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A Survey of Ant Colony Optimization Based Algorithms for Efficient Routing in Mobile Ad-Hoc Networks

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Abstract*: Mobile ad hoc networks are self organizing mobile nodes. Given that these portable gadgets are free to join, leave and the network topology can alter regularly. Devices in such networks must interact with one another and function autonomously through wireless channels because to a lack of infrastructure. It is difficult to create a proper routing protocol for MANETS. Swarm Intelligence (SI), may provide possible optimum solutions that guarantee high resilience, adaptability, and affordability. Additionally, they are capable of handling complex large-scale issues without the need for a centralized control system. In addition to the fundamental requirements for routing in MANETs are expected to function independently organized and provide minimal packet lag, rate of increase in packet delivery, and effective assimilation to changes in the network configuration. In dynamic MANETs, ant colony optimization has been effectively employed to strike a balance between the different connectivity limitations. This paper offers a thorough analysis of different categories of MANET ACO-based routing methods.*

Keywords: MANET, Swarm Intelligence (SI), WSN, ACO, FANTs, BANTs, Energy Efficiency, MMP

I. INTRODUCTION

Mobile Ad hoc NETworks (MANETs) are infrastructure less networks which consist of wireless mobile devices. Since these mobile devices canjoin and leave the network freely, the network topologycan change very frequently. Due to the lack of infrastructure, devices in such networks need to cooperate with eachother and work in a self-organized manner through wireless channels. Besides the basic routing requirements, new routing protocols designed for MANETs are supposed to work in a self-organized manner and provide low packet delay, high packet delivery rate and effective adaptation. Colony optimization algorithms do not depend on any kind of coordinated system and also it does not follow any direct ahead principles. In the past two decades, a number of new technologies that are inspired by biological processes have been developed. Swarm intelligence is a method of computational intelligence that is based on the general behavior of decentralized, autonomous systems. A basic SI system consists of a collection of simple agents that interact with one another and their immediate surroundings on a local level. In a SI system, agents operate independently and according to a few basic rules but, the social interactions between such creatures have the potential to produce significant advantages and frequently result in wise global conduct.

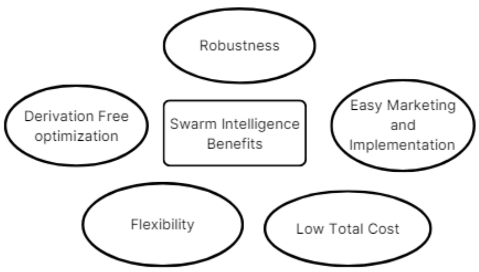

Fig 1 Swarm Intelligence Benefits

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Some well-known meta-heuristics in the SI field include Particle Swarm Optimization (PSO), Stochastic Diffusion Search (SDS), and Ant Colony Optimization (ACO).As a design paradigm for fresh strategies that uphold and enhance routing in self-organizing and dynamic ad hoc networks, ACO algorithms have garnered a lot of interest.ACO algorithms are realistically used in various routing protocols, based on the choice of certain specific parameters like ant types,the variables of pheromone reinforcement and evaporation.

II. ROUTING IN MANETS

In a wireless ad-hoc environment, additional issues emerge and the use of conventional routing protocols is unsuccessful.There is a lack of infrastructure and a well-structured hierarchy; therefore, topology modifications must spread throughout the entirenetwork, not just the next level up in the hierarchy. Node Failures and mobility both sharply increase at the same time.Data transmission costs significantly increase, and the service quality also deteriorates heavily. Furthermore, under energy-constrainedsettings the cost of maintaining routing fresh information becomes intolerable. Memory computational limitations, communication costs and restricted energy are the most important properties to be considered in the routing of mobile Adhoc networks. The class of machine learning algorithms is used to learn the behavior automatically from the environment and adapts accordingly. A good machine learning approach can be selected by considering the following properties wireless ad-ad-hoc nature, mobility, topology changes energy limitations and physical distributions.

III. SWARM INTELLIGENCE

Swarm intelligence refers to the intelligent behaviors that emerge from interactions among a swarm of social insects, such as ants, while working collaboratively toward a shared objective, such as food gathering. Ants may determine the shortest pathways by using a mechanism called stigmergy, which can be characterised as indirect communication between individuals via the environment. The ant algorithm's fundamental concept is based on the manner in which actual ants seek for food. Once ants leave their nest in quest of food and walkway of the food. When an ant comes to a cross roads, it has to choose the next course of action. On the way to the path of food ants leave behind a pheromone that identifies the chosen route. The pheromone is a chemical substance secreted by the ants on the surface it travels, this concentration along a specific pathis a sign of its application. This pheromone trails are the attraction towards other ants that subsequently strengthens them even more. This autocatalytic process causes the shortest path quickly appears.

IV. ANT COLONY OPTIMIZATION BACKGROUND

Ants are an omnipresent insect that lives in colonies from a handful to millions unlike human beings ants communicate with each other and its colony species using a volatile chemical substance called pheromone. This substance sample can be used for both foods foraging called trail pheromone and protecting the colonies from predators called alarm pheromone. The natural foraging behaviour of ants is considered to find best possible solutions for various problems, ants starts from nest in search for food in various directions also it lays the pheromone all along its path once it finds some pheromone trails the probability of choosing that path is more than the random one, followed by other ants moving out from the nest.

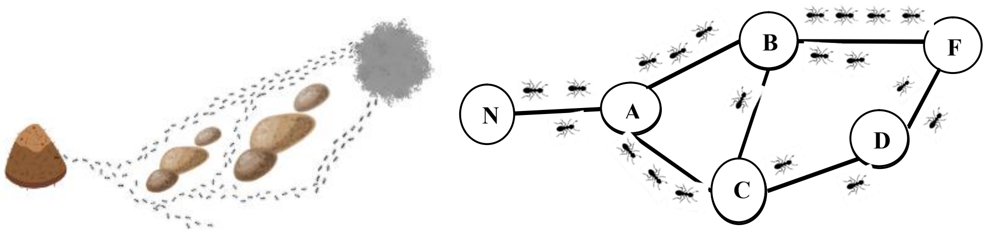

Fig 2Natural ant'sfoods foraging and its graph structure

In artificial ants the pheromone stands in for the information exchange between the individual ants. If more pheromone trails more probability of movement in the same path, otherwise evaporation of the trails also occurs. Ant colony optimization is one of the swarm intelligence techniques used to find optimal solutions for many problems. At the first

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step the problem needs to be represented in graph and when an artificial ant moves from one node to next node the choice of path is made based on the probability of pheromone updates of the ants on the way from source to destination.

V. ACO BASED ROUTING PROTOCOLS

ACO algorithms cover a wide range of applications rather than optimal routing process like quality of service, energy efficiency, security and location statistics. According to the functionalities of the protocols they are classified into the following broad categories,

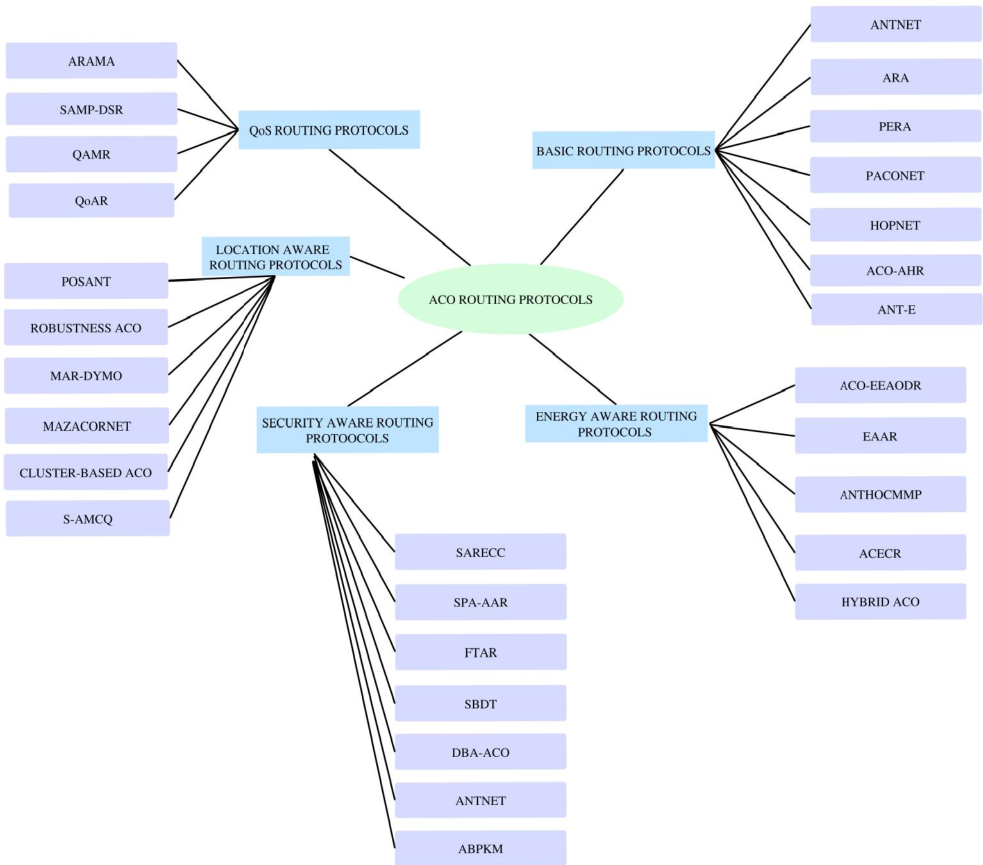

Fig 3 .Categories of ACO protocols

A. Basic ACO Protocols

Ant net is an ancestor of ACO used to solve internet routing each node proactively sends FANTs to a destination node.Once the forward ants reach the destination BANTs are sent back to the source node following the reverse path. BANTs update the network status and routing table at each intermediate node. At each intermediary node, BANTs update the network status and the routing database [2].

ARA is an on demand routing algorithm based on meta-heuristic algorithm that consists of three phases route discovery phase ,route maintenance phase and route failure handling. In route discovery sender node broadcasts FANTs.The intermediate node recognizes duplicate nodes by their hop count and eliminates them; the source nodes receive BANTs once more. This technique make use of data packets for preserving the route, periodic ants may cause route overhead and can be avoided using data packets [3]. Any time a link fails, its pheromone value is set to zero to activate it. A different link is chosen by the node and if it is unable to find another ink it informs its neighbors to repeat the same process until the route is discovered or source node receive an error message.

PERA algorithms used in MANETs to discover route, it is a proactive routing protocol and uses ant like agents to discover and maintain routes in MANETs. Three types of ants that are sent out proactively are used in this algorithm they are regular ant, uniform FANTs and BANTs. Regular ants and uniform FANTs investigate and strengthen the network's accessible paths [4]. Routing of uniform FANTs are done by using a different method which is the uniform probability to choose the next hop instead of using routing table .Previously discovered paths routing overhead is avoided by using FANTs, the routing other metrics are adjusted at every hop based on the information supplied by backward ANTs .

Six different ants are used by AntHocNet. Reactive FANTs (RFANTs), Reactive BANTs (RBANTs), RePair FANTs (RPFANTs), and RePair BANTs are all types of FANTs (RPBANTs). When there is no routing information about the destination node, reactive FANTs are broadcast or unicasted by the source node. After reactive FANTs reach the destination, they are converted to reactive RBANTs and transmitted back to the source. At every intermediate node, RBANT refreshes the pheromone table and gathers all the data about each link in the path. The proactive routing process is started once the route has been established. Source nodes transmit PFANTS to the destination, which receives both virtual and conventional pheromones to determine the next hop. PFANT reaches destination node it is transformed to PBANT. On the journey back to the source, the PBANTs update the standard pheromone table [5].

In order to explore the network, the algorithm PACONET reactively broadcasts FANTs in a constrained manner. The pheromone value is updated at each intermediate node, and FANT keeps track of all nodes visited as well as the total time travelled. When FANT once reached the destination node a BANT is generated and it uses the entire source by updating the pheromone value. In this algorithm both FANT and BANT updates pheromone.

HOPNET is of ACO algorithm and zone routing framework that performs traditional route identification among the neighbor node's and on demand interaction across neighbor nodes [6]. Ant-E an on demand routing protocol reduces costs by employing Blocking Expanding Ring Search (Blocking-ERS) [8] and manages retransmission to increase the Packet Delivery Ratio (PDR).

A hybrid routing algorithm called ACO-AHR is discussed in [8] that combine proactive routing probe and maintenance with reactive routing setup. Agents come in two varieties: ant agents and service agents. During the setup of reactive routing, origin node transmits FANT, each FANT keeps track of every node it has visited along the way to prevent path cycles. All of the data gathered by the associated FANT is carried by each BANT. It figures out how long it will take from one intermediary node to the destination node. A service agent is produced when a BANT ant gets to the source node. With the data obtained by the service agent, the intermediate nodes' routing tables are updated.

B. Energy Efficient ACO Routing Protocols

Effective usage of node energy is one of the important factors taken into account in the designing of routing techniques for wireless mobile networks, particularly for mobile devices, which use the data collected by the BANT to update the routing table at intermediate nodes. Proactive FANTs are initiated as part of proactive routing maintenance procedure while the data transmission is still live. The proactive FANTs are unicasted, although there is a slight chance that they could be broadcast. In the second scenario, new routes can be discovered by the FANTs. As the packets are always sent along the shortest pathways, many conventional routing methods experience unexpected mortality of network nodes. As a result, nodes that take the fastest route use more energy than other nodes. Recently, this issue has drawn greater attention, and more energy-efficient protocols with the goal of extending network lifetime are being suggested.ACO-EEAODR algorithm as discussed in paper [9] is a result of incorporating energy efficient ad hoc on-demand and ant colony technique routing protocol, a protocol that chooses the most energy-efficient path while taking into account both the length of the path and the remaining battery power. The remaining battery power is taken into consideration when updating the pheromone values in each node. Alternatively, an ant would rather jump to a node with more battery life than considering the shortest route. When forwarding a packet, a node takes power consumption and multi-path transmission into account in order to extend battery life. The suggested algorithm [10] also takes into account the remaining battery capacity. The routing table's pheromone is updated during the discovery process for the route using the route's highest and lowest remaining battery energy as well as the hop count. According to the findings, EAAR uses the least amount of energy overall and experiences fewer packet losses than AntHocNet [2]. In high mobility scenarios, however, the delivery pace and energy consumption per packet fall short of the preceding two indicators in quality. This is most likely a result of EAAR needing additional time to decide on the appropriate data transmission route.

A reliable ACO routing system called AntHocMMP [11], employs ant agents to discover the best routes according to the Max-Min-Path (MMP) strategy. MMP method first chooses a number of absolute routes from the initial node to end

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node. FANTs are transmitted on all relevant paths during the second phase. In order to determine the shortest and most reliable way, FANTs update the pheromone values at each intermediary node as they travel along the respective paths. Moreover, AntHocMMP detects connection failure and chooses new relative pathways using an adaptive re-transmission technique. However, this method as of now travelled through all feasible energy-efficient routes from the initial to the target node in starting phase, thus the pheromone deposits have no impact on the algorithm.

Instead of using simply the remaining capacity of node's battery, ACECR proposed in paper [12] considers both the standard energy and the bare minimum energy of a network to choose one that, when seen globally, has more remaining energy. BANTs update the pheromone table during the route discovery phase by determining the average energy of a path and hop count as well as the maximum and lowest residual energy values of the nodes. In terms of data transmission rate, transmission path traffic rate, usage of node energy, and average delay, ACECR outperforms the previously discussed algorithms.

A routing protocol that focuses on energy efficiency and security called hybrid ACO in [13] is a probabilistic technique like Simulated Annealing (SA) used to identify the preceding node unlikely to converge to a local maximum. Each network link receives the initial pheromone value during the transmission's starting phase. Initial sender node disseminates FANTs when new route needs to be found. Each FANT shortlists certain count of neighbors of the present transmission node, indicated with some specific notations like L1, using SA before proceeding to the subsequent hop. Five of each selected nearby node's own neighbors are shortlisted using SA and are denoted with the L2 symbol. The trust values are used to determine the optimum L2 node. The appropriate upstream L1 node is also found when the best L2 node has been chosen. The FANT then relocates to this noted node in L1. The values of all the linkages are propagated on each of the FANT's operations. The trust values for URLs that the FANT hasn't visited deplete steadily over time. Same procedure is repeated so far the FANT reach the target node.

C. Security Aware ACO Routing Protocols

Several security vulnerabilities, including as wormhole attacks, flooding attacks, and others, can affect the network layer. These vulnerabilities typically have significant negative impacts on the network when they are initiated during the routing process. In the worst-case scenarios, a hacker might even make network connectivity impossible. Therefore, there is a need for defence systems that assist network users in such attacks.

Elliptic Curve Cryptography an ant based routing is proposed in [14] for cluster based ad hoc networks. First operation used is to calculate the trust value between adjacent nodes which further decides the secured route for data transmission.. The other makes use of ECC for source and destination mutual authentication along with the AntNet routing technology for route finding. Each node in the cluster maintains trust values for all of its neighbors in the network. A trust value is determined using a measure of uncertainty and is an increasing function that is related to the likelihood of each packet being successfully transmitted. The source node utilizes AntNet to search for multiple routes during route construction as in [2]. After collecting the trust values of each node in the path, a single trust worthy value is chosen for the packet transfer using node reliability.

The SPA-ARA routing protocol proposed in [15] guarantees security as well as energy consumption in MANET that sends out ants to scout the network, just like previous ACO-based routing algorithms. A source node first checks its pheromone table before sending data packets to a single destination node. If route information is available, the associated node with the highest next-hop availability is selected as the next hop. Message Authentication Code is used to protect the data sent through randomly selected path. The source node broadcasts reactive FANTs when there is insufficient routing information for destination.

HMAC keyed hash method as in [16] produces a message authentication code with a common group key is linked to these reactive FANTs. After receiving reactive FANTs, intermediate nodes first check the reliability of the connected MAC If it is correct, the intermediary node looks up the trust value of the preceding hop in its own trust pheromone table. Only if this trust value is higher than a preset threshold value does the intermediate node accept the FANT and employ a two-party key setup protocol to construct a secret key with the previous hop node. The BANT is then validated using this hidden key. After receiving FANT, the destination node responds similarly to the intermediate nodes. The destination node only creates a corresponding BANT if the FANT has a valid MAC and the trust value of the previous hop is higher than the threshold. If not, it just discards the FANT without doing anything else. This BANT

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is secured by a MAC made using the secret key between the destination node and the next hop on the path to the source node. Hop after hop, intermediate nodes use the matching secret keys to verify the MAC of each BANT on successful travel to source node updating all the pheromone tables along the way, the ants complete authentication using associated MACs and paired secret keys. Hop count, routing duration and left over battery power are selected as the enhancing elements, which have a direct impact on the pheromone update procedure to maximize network longevity.

To select an optimal path, a fuzzy-based trusted ant routing (FTAR) protocol is proposed in [17] provides a combination of swarm intelligence and the fuzzy system. FTAR uses same principles seen in many other traditional ACO routing protocols during the route finding phase. Blocking Expanding Ring Search is used by FANTs to move through the network (Blocking-ERS).A dynamically adjusted threshold value is utilized to find black hole nodes in the proposed DBA-ACO algorithm as in [18]. The threshold value is the average difference between the destination sequence numbers in the routing table and those that were returned by the BANTs. If the destination sequence number a BANT forwarding node returns exceeds the threshold value, it is referred to be a black hole node. As soon as a black hole node is identified, alarm packets with its ID are broadcast throughout the network. The malicious node can then be isolated by the other nodes in the network. This strategy strengthens the security of the routing protocol without relying on any cryptographic methods.

A protocol named ANTNET [19] initially gathers pathways using AODV, and then utilizes the ANTNET algorithm to find abnormalities. Lastly, it rediscovers pathways using the ACO technique. However neither the pheromone's updating mechanism nor the specific responses that followed the discovery of the black hole nodes are described. To adopt ACO for self-organized public key management as suggested in Autonomous Bio-inspired Public Key Management in order to prevent nodes acting illegally and ensure the accuracy of the public keys [20]. The trust value in this technique, which is calculated based on identity assurance, is the degree to which the public key being supplied can be trusted to represent a specific node and not some other nodes in the network. This relates to the extent to which a given node can be assumed to be represented by the provided public key and not by one or more other nodes in the network. To integrate the trust-based public key approach and an ACO algorithm, the authors use the trust value as the pheromone value in the ACO algorithm. The suggested approach is broken down into four fundamental steps: finding the certificate chain, authenticating public keys using certificates, and updating the pheromones on the certificate chains.

D. Location Aware ACO Routing Protocols

An algorithm that mixes location data with the established ACO routing algorithm in an effort to speed up route establishment while using fewer control messages is reactive POSition based Ant colony protocol. Each node in POSANT is assumed to be aware of its own location as well as the position of the destination node with relation to its neighbours.

A location-independent position-aware ACO routing strategy for MANETs as Robustness-ACO [21], that uses the GPS data of visited nodes to build pathways based on robustness. To determine a link's robustness value, the authors provide two robustness functions. Using the GPS data of its neighbors, each node forecasts link disconnections and redistributes the pheromone to quicken the development of alternate paths. This technique is more suited to frequent link disconnections and dynamic network evolution. Dynamic MANETs on demand (DYMO) routing protocol proposed in [22] employed for vehicular Adhoc networks updates the pheromone and routing decisions by using the vehicle information, including speed and position. A protocol is introduced in [23] achieves scalability separating the networks into zones then employs a proactive route-finding strategy within the zones and a reactive strategy between the zones to lessen broadcasting and congestion. A zone-based hybrid ACO routing protocol proposed in [24] divides the network into several virtual clusters in order to accomplish efficient management, first broadcasting a Member Packet (MEP).

S-AMCQ proposed in [25] uses the ACO algorithm to discover a variety of routes that satisfy various QoS requirements throughout the route discovery process. It also uses a verification method to protect itself from outside attackers, for the detection of internal attackers an extended VANET-oriented evolving graph (VoEG) model is utilized that performs plausibility checks on routing control messages.

E. QoS based Routing Protocols

ARAMA a proactive routing algorithm suggested in [26] considers parameters, such as residual energy left, delay, number of peers, etc., collected by the ARAMA FANTs on both local and global paths. Based on this path index, the path grade is determined once the FANT reaches at its destination. A BANT updates the pheromone table at each hop while travelling in the opposite direction to the source node. Each node in SAMP-DSR as mentioned in [27] has two operational modes: "local mode" and "global mode." To aid the ants in efficiently convergent, nodes flip between the two modes according to the rate of network structure change.

A QoS-enabled ant colony based multipath routing protocol for MANETs proposed in [28] chooses paths depending on the probability of the preferred path and Next Hop Availability (NHA). The NHA is characterized as the availability of nodes and links for routing along a path while taking into account both energy and mobility concerns. The optimum path matching the QoS conditions is determined by QAMR using a path preference probability that takes into account several factors like delay, bandwidth, and hop count. Ant colony optimization-based multi-rate ad hoc network protocol (QoRA) referred in [29] estimates QoS parameters locally in order to decrease the overhead when gathering data from different pathways and to prevent congestion during data transmission.

VI. CONCLUSION

Infrastructure less nature of MANETs routing becomes a challenging task in routing while considering the following parameters like Data Delivery Ratio (DDR), end to end delay and the routing overhead. Apart from the above mentioned parameters protocols category wise special metrics can also be used to evaluate the performance. This work presents a thorough analysis of the current ACO-based MANET routing technologies and will encourage future protocol designers to take into account the numerous protocol properties that have already been studied.

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