route optimality and energy consumption. Okdem, Selcuk, and Dervis Karaboga in research paper, Routing in wireless sensor networks using ant colony optimization [37], define a new routing scheme and adapted ant colony optimization (ACO) algorithm and results are tested via Proteus Simulation Program. S Kannan, TKalaikumaran, S Karthik, V P Arunachalam, proposed MAARA (MULTIAGENT ANT BASED ROUTING ALGORITHM) [38] which is a hybrid algorithm that combines ant algorithm and multi agent systems. The algorithm is simulated over ns 2 and the results are better than AODV, DSR, ANTHOCNET, in terms of delay, packet delivery ratio, more connectivity, and less packet loss. Sehi, Siba K Udgata, "Efficient ant routing protocol for MANET proposed an ANT-E : EFFICIENT ANT ROUTING PROTOCOL [39]. The paper shows a protocol which is reactive and multipath routing that combines blocking expanding ring search (blocking ERS) with ACO. The protocol can be simulated with NS2. It out performs AODV and DSR in terms of packet delivery ratio, reliability, overheads, end to end delay etc. There are three types of overheads in the protocols, Data packets, control packets (FANT and BANT) and neighbor control packets (broadcast hello messages). Also birth and arrival time is measured. The algorithm has following phases: Route Discovery Phase: The phase is to create new paths. The source can disseminate Forward ant with destination node address, next hop and pheromone value, to its one hop neighbors. The neighbors forward FANTS to their neighbors until a route is found by blocking ERS. Otherwise source is informed by reply message. Duplicate FANTS are discarded because of unique sequence number, loops are avoided by buffering route requests, duplicate packets are discarded based on sequence number and source address. When ant reaches at destination backward ant is created to retrace the path in backward direction. The second phase is Route Maintenance Phase: Established paths do not maintain same pheromone value. When a data packet is relayed on path, it increases pheromone on path by 1 unit and strengthen the paths. The pheromone exploration takes place side by side. The next is Route Failure Handling: If the node gets a route error message (rerr) for a certain link, it deactivates The Link By setting The Pheromone Value to 0. The node searches for alternate link if packet does not reach the destination then source initiates a new routs discovery phase. The unsuccessful packets are retransmitted by intermediate nodes when they receive NACK from receiver node. A number of routing algorithm for routing in Mobile Ad Hoc Networks is proposed. All the ant based routing algorithms are summarized in the Table 2.

Algorithms	Year	Authors	Type of Routing
Ant based colony	1997	Ruud Schoonderwood	Proactive
Ant net	1997	Gianni Di Caro	Proactive
CAF	1998	M.Huesse, P.Kuntz, D.Snyers and S.Guerin	Position based
RBA	1998	T. White, B. Pagurek, and F. Oppacher	Proactive
ASGA	1998	Tony White	Hybrid
AARA	2001	H. Matsuo and K Mori	Proactive
ASDR	2002	Kasabalias and Sharkawli	Zonal
ANT-AODV	2002	Shrivanajay Marwala, Chen kong Tham, Dipti Shrinavasan	Hybrid
ARH	2002	Fujta	Reactive
ARA	2002	Mesut Gunes, Udo Sorges and I.Bouazizi	Reactive
MABR	2003	Heissen and Braun	Proactive
PERA	2003	John S Baras, Harsh Mehta	Proactive
EARA	2003	Zhenyu Liu and Kwialkowska Costas Constantinou	Reactive
TERMITE	2003	Martin Roth and Stephen Wicker	Proactive
ADRA	2004	Xiangquan Zheng,Wei Guo and Renting Liu	Reactive
Anthoc net	2004	Gianni Di Caro, Frederick Ducatelle LM Gambardella	Hybrid
ANSI	2005	Rajgopalan and Shen	Reactive
AMQR	2005	Liang gui Liu, Guang Zeng Feng	Reactive
MANSI	2005	Martin and Wicker	Reactive
GPSAL	2006	D. Camara and A.A.F.	Proactive

		Loureiro	
MANHSI	2007	Zeyad M Alfawar	Hybrid
POSANT	2008	Shabab Kamali and Jaroslav Optarny	Reactive
HOPNET	2008	Jianping Wanga, Eseosa Osagiea, Parimala Thulasiramam and Ruppa Khulasiramam	Hybrid
ACO-AHR	2008	Wan-Jun Yu, Guo-Ming Zuo and Qianq-Qian Li	Hybrid
PACONET	2008	Eseosa Osagie, Parimala Thulasiramam and Rupple Thulasiramam	Reactive
PSO-ODMRP	2008	E. Babura, and V. Vasudevas	Reactive
PAR	2009	S P Prasad, Y P Singh, C S Rai	Hybrid
FACO	2009	M.M.Goswami, R.V. Dharaskar, V.M.Thakare	Hybrid
ABRA	2009	Hamideh Shokrani, Sam Jabbehdari	Reactive
Models for pheromone evaluation ACOMANet	2009	Fernando Correia, Teresa Vazao, Victor J. Lobo	Hybrid
MAARA	2010	S Kannan , TKalaikumaran, S Karthik, V P Arunachalam	Hybrid
ATBRA	2010	Chi chenn leh, Chun Chich Huang , Wen Tiang Liang	Hybrid
ANT-E	2010	Srinivas Sehi, Siba K Udgata	Hybrid
ODAMARA	2011	Ashima Rout, Srinivas Sethi, Debajyoti Mishra	Hybrid
AEDMRA	2011	Zheng-Yu Wu, and Han-Tao Song	Reactive
ODASARA	2011	R.RameshKumar , A. Damodaram	Reactive
SAMP-DSR	2011	D. Sivakumar and S. Ganesan	Reactive
AntNet-RSLR	2011	Ahmed. A. A. Radwan1, Tarek. M. Mahmoud, Essam. H. Hussein	Hybrid

Table 2. Year-wise list of proposed ant based routing algorithms for MANET.

Ashima Rout, Srinivas Sethi, Debajyoti Mishra in the research paper [40] discussed ant based routing protocol to optimize the route discovery and maximize the efficiency of routing in terms of packet delivery ratio (PDR) using the blocking expanding ring search (Blocking-ERS), third party route reply, local route repair and n-hop local ring techniques. These techniques control the overhead and minimize the end-to-end delay with improvement of PDR. The Optimized-Ant routing protocol is based on Ad Hoc On-Demand distance Vector (AODV) and inspired by the Ant-Colony Optimization (ACO) used to solve complex optimization problems and utilizes a collection of mobile agents as ANTS to perform optimal routing activities. D Shivakumar and S Ganeshan proposed a new On-Demand Ant-based Multiagent Routing Algorithm (ODAMRA) [41] for Mobile Ad hoc Networks (MANETs), which combines the on-demand routing capability of Ad hoc On-demand Distance Vector (AODV) with some modifications in the existing ant colony optimization mechanism using ant-like mobile agents. In the conventional AODV algorithms, the actual communication is to be delayed until the route is determined. Therefore, this is not suitable for real-time data as well as multimedia communication applications. The proposed algorithm provides high connectivity, reducing the number of route discoveries before starting new connections. Hence, this may lead to elimination of the delay before starting the actual communication and it can be suitable for real-time communication in MANETs. Zheng-Yu Wul, and Han-Tao Song in research paper titled Ant-based Energy-aware Disjoint Multipath Routing Algorithm for MANETs [42] present a novel approach called ant-based energy-aware disjoint multipath routing algorithm (AEADMRA). It is based on swarm intelligence and especially on the ant colony-based meta heuristic. It can discover multiple energy-aware node-disjoint routing paths with a low routing overhead. Authors use combination of Swarm Intelligence and node-disjoint multipath routing to overcome the problems of routing in MANETs. R. Ramesh Kumar, A. Damodaram in research paper titled A Novel on Demand Ant Based Security Alert Routing Algorithm for MANET in Grid Environment [43] present on Demand Ant based security alert routing Algorithm (ODASARA) for mobile adhoc networks in grid environment, which combines the on-demand routing capability of Ad Hoc On-Demand Distance Vector (AODV) routing protocol with a Ant Colony Optimization mechanism using ant like mobile agents.

V. CONCLUSION

In this research paper, we present the review of all proposed routing protocols based on Swarm Intelligence and find that SI based more especially ACO as a powerful means to solve routing problems in Mobile Ad hoc Networks (MANETs). We also describe the characteristics and principle of Swarm Intelligence which are used to enhance the efficiency and effectiveness of routing algorithms. It is proposed that SI based routing algorithms are solutions, when routing becomes a crucial problem and / or to find a route across a dynamic topology becomes difficult, that cannot be solved with traditional routing techniques, at least not without facing intractable complexity. The basic principle is to use ants like packets and let ant routing operate to gather routing information. Authors are working on the Swarm Intelligence based algorithms to find solutions to routing problems in Mobile Ad hoc Network (MANET).

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