INTELLIGENT ROUTING TECHNIQUES FOR WIRELESS SENSOR NETWORKS USING SWARM INTELLIGENCE: A SURVEY

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ABSTRACT

A Mobile Ad-Hoc Network (MANET) is a collection of autonomous self-organizing wireless mobile nodes forming a temporary network without using centralized access points. They use wireless medium for communication, hence two nodes can communicate directly if and only if they are within each other's transmission radius in a multi-hop fashion. In MANET, each node can act as a node as well as a router. But due to non-availability of centralized administration, there is a difficulty of routing optimization. Many conventional routing algorithms have been proposed for MANETs. There are various protocols like AODV, DSDV, DSR, ZRP etc. available for routing in MANET. Routing strategies are an important feature of network administration, as they have a significant influence on the overall network performance. An emerging area that has recently captured much attention in network routing researches is Swarm Intelligence (SI). Besides conventional approaches, a lot of new researches have proposed the adoption of Swarm Intelligence for MANET routing. Swarm Intelligence refers to complex behaviors that arise from very simple individual behaviors and interactions, which is regularly observed in nature, particularly among social insects such as ants, bees, fishes etc. While each individual has little intelligence and simply follows basic rules using local information obtained from the environment. Basically, Swarm Intelligence is an artificial intelligence technique based around on the study of collective behaviour in decentralized, self-organized systems. Ants routing resembles basic mechanisms from distributed Swarm Intelligence in biological systems and turns out to become an interesting solution where routing is a crisis. Ants based routing is becoming more popular because of its adaptive and dynamic nature. Also, they are more robust and reliable than other conventional routing techniques. Ant Colony Optimization is well-liked among other Swarm Intelligent Techniques. In this paper, we study bio-inspired routing protocols for MANETs. This paper also introduces the preliminary studies for Mobile Ad Hoc Networks.

Keywords*: *Ant Based Routing Protocol, ABC, MANET, SI

I. INTRODUCTION

Wireless sensor networks (WSNs) [1] consist of a large number of autonomous nodes equipped with sensing abilities, wireless interfaces, limited processing and energy resources. WSNs are used for distributed and cooperative sensing of physical phenomena and events of interests. Yet, they can also be mobile and capable of interacting with the environment. In these cases, the network is more appropriately referred to as a robotic network and/or as a sensor-actor network. Wireless networks have become increasingly popular in the computing industry. This is particularly true within the past decade, which has seen wireless networks being adapted to enable mobility. There are currently two types of mobile wireless networks. The first is known as the infrastructure network (i.e., a network with fixed and wired gateways). The bridges for infrastructure networks are known as base stations. A mobile unit inside these networks connects to, and communicates with nearest base station that is within its communication radius. The second type of mobile wireless network is the infrastructure less mobile network, commonly known as an ad hoc network. These networks have no fixed routers; all nodes are capable of movement and can be connected dynamically in an arbitrary manner. Nodes of these networks function as node as well as routers which discover and maintain routes to other nodes in the network. WSNs can be employed in a wide spectrum of applications in both civilian and military scenarios, environmental monitoring, surveillance for safety and security, automated health care, intelligent building control, traffic control, object tracking, etc. [2,3]. From the point of view of information processing, in WSNs, aggregation of the sensed data and its use for statistical inference can be realized in a number of ways, resulting in different network architectures. The requirements of routing protocols for WSNs are similar to those of routing protocols for mobile ad hoc networks (MANETs) [5]. However, compared to MANETs, in the case of WSNs, the restrictions on energy efficiency are more compelling, nodes are usually static, and the networks are in general assumed to be much larger. Moreover, while in the case of MANETs traffic patterns strictly depend on the application and are address centric, in WSNs they are usually data-centric. So far, a large number of different routing protocols have been proposed for WSNs based on a variety of different mechanisms and optimization criteria. In recent years, several wireless routing protocols are designed to provide communication in wireless environment, such as AODV, DSR, DSDV, ZRP, LEACH, OLSR etc. The paper is introduced with a review of all necessary background and previous work in the general fields of swarm intelligence and network routing.

II. SWARM INTELLIGENCE

In nature several animals tend to live in large swarms like insect colonies, bird flocks or fish schools. The reason is that in the swarm each animal is more effective for evolution than single animals. Many social insects like ants, bees, termites, or wasps live in colonies or hives. They exhibit an astonishingly well developed social behavior and are able to self-organize, even in the absence of a central leader like a queen. Honey bees communicate locations of food sources by the language of dance that is understood by all nearby honey bees. On the other hand, many insects use a form of indirect communication called stigmergy. Stigmergy works by leaving traces in the environment that can be understood by other insects. Swarm Intelligence (SI) [6] is an Artificial Intelligence technique based on the study of collective behavior in decentralized, self-organized systems. The term “swarm intelligence” was introduced by Beni & Wang in 1989, in the framework of cellular robotic systems. Swarm intelligence is “The emergent collective intelligence of groups of simple agents” [6]. It gives increase to complex and intelligent behavior through simple, unsupervised interactions between a total numbers of autonomous swarm members. Usually there is no centralized control structure dictating how the individual agents should behave, but interactions between such agents lead to the appearance of a global behavior. Swarm is considered as biological insects like ants, bees, wasps, fish etc. The quick coordinated flight of a group of birds with very little visual communication and the concerted effort of an ant colony in gathering food, building nests, etc are some of the vivid examples of emergence in natural world. SI has found immense applicability in fields like Robotics, Artificial Intelligence, process optimization, telecommunications, routing, software testing, networking etc. Swarm Intelligence is subfield of Computational Intelligence which provides solution for complex optimization problems which are not easily tackled by other techniques. Swarm Intelligence based approaches are bio inspired. Swarm is defined as a set of mobile agents that collectively solve troubles. Each individual of the swarm has easy rule of action and access to a limited amount of information via its immediate neighbor. On the other hand, even with of limited information and simple actions of members, the swarm, as a whole, is capable to accomplish very hard problems of the computation and optimization. Swarm Intelligence consists of Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO) and Honeybees paradigms. These paradigms copy the behavior of real insects for food searching, organized living and self-protective styles for computational problems.

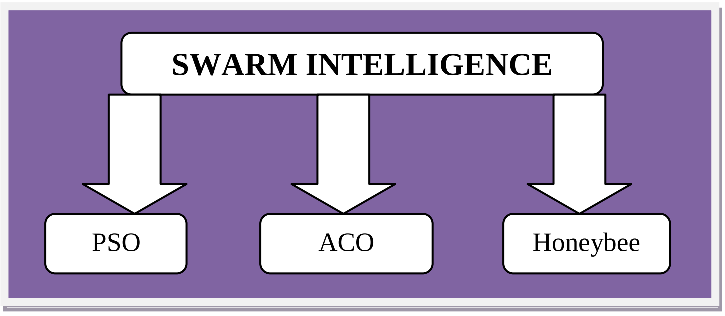

Figure 1. Sub-Domains of Swarm Intelligence

The SI based techniques are more capable from other conventional techniques for optimization problems. These approaches are more suitable for the routing and energy resources optimization, due to the nature, architecture, topology and functionality of ad hoc and wireless sensor networks. Bio inspired approaches are more promising due to the following prominent aspects i.e. [7] a) Locality of interactions, b) Availability of multiple paths, c) Self-organized behaviors, d) Failure backup, e) Ability to adapt in a quick and robust way to topological and traffic changes and component failures, f) Scalable performance robustness to failures, g) Losses internal to the protocol, h) Easiness of design and tuning.

2.1 Particle Swarm Optimization

Particle Swarm Optimization is subfield of Swarm Intelligence which exploits the behavior of swarms for the solution of complex problems. The particle swarm optimization natured algorithm maintains a swarm of particles. Particle Swarm Optimization exploits the mutual intelligence and information sharing capacity of swarms. PSO applies the idea of social interaction for the solutions of hard and optimization problems. It was developed [8] in 1995 by James Kennedy and Russell Eberhart. In PSO each particle individually emerges a potential solution for the hard problem to be solved. In PSO, particles are flown through the multi-dimensional search space and the next location of each particle is determined as a factor of its own experience and that of other particles. The working of PSO based on fundamentally on the position of particle and velocity of the particle at given time. The searching depends on the previous location and velocity of the particle. The particles will mostly search the space between the global best and their personal bests for the improved solutions. At the start of PSO algorithm, particle position, personal best position and velocities of particles are initialized randomly within the constraints of the search space and after that the parameters updated accordingly given strategies. As bio inspired approaches are iterative, some termination mechanism is applied. For PSO algorithmic, stopping state can be implied are maximum number of iterations, acceptable solution achievement or no improvement observed over a number iterations. There are various types of PSO algorithms proposed for the solution of problems, like Network security, Optimization, Association rule mining, Classification purposed and mostly in Wireless Sensor Network.

2.2 Ant Colony Optimization

The phenomenon of emergence found in natural systems show how simple behavioral patterns from participants give rise to complex self-regulatory behavior of the complete system [9]. Ant Colony Optimization (ACO) [10] is a branch of a newly developed form of Swarm Intelligence. Ant Colony Optimization is paradigm of Swarm Intelligence that is inspired by the collective behavior of ants. The Ant Colony Optimization algorithmic approach models the concept of food foraging, net building, and division of labor, cooperative support, self assembly and cemetery organization of real ants for the meta-heuristic approaches, for the optimization problems. ACO meta-heuristic approach was proposed by Marco Dorigo in 1996. The basic principle of ACO is ability of ants to find the shortest path between their nest and a food source. Ants are able to find the shortest path between their nest and food source, without any central and active coordination. The real ants drop a pheromone, chemical from their bodies naturally, on the path which leads them for the various decisions. The path optimization between nest and food is achieved by ant colonies by exploiting the pheromone amount dropped by the ants. The path selection of the ants is done on the bases of the pheromone concentration deposited on the set of paths. With high concentration of pheromone value path selection probability is greater than others. The indirect pheromone based communication is known as stigmergy. There is a natural evaporation of the pheromone, which favors the shorter path than the larger one. An artificial ant can be considered as a simple computational agent. In basic ACO algorithm pheromone value update and pheromone value evaporation is done by using the mathematical expression. Normally, the rate of pheromone evaporation is directly proportional to the length of path. Similarly to the PSO, ACO works in iterative manor and various termination criteria are anticipated. The stopping criteria for ACO algorithm suggested are, a) fixed number of iterations, b) adequate solution and c) the number of ants that following the same path repetitively.

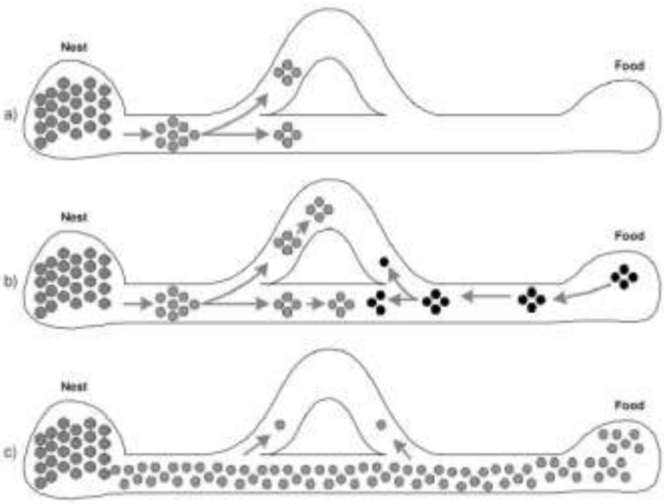

Figure 2 : All ants take the shortest path after an initial searching time

In groups of insects, which live in colonies, like ants and bees, an individual can only do simple tasks on its own, which the colony's cooperative work is main reason determining the intelligence behavior it shows. Figure 2 shows a scenario in which the best route between two choices is chosen by the ants. Ant colony optimization (ACO) [11] is an optimization technique inspired by the exploratory behavior of ants while finding food. The ants in the colony form a collective behavior. A colony of ants has a wide range of duties like collecting food, building/guarding the nest, removing the dead ants, etc and has simple one-to-one communication. The individual messages passed between ants are very insignificant, but the collective messages help in coordinated work control of ants without the presence of a centralized control system. Ants use scent called pheromone for communication among them. Ants have ability to smell this pheromone. They can produce few different types of pheromones – usually one each to signify different work categories like collecting food trails, signifying emergency, moving dead ants, etc. The source of ACO is the pheromone trail laying and following behavior of ants which use pheromone as a communication medium. While searching the environment for food, the ants deposit pheromones on the ground. Other ants are attracted by pheromones and tend to follow trails of previous one. This process enables the ants to find shortest paths between the nest and a food source. When ants fan out to find food, it may happen that a lucky ant finds a short path to a new food source. It then takes some food with it and makes its way back to the nest. Since it is attracted by its own pheromone trail, it is likely that the ant follows its own path back to the nest, thereby leaving a second pheromone trail. If other ants happened to take a longer path to the food source, they arrive after the first ant and, when trying to make their way back to the nest, there is a good chance for them to be attracted by the short path, where already two pheromone trails have been laid. This reinforces the short path even more and makes it more attractive. Concerning the longer path, pheromones tend to evaporate after some time, so in the long run the long paths will be forgotten and almost all ants will take the short path. The characteristics of ants are similar to the characteristics of MANETs. This helps us to apply the food searching characteristics of ants for routing packets in MANETs.

2.3 Bee Colony System

Honey bee colonies have attracted a strong interest as a potential source of inspiration for the design of optimization strategies for dynamic, time-varying, and multi-objective problems. Bee colonies show structural characteristics similar to those of ant colonies. Bees utilize a sophisticated communication protocol that enables them to communicate directly through bee-to-bee signals and when required, similar to ants, use stigmergic feedback cues for bee-to-group or group-to-bee communication. In these two classes of insects, communication and cooperation is realized according to radically different modalities due to the different nature of these insects (ants mainly walk, while bees mainly fly). In the case of ants communication is achieved via a pheromone trail that is laid on the ground while walking, in the case of bees it is a form of visual communication that plays an equivalent role.

Bee Colony Optimization (BCO) [12] is the SI system where the low level agent is the bee. BCO is the name given to the collective food foraging behavior of honey bee. This system is a standard example of organized team work, well coordinated interaction, coordination, work division, simultaneous task performance, specialized individuals, and well-knit communication. In a bee colony there are different types of bees like a queen bee, many male drone bees and thousands of worker bees. The Queen's responsibility is of laying eggs so that new colonies can be formed. The Drones are males of the hive and are responsible to mate with the Queen. This is their sole role in the hive. The worker bees are the females of the hive. They are the major building blocks of the hive. They build the honey bee comb, clean it, maintain it, guard it and feed the queen and drones. In addition to these, the main job of a worker bee is to search and collect rich food. There are two types of worker bees namely scout bees and forager bees. Scout bees fly around and search for food sources available randomly. They return back to the hive after they exhaust their energy and distance limits. Upon returning to the hive they share their exploration experience and a lot of important information with the forager bees. The scouts tell the foragers about the location of rich food sources which comprises of the direction of the food source from the hive with respect to sun and distance from hive. This is completed using a dance called "waggle dance" which is in the figure of digit "8". It also indicates the quality of food. The forager bee closely observes the scout bee to learn the directions and information given by scout and then goes to collect food.

III. SWARM INTELLIGENCE BASED ROUTING

Swarm intelligent (SI) based routing discussed in this section. SI routing does away with firm rules and instead allows the system to self-organize on its own accord. Swarm intelligent based routing for wired and wireless networks are discussed with ad-hoc protocols.

3.1 Wired Networks

A number of proposals exist which apply the principles of swarm intelligence to routing in wired networks. These include Ant-Based Control (ABC), AntNet, Cooperative Asymmetric Forwarding (CAF), Virtual-Wavelength Path Routing (VWPR), Multiple Ant Colony Optimization (MACO) [13], Mobile Ants-Based Routing (MABR) [14], among others. ABC is the oldest with its introduction in 1996. AntNet is to be credited as the most well known due to its solid performance and design by the inventors of the related and extremely successful Ant Colony Optimization (ACO) algorithm. CAF optimizes some approaches used by AntNet and also extends a distance vector methodology. VWPR is included for its introduction of the pheromone repel feature in routing, a vastly underappreciated technique in this field borrowed from ACO. The Multiple Ant Colony Optimization algorithm is a more straightforward adaptation of ACO to routing. It uses the idea of having multiple ant colonies discover paths, each being repelled by the pheromone of the other. This ensures that a larger search space will be covered and thus better routes should be found faster. MABR is based on AntNet and describe a hierarchical location-based routing scheme. The network topology is broken into a regular grid by an abstraction layer, and pheromone based routing is executed on the grid.

3.2 Wireless Routing

The routing problem in mobile wireless ad-hoc networks has received some attention from the swarm intelligence community. The properties of SI algorithms are very well suited to the problem, which requires optimization in a dynamic environment. The Probabilistic Emergent Routing Algorithm (PERA) is the first routing algorithm to be proposed in 2002. This was quickly followed by the Ant-like Routing Algorithm (ARA) and Termite in 2003, with Ad-Hoc Networking with Swarm Intelligence (ANSI) in 2004. Many of these algorithms extend AntNet or

ABC to the ad-hoc problem; the forward/backward ant architecture is used for route discovery and then various route repair and error schemes are proposed.

3.3 Ad-Hoc Networking with Swarm Intelligence

The Ad-Hoc Networking with Swarm Intelligence algorithm (ANSI) by Rajagopalan and Shen is the most recent addition to the SI MANET routing family in 2004 [15]. This algorithm is introduced with the intention of creating an algorithm with complementary proactive and reactive components, able to adapt to more flexible metrics, such as a node capability. In contrast to many other SI routing algorithms, ANSI allows a proactive routing feature in addition to the standard reactive approach. This follows in the footsteps of other dual mode MANET routing algorithms such as the Zone Routing Protocol (ZRP) [16] and the Sharp Hybrid Ad-hoc Routing Protocol (SHARP) [17]. Such systems are generally defined such that a node proactively keeps track of routes to all destinations within a certain zone, and routes to the rest are maintained reactively. A separate proactive routing protocol and reactive routing protocol are defined to handle each case. The hybrid protocol is often designed such that any previously defined proactive and reactive algorithms can simply be plugged in. The hybrid protocol then defines how zones are managed. The zone of a node is an area defined by a given hop diameter. The zone may be predefined or calculated online according to the needs of the network. In ANSI, proactive ants are sent periodically by each node in order to establish routes to their source. This is similar to the route discovery approach used by PERA. The impact of the flood is minimized by using packet identifiers, a limited time-to-live in each packet, and a probabilistic flooding (gossiping) scheme. As each proactive ant moves through the network, it updates the current node with information from its stack. ANSI follows the PERA method for reactive routing to non-local destinations. Forward ants are flooded while keeping their path and metric information on a stack. When a forward ant arrives at the destination, a backward ant is unicast along the forward ant's reversed path to the source. However, the forward ant flood radius is increased iteratively, equivalent to AODV's optional expanding ring search.

IV. SWARM INTELLIGENCE BASED ROUTING PROTOCOLS AND ALGORITHMS

Akkaya and Younis [2] group routing protocols for WSNs into four categories: (1) data-centric, (2) hierarchical, (3) location based, and (4) QoS-aware. Data-centric protocols do not require a globally unique ID for each sensor node, and perform multihop routing by using attribute-based naming approaches. Hierarchical protocols separate the network into small clusters with a representative node acting as a cluster head. Location-aware algorithms make use of the information related with geographical position of a node to perform energy efficient routing. QoS-aware protocols can explicitly deal with multi-constrained requests for data transmissions. More recently, Boukerche et al. [18] have proposed a taxonomy that enlarges Akkaya and Younis's by considering six architectural categories: attribute-based, flat, geographical, hierarchical, multipath, and QoS-based.

The new category flat refers to the case in which a large number of nodes collaborate together to sense the environment. The nodes are all similar and global IDs cannot be assigned to them. This category includes the algorithms that compute multiple paths from sources to destinations in order to cope effectively with failing nodes. In this section, we review selected SI routing protocols for WSNs and highlight their properties with respect to the taxonomy of routing protocols. In the following subsections, we discuss ACO-based protocols, bee-inspired protocols and others.

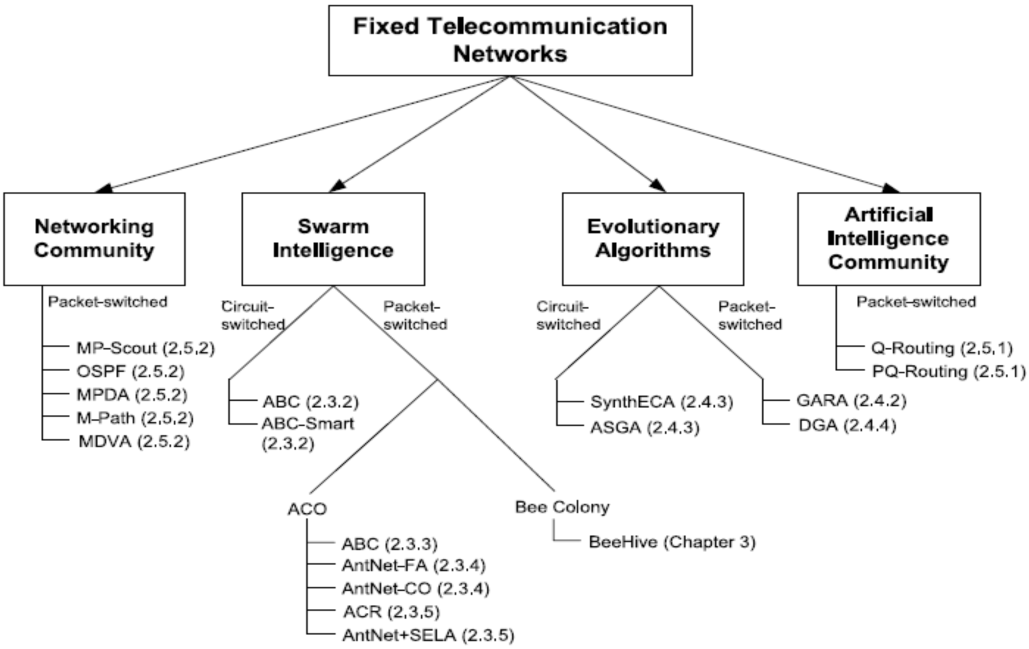

Figure 3. A taxonomy of routing protocols for fixed telecommunication Networks [19]

4.1 Ant Based Routing Protocol

ANT Based Routing Protocol has taken the inspiration from real ants which are wandering around their nests to forage for search of food. Upon finding food they will return back to their nests and simultaneously deposit pheromone trails along the paths. The ant selects its next hop based on the amount of pheromone deposited on the path to the next node. The problem of finding shortest paths maps quite well to the problem of routing in networks. The ants are nothing but small control packets, which have the task to find a path towards their destination and gather information about it. Ant-like mobile software agents, who are analogous to the ones used real ant colony's biological behaviour, are employed for discovering network topologies and thus efficient routing in the networks. Ant-like mobile agents are an effective means to discover the network topology in particular in circumstances such as MANET in which the network topology frequently changes. Routing based on ant-like agents does not require frequent exchanges of update messages for routing tables. As the network population becomes dense, an ant-like agent becomes more effective for load balancing in the network. Ant-like agents are a known means to mitigate congestion. The pheromones may be used as a measure for any metric under consideration such as average delay, bandwidth and jitter. The basic principle of all these algorithms is that current traffic conditions and link costs are measured by transmitting "artificial ants" into the network. These ant packets mark the travelled path with an "artificial pheromone," that is, update the routing table depending on the collected information. Therefore, they increase the probability of choosing a certain link for a given destination. Results from ant based routing applications in fixed and wired network are very promising.

4.1.1 Ant Based Control

Ant based control (ABC) is another stigmergy based ant algorithm designed for telephone networks. It shares many similarities with AntNet, but also incorporates certain differences. Ant-Based Control was introduced by

Schoenderwood, Holland, Bruten, and Rothkrantz in 1996 and is considered to be the first biologically inspired routing algorithm [22]. It is a routing algorithm for circuit-switched (eg. telephone) networks which routes calls based on the local interaction of mobile agents. Mobile agents (ant packets) traverse the network, updating routing tables at each node depending on the observed path quality. Routing tables consist of next hop probabilities for each destination. Ants traveling in one direction influence the placement of calls in the opposite direction. Symmetric bidirectional links are assumed. ABC follows the ant food foraging analogy very closely. The basic principle relies on mobile routing agents, which arbitrarily explore the network and bring up to date the routing tables according to the current network state. The routing table, storing probabilities instead of pheromone concentrations, is exactly similar as in AntNet. Also, probability balanced randomness of the ants path selection is employed to favour the detection of new paths. One significant difference applies to the use of the routing agents is; ABC only uses a single class of ants (i.e. FANTs), which are initiated at regular time intervals from every source to a randomly chosen destination. After arriving at a node they immediately update the routing table entries for their source node, meaning that the pheromone pointing to the previous node is increased. It is important to see that only the backward route is influenced, and packets travelling towards the ant's source profit from that route update. Ant packets are launched on regular intervals by each node in the network to a random destination. They are routed randomly according to the probabilities present in the pheromone table for their particular destination. In order to encourage ants to try new paths, a noise factor is added to the routing decision. This is necessary in case the network conditions should change or better routes become available. If a high probability route exists, there is little incentive to stop using it, even if its quality drops. The probability update equation only allows routing probabilities to be positively reinforced when a link is used.

4.1.2 Ant Net

AntNet is an approach from 1997 by Dorigo and Di Caro to using the social insect analogy to solve the routing problem in wired packet switched networks [23]. Unlike ABC, AntNet assumes asymmetric bidirectional links. Routes from destination to source, also known as reverse routes, cannot be influenced by an ant moving from source to destination as was the case in ABC. An ant moving in the forward direction will experience different costs than an ant moving in the reverse direction. AntNet is an algorithm conceived for fixed and wired networks, which derives features to use two different network exploration agents, i.e. forward and backward ants (BANTs), which collect information about delay, congestion status and the followed path in the network. At regular intervals, each node in the network sends a forward ant packet to a randomly chosen destination. Forward ants are routed probabilistically as in ABC. Each node contains a routing (pheromone) table indicating the utility of a particular link to arrive at a destination. This utility is described by a probability. In order to ensure that the entire network is explored consistently, a forward ant chooses a next hop uniformly according to an exploration probability. This feature serves the same purpose as that of noise in ABC. Forward ants (FANTs) are emitted at regular time intervals from each node to a randomly selected destination. This transmission occurs asynchronously and concurrently with the data traffic. As soon as a FANT arrives at the destination, a BANT moves back to the source node reverse the path taken by the FANT. The subdivision in forward and BANTs has the following reasons. The FANTs are just employed for data aggregation of trip times and node numbers of the path taken without performing any routing table updates at the nodes. The BANTs get their information from the

FANTs and use it to achieve routing updates at the nodes. Each node in the network maintains two structures, which the agents co-operate with and concurrently read and write to routing table.

4.1.3 Probabilistic Emergent Routing Algorithm (PERA)

The Probabilistic Emergent Routing Algorithm (PERA) designed by Baras and Mehta in 2002 is the first swarm intelligent MANET routing algorithm [24]. It operates very much in the way of AntNet, using forward and backward ants to collect and distribute information about the network. It also borrows elements from more traditional contemporary routing algorithms such as AODV and DSR. This algorithm works in an on-demand way, with ants being broadcast towards the destination at the start of a data session. Multiple paths are set up, but only the one with the highest pheromone value is used by data and the other paths are available for backup. The route discovery and maintenance is done by flooding the network with ants. Both forward and backward ants are used to fill the routing tables with probabilities. These probabilities reflect the likelihood that a neighbour will forward a packet to the given destination. Multiple paths between source and destination are created. First of all, neighbours are discovered using HELLO messages, but entries are only inserted in the routing table after receiving a backward ant from the destination node. Each neighbour receives an equi- probable value for destination. This value is increased as a backward ant comes from that node, establishing a path towards destination. As ants are flooded, the 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.

4.1.4 Ant Agents for Hybrid Multipath Routing [AntHocNet]

Frederick et al proposed a routing algorithm for mobile ad hoc networks, inspired by bio ant colonies behavior, named as AntHocNet [25]. Ant Agents for Hybrid Multipath Routing in Mobile Ad hoc networks (AntHocNet) technique is used for the typical path sampling. AntHocNet is a multipath routing algorithm for mobile ad-hoc networks that combines both proactive and reactive components. It maintains routes only for the open data sessions. This is done in a Reactive Route Setup phase, where reactive forward ants are sent by the source node to find multiple paths towards the destination node. Backward ants are used to actually setup the route. While the data session is open, paths are monitored, maintained and improved proactively using different agents, called proactive forward ants.

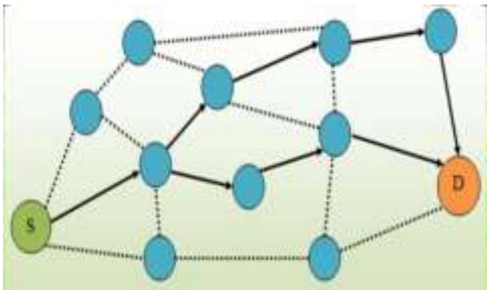

Figure 4. Kite-shaped, multiple paths

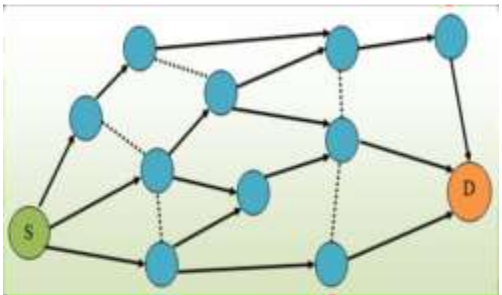

Figure 5. A mesh of multiple paths

The proposed algorithm works reactive an well as proactive components. Multiple paths are built up between the source and destination in reactive behavior. In AntHocNet data is stochastically spread over the paths depending on the estimated quality. Proactively all the paths are monitored during the course of session. The simulation of this algorithm is done in the Qualnet. The simulation results are better than the AODV algorithm. The ACO behavior is incorporated in the pheromone bootstrapping mechanism is exploited for the efficient learning of pheromone table. Figure 4 shows the reactive path setup process which depicts the Kite-shaped scenario.

Figure 5 shows the multiple path setup process in the AntHocNet algorithm which mesh of multiple paths. AntHocNet algorithm is better in performance than AODV protocol.

4.1.5 ABDRA

Rajeshwar Singh et al proposed routing algorithm for MANETs based on Swarm Intelligence paradigm named as Ant Based on Demand Routing Algorithm (ABDRA) in [27]. This is multi-path routing algorithm, resulted in upgrading in packet delivery ratio. The ABDRA exploits various features of both AODV and DSR algorithms. This algorithm is able to reducing the route discovery time that results in effectively network topology change management. In ABDRA, two ants FANT (forward ant) and BANT (backward ant) are used. FANT is formed at source and moves to destination while BANT is formed at destination and follows the part of FANT. The route finding is done by searching the destination path from the routing table. On the non availability in the routing table, forward ant is formed and broadcasted to all adjoining nodes. The congestion is controlled by the route maintenance phase by changing the pheromone value. This algorithm is simulated in NS2.29 and compared with AODV protocol. The performance metrics was average end to end delay and packet delivery fraction for evaluation of AODV and ABDRA. The simulation results provide the performance of ABDRA is better than AODV.

4.1.6 ARAMA

Ant Routing Algorithm for Mobile Ad-hoc networks (ARMA) algorithms was proposed by O. Hussein and T. Saadawi in 2003 [28]. Every node in the network can work as a source node, destination node, and intermediate node. The functionality of source, intermediate and destination nodes is sending forward ants for path request, updating of the probability routing table and gradation of forward and backward ants correspondingly. The search or path maintenance to a destination is done by sending forward ants. ARAMA is implemented using OPNET simulation model for MANET node to study the performance of ARAMA. In addition, ARAMA is self-built and self configured routing protocol for MANETs that combines both on-demand and table based routing features.

4.1.7 EEABR

Tiago Camilo et al proposed a new energy constrained routing protocol based on subfield of Swarm Intelligence paradigm, Ant Colony Optimization for Wireless Sensor Networks, known as Energy-Efficient Ant-based Routing algorithm (EEABR) in [29]. The EEABR algorithm exploits bio inspired, ant behavior, meta-heuristic approach, Ant Colony Optimization (ACO) for optimization in selection of paths between the sensor nodes and destination node with under consideration of short in length, energy efficiency and lifetime maximization of the Wireless Sensor Network. In this algorithm, the selection of next network node probability is a function of the node energy and pheromone value deposited on the connections between the nodes. The proposed approach promises for the reduction of communication load related to the ants and the energy consumption during communications. The energy saving is directly proportional for the lifetime of the network. In EEABR algorithm, ant information is stored on every node while timeout value, previous and forward node information and the ant identification is stored in the routing table. On the arrival of forward ant, node searches the routing table for the corresponding ant identification, if found then ant is eliminated otherwise node saves necessary information relevant to the ant. On receiving of backward ant, node searches its routing table for the next node. Backward ant record is updated according to a defined time period. The authors have given simulation results in NS2, comparison of proposed approach (EEABR) against basic ant-based routing algorithm (BABR) and improved ant-based routing algorithm (IABR). For the performance comparison, four metrics were used, that are average energy, minimum energy, standard deviation and energy efficiency. With respect of performance metrics, the proposed approach is promising.

4.1.8 LEACH-P

Liao Ming-hua et al proposed a energy aware routing algorithm based on ant colony principle and Low Energy Adaptive Clustering Hierarchy (LEACH) protocol named LEACH-P, for wireless sensor networks in [30]. This routing method concentrates on the minimization of energy consumption during the data transmission to the sink by multiple hops. In the new protocol, the node energy consumption is predicted during the next-hop probability calculation. The proposed algorithm works in four steps. The cluster-head nodes are elected according to LEACH protocol and a cluster-head is selected from the cluster-head set. The LEACH-P algorithm is simulated in MATLAB 7.0. This approach is compared with LEACH, with respect to the network lifetime and cluster-head energy consumption. The simulation results gives the performance of LEACH-P algorithm is promising. As a future work, the relationship between the node hop and the optimal path can be researched.

4.2 Bee Inspired Routing Protocols

Bee Colony Optimization (BCO) can be applied to software testing, puzzle solving, numerical complexity problems, routing problems, networking problems, assignment problems, optimization problems, accident diagnosis etc. BCO has immense capabilities to solve problems with minimum scope to solution. In the area of routing protocols for ad hoc networks, researches have proposed few protocols based on BCO, which include Artificial Bee Colony (ABC), BeeAdHoc protocol etc.

4.2.1 BeeAdHoc

BeeAdHoc is a nature inspired routing protocol for MANETs based on the foraging principles of honey bees [32]. It mainly utilizes two types of agents – scouts to discover routes and foragers to transport data. Figure 6 will give an overview of the BeeAdHoc architecture. In this, every node maintains a hive with an Entrance, Packing Floor and a Dance Floor. Entrance provides an interface to the Media Access Control (MAC) layer of the network stack and handles all incoming/outgoing packets. A scout received at the entrance is broadcasted further if its time to live (TTL) timer has not expired or if it has not arrived at the destination. The information about the id of the scout and its source node is stored in a table. If another replica of an already received scout arrives at an entrance of a hive then the new replica is killed. If a forager with a same destination as that of the scout already exists in the dance floor then the route to the destination is given to the scout by appending the route in the forager to its current route. If the current node is the destination of a forager then it is forwarded to the packing floor else it is directly forwarded to the MAC interface of the next hop node.

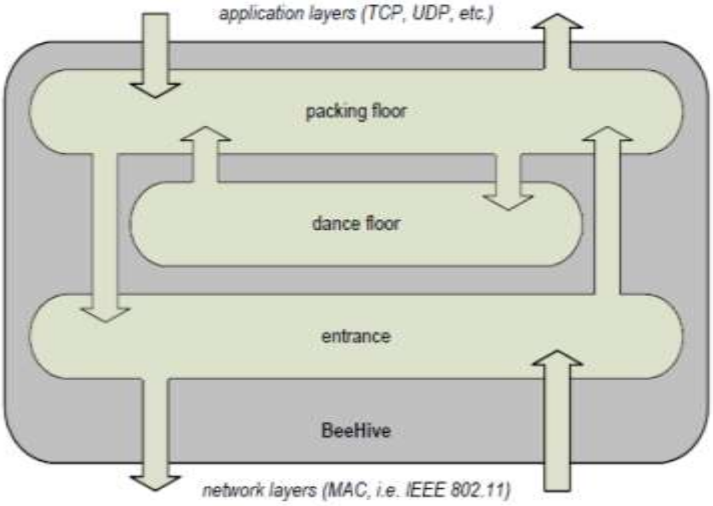

Figure 6: Overview of the BeeAdHoc architecture

Packing floor is an interface to the transport layer and receives data from it. Once a data packet arrives from the transport layer, a packer is created in this floor which stores the data. After this, packer tries to locate a suitable forager for the data packet from dance floor. If it finds then it handovers the data to forager and dies. The dance floor is the heart of the hive because it takes important routing decisions. Once a forager returns after its journey it recruits new foragers by dancing according to the quality of path that it traversed. A lifetime forager evaluates the quality of its route based on the average remaining battery capacity of the nodes on its route. A lifetime forager might allow itself to be cloned many times in two scenarios: one, the nodes on the route have enough remaining battery capacity (good route), two, if large number of packers are waiting for it even though its route might be having nodes with little battery capacity. On the other hand, if none of the packers are waiting then a forager with a very good route might not dance because its colleagues are doing a nice job in transporting the data packets. This concept is directly borrowed from the behavior of scout/forager bees in Nature, and it helps in regulating the number of foragers for each route.

4.3 PSO-ODMRP

E.Baburaj and V.Vasudevan proposed a new, bio-inspired, based on PSO, On Demand Multicast Routing Protocol (PSO-ODMRP) to reduce the vulnerability in multicast routing protocols, due to component breakdown in ad-hoc networks [33]. The working procedure of On Demand Multicast Routing Protocol is a mesh-based. The ODMRP is a demand driven multicast protocol, forming a mesh of nodes used for forwarding data packets between source and receiver. A multicast tree is built by the source periodically for groups by flooding a control packet throughout the network and nodes responding to the flood join the tree. PSO based algorithms is designed on the natural principle of a fitness function. Due to the control of physical and social behavior such as movement of hosts, interference, terrain, battery power or weather, links can go up and down in a MANET. The simulation is done in NS-2 for ODMRP and PSO-ODMRP protocols for the performance evaluation. The performance metric for this comparison was consists on "packet delivery ratio" and "control overhead". The simulation results are promising for PSO-ODMRP than ODMRP. The author find out that the performance of proposed protocols is good in low mobility while it decreases with the increase in mobility. This proposed protocol is more appropriate for the MANETs where topology changes are frequent and power constrained.

4.4 M-DiPSO

Ping Yuan et al proposed optimal multicast routing protocol in Wireless Ad hoc Sensor Networks named as Multiphase Discrete Particle Swarm Optimization (M-DiPSO) [34]. M-DiPSO gives flavor to of discrete version of particle swarm optimization algorithms. This approach incorporates hill climbing using random-sized steps in the search space. So the hill climbing speeds up the convergence. The particles in the swarm deployed in M-DiPSO, are divided into groups that follow various search strategies. This approach focused on connectivity and broadcast constraints as well as energy-aware multicast routing. This method is appropriate for static and low speed wireless ad hoc networks.

4.5 TPSO

Shahin Gheitanchi et al proposed a model for communication networks based on Swarm Intelligence approach, particle swarm optimization, named trained PSO (TPSO) in [35]. The proposed approach is promising to reduce traffic and computational overhead of the optimization process. The TPSO approach is employed for the finding of node, possessing highest processing load, in an ad-hoc network. The working of the TPSO is similar that of basic PSO with some modifications. Here each particle exploits fitness function specific for the measure of solution quality. The local best (LB) and global best (GB) solutions are saved simultaneously and comparison is done between LB and GB to choose direction. Due to the distributed nature of particles, the proposed model for ad hoc networks is promising for efficient distributed processing with multi-objectives. The authors simulated the TPSO against PSO, in ad-hoc collaborative computing network with 50 nodes and 30 particles. The simulations results show the very low traffic overhead for the TPSO against PSO. The particles convergence is near constant in comparison to PSO.

V. CONCLUSION

Wireless sensor networks consist of large sets of resource-constrained nodes. The design of effective, robust, and scalable routing protocols in these networks is a challenging task. On the other hand, the relatively novel domain of swarm intelligence offers algorithmic design principles, inspired by complex adaptive biological systems that well match the constraints and the challenges of WSNs. Therefore, a number of routing protocols for WSNs have been developed in the last years based on SI principles and taking inspiration from foraging behaviors of ant and bee colonies. In this paper, we have presented a rather extensive survey of these SI-based algorithms for routing in WSNs. We have also pointed out a number of methodological flaws in the way these algorithms are commonly presented and empirically evaluated. Finally, we have outlined a general recipe for the definition of scientifically sound experiments and performance evaluation. In this survey paper, Swarm Intelligence based classification, PSO, ACO and Honeybees, nature inspired routing algorithms in WSNs are critically analyzed and their suitability is observed. SI based routing techniques are more promising for specific nature of Ad hoc & Sensor

Networks due to the freely mobility and frequent topology changes. The researches done have made known that ant based routing protocols can eliminate at least one or several problems such as battery life, scalability, maintainability, survivability and adaptability. Therefore, ant based approaches are attracted by much researchers than other approaches. This paper concludes that ACO approaches are very promising for route optimization in MANETs while PSO is very effective for load balancing and energy optimization in WSNs.

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