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A survey on bio inspired meta heuristic based clustering protocols for wireless sensor networks

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Abstract. Recent studies have shown that utilizing a mobile sink to harvest and carry data from a Wireless Sensor Network (WSN) can improve network operational efficiency as well as maintain uniform energy consumption by the sensor nodes in the network. Due to Sink mobility, the path between two sensor nodes continuously changes and this has a profound effect on the operational longevity of the network and a need arises for a protocol which utilizes minimal resources in maintaining routes between the mobile sink and the sensor nodes. Swarm Intelligence based techniques inspired by the foraging behavior of ants, termites and honey bees can be artificially simulated and utilized to solve real wireless network problems. The author presents a brief survey on various bio inspired swarm intelligence based protocols used in routing data in wireless sensor networks while outlining their general principle and operation.

1. Introduction

Recent advancements in miniaturization of technology has led to the proliferation of the development of tiny sensor nodes which are capable of sensing data from the environment aggregate and interpret it, subsequently transmitting it to other such similar devices in its vicinity, forming a network of sensory devices. When deployed in a large collection in a testbed, they form a dense network of active sensor nodes forming a wireless sensor network as shown in Figure 1.

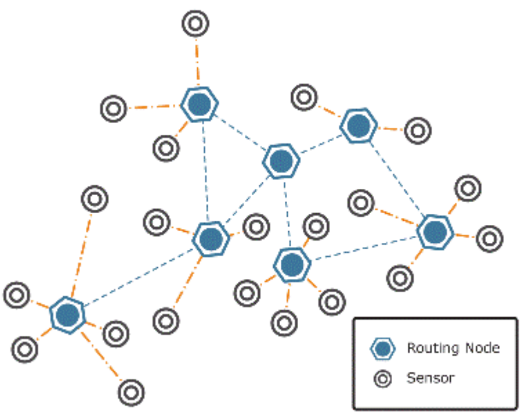

Figure 1. A Wireless Sensor Network

These sensor networks when operate following certain operational instructions work intelligently as a unit and can be deployed in various applications like remote sensing, intruder detection, vital s monitoring in patients, tactical surveying of geographic areas etc., an example shown in Figure 2.

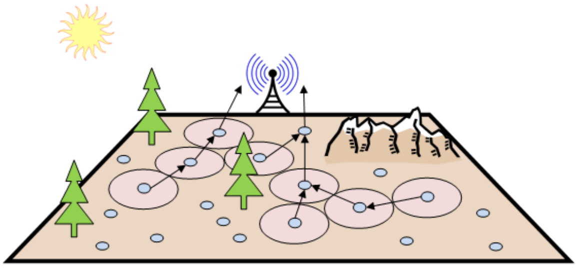

Figure 2. A Pictorial of a Wireless Sensor Network in real time application

Development of hybrid data routing protocols is a very active research topic because of the rapid proliferation of wireless sensor network remote sensing applications. An effective routing protocol makes nodes in a network to choose the most optimal route to route data from the sensory source node to the destination node where the data is aggregated. Variations in network topologies, latency during data forwarding, energy constrains and security of data within the network is major challenges in the design of routing protocols in a WSN.

Swarm intelligence is a bio-inspired meta heuristic developed based on the collective behavior of distributed, decentralized, self- organizing intelligent systems which communicate locally and globally with one another and their environment. These agents abide very simple rules and although there is a centralized control structure directing their behavior, their mode of interaction makes them appear to be working synchronously forming an intelligent global swarm behavior. The behavior of these agents is said to be swarm intelligent if it works with accordance to two properties, self-organization of the system and division of labor among individual agents

Data routing protocols in wireless sensor networks which work based on bio-inspired swarm intelligent models are very successful due to the similarities of operation of individual agents in each collection , which has eventually led to a lot of research efforts in their development and optimization.

The insect swarm represents a distributed adaptive system of smart control packets, each packet consuming resources from the network for its exploration, efficiently co-operating with other such similar agents by exchanging information, fitness of the data coming from each of these agents is calculated and it quality is estimated. In the sub sections below, the author presents a brief survey on swarm intelligent algorithm based data routing protocols in wireless sensor networks.

2. Literature Survey

With the increasing demand for routing protocols in wireless sensor networks to be effective, robust and scalable, in recent literature many bio-inspired meta heuristic based clustering protocols have been proposed for energy efficient data routing.

Salem et al [1] published a survey on routing protocols based on swarm intelligence concepts. His comprehensive survey details a number of design challenges along with each work being classified based on its simulation results and its area of application. Subsequently a bio-inspired Bee-Cup [2] clustering protocol was proposed. In the protocol clustering was modeled as an optimization problem in mobile learning. In this hybrid protocol, first the number of clusters is estimated adaptively and then cluster heads are selected based on their fitness. Another artificial bee colony algorithm proposed is the Bee Sensor, based on the foraging technique of honey bees. In the algorithm individual agents through local interactions self-organize to develop a system level behavior that shows lifelong adaptively to changes in the area where it is deployed. An energy efficient data routing protocol was developed which worked with de-centralized agents. Data Aggregation Ant Colony Algorithms (DAACA) was proposed by C Lin et al [3], the research an ant colony based routing protocol with four different pheromone adjustment strategies to have a longer network lifetime. Subsequently M.F de Castro later developed a hybrid protocol based on ant colony model, his work was to develop an algorithm to increase the sensor node lifetime with an automatic distributed routing protocol, but on the contrary it was not at all efficient in routing data in a network with a large number of sensor nodes.

Next came the Artificial Bee Colony (ABC) based algorithms, Li Qin et al [4] proposed DEEC based routing protocol, in which nodes have different energy levels when the network starts to function. The node with the highest ration of residual energy to average energy of network will be selected as the cluster head. This mechanism makes the network have uniform energy distribution throughout. One drawback of this protocol is that cluster formation is done in a random basis after cluster head selection, leading to quicker exhaustion of cluster heads belonging to larger, denser cluster as compared to ones with leaser, sparser nodes.

The next set of development in the Swarm Intelligence based routing protocols came in the form of the termite hill algorithm. The new algorithm follows a reactive multipath data routing protocol which mimics the behavior of termites in nature where they build hillock like structures. A.M Zungeru et al [5] proposed a proactive routing protocol which uses intelligent routing tables to minimize energy consumption. In the paper he proposed an algorithm which gives higher priority to distance to sensor nodes over energy remaining tin the node while selecting cluster heads and thus attains better energy efficiency. The newest to join the swarm intelligence based routing protocol is the Gene Regulatory Network (GNR) developed by N.E Mawass[6]. In this protocol each node has a GRN based controller that works to develop a self-organized adaptive network which ensures redundancy in the network. In the next section we will survey some of the prominent swarm intelligence based routing protocols one by one.

3. Review of Bio Inspired Data Routing Models

3.1 Particle Swarm Optimization (PSO) Model

Particle swarm optimization (PSO) is a population based stochastic optimized data routing technique, which mimics the social behavior of a flock of birds or a school of fish to route data in a wireless sensor network. First the system is initialized with a population of random solutions. Then the fitness of each of these solutions as an information producing source is calculated. The solution which has the highest fitness is known as the global best. All the nodes try to obtain the solution which is in the direction of the global best solution. For this there is again a computation of the fitness of its local neighbors. The neighbor with the highest fitness becomes the local best and the path of data routing from the sensor node toward the global best is done in the direction of the local best solution. In this approach global and local solutions are calculated to produce a solution with the most fitness for the given objective function. PSO was first proposed by Eberhart to produce a bio- inspired meta heuristic that would improve packet delivery ratio, reduce computation and increase the network exploration of the network. The particle swarm optimization algorithm has two phases:

1) Set up Phase: In this phase operations like neighbor discovery, network configuration and data broadcasting is done.

2) Steady State Phase: In this phase the data routing path has been calculated and data from the sensor node is obtained in time division multiple access.

3.2 Ant Colony Optimization (ACO) Model

Ant colony optimization is a probabilistic technique used to find the shortest path in between two sensor nodes in a network. The ACO algorithm is a development over the comprehensive routing protocol (CRP) first developed by Guo in 2010. There are three phases in the algorithm routing table setup, data communication and route maintenance. The algorithm starts of in an initialization phase in which the fitness of the solutions of each sensor node is calculated. The solution with the highest fitness of solution is the node from where the information is obtained. Following an experience based iteration technique the shortest path to the destination node is selected and there is a data transmission only along that path while the other nodes remain idle. As a result of real time computation techniques and lesser control overhead used in ant colony optimization based techniques; it delivers a statistically higher performance as compared to conventional network routing techniques. Limitations of this algorithm are many, on being its overdependence on the computation of outputs in its previous stage, which reduces its performance. However ACO is still preferred to be used in dynamic networks because of its ability to prevent link failures.

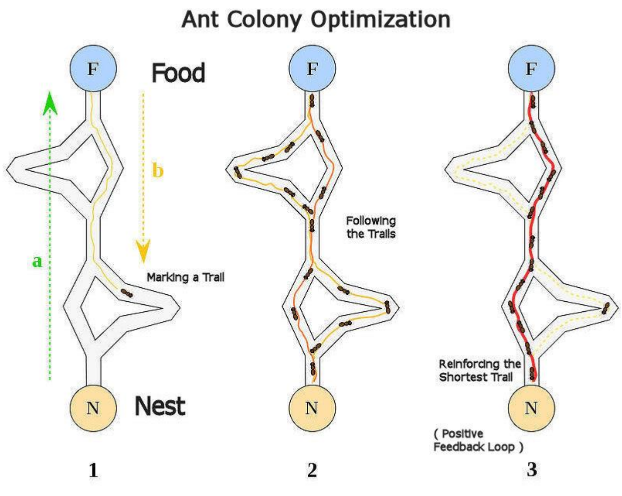

Figure 3. Ant Colony optimization

One drawback of this approach was its inability to deal with link failures and considerations of Quality if Service (QoS) metrics. A multi constrained QoS technique IAMQER, an ant colony based energy efficient routing protocol was developed by Wang et al [7]. This new algorithm reduced energy consumption over sensor nodes while increasing the network packet delivery ratio, but as this new technique required longer data processing time at sensor nodes and cluster heads it had much higher latency.The ACO algorithm enhances performance of network in terms of network lifetime and load balancing of the network by providing various solutions in finding the shortest path between source node and the destination cluster head.

3.3 Bacteria Foraging Optimization (BFO) Model

Bacteria Foraging Optimization is another such bio-inspired data routing algorithm which is based on the foraging behavior of Escherichia coli bacteria. The bacteria foraging optimization uses the strategy of allowing agents to stochastically and collectively swarm toward optima. The algorithm works in three phases of operation namely the Chemotaxis, Reproduction and the Elimination and dispersal phase. In the first stage, Chemotaxis the fitness of each wireless sensor node is calculated by its proximity to other neighboring sensor nodes. In the next stage of Reproduction only those sensor nodes which have a better fitness as compared to its neighbors is selected and is made cluster heads, which can then employ other sensor nodes under it. Over a period of time when the fitness of the cluster reduces to lesser than other such nodes in its vicinity, it is eliminated and all the sensor nodes in its cluster is released following which another cluster head is elected and this concludes the third phase of the algorithm. The approach in BFO obtains better results when compared with conventional swarm intelligence based algorithms as it has better computational efficiency when applied to complex scenarios. A flow chart depicting the working of Bacteria Foraging Optimization is given in Figure 4.

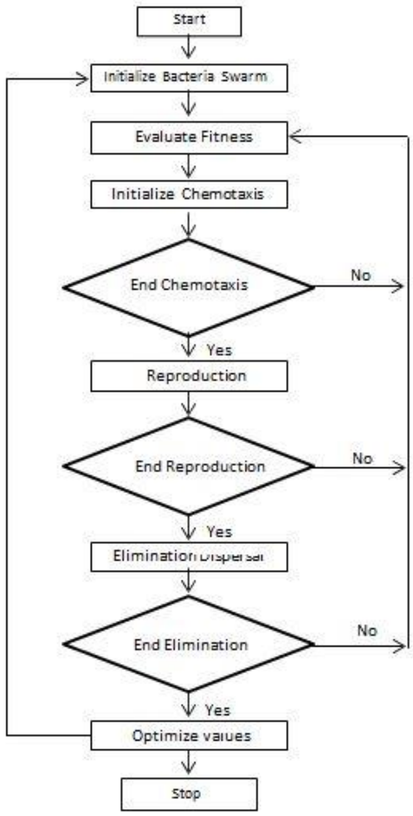

Figure 4. Flowchart of Bacterial Foraging Optimization Protocol

The BFO algorithm is very versatile, other than data routing it is used in many research fields like color image quantization and face recognition.

3.4 Artificial Bee Colony (ABC) based Protocols

Artificial bee colony meta heuristic is an evolutionary data routing path algorithm mimicking the foraging behavior of bees in a swarm. The algorithm is designed to optimize multivariable and multimodal continuous functions. The artificial be colony model consists of three types of agents also known as bees the scout bees, the onlooker bees and the employed bees. These individual agents have certain defined functions to perform while the network works in different phases of operation namely:

1) *Initialization Phase:* The ABC metaheuristic starts of with initial population number randomly generated through D-dimensional real set of vectors.
2) *Employed Bee Phase:* In this phase the fitness of each of the agents is calculated based on the solution obtained from them in the previous phase.
3) *Onlooker Bee Phase:* Once the fitness of each of the agents is calculated, the agent with the highest fitness among other agents is selected and is made as the cluster head in that neighborhood. It then serves as a node for data aggregation from nodes under it and a pathway of communication for the base station to that cluster.
4) *Scout Bee Phase:* The scout bees are responsible to find out new food sources by randomly searching around examining every food source they find. After a certain number of trials following the cycle number predefined, if a solution cannot be improved further then the food source is abandoned and the corresponding employed bee becomes a scout bee again

The drawbacks of the conventional artificial bee colony algorithm are its low convergence rate and its inefficiencies in the exploratory process while newer multi-hop proactive processes result in higher overhead causing reduction in throughput and higher latency of the network.

3.5 Spider Monkey Optimization (SMO) protocol

Another recent swarm optimization based data routing algorithm in development is the Spider Monkey Optimization protocol. The algorithm is modelled by the fission-fusion social structure behavior of spider monkeys in particular. Similar to other population based algorithms; this algorithm is a trial and error basedcollabo0rative iterative process. The algorithm consists of 6 phases: The local leader phase, the global leader phase, the local leader learning phase, the global leader learning phase, the local leader decision phase and the global leader decision phase. In the first phase of the algorithm, there is a generation of uniformly distributed agents, each corresponding to a particular sensor node. In the next phase known as the Local leader phase, each agent modifies its solution based on the instructions of then local leader, and the fitness of this new solution is obtained. If this new solution is better than the old solution then the solution is updated or else the old solution is still used. The subsequent phase is the global leader phase in which all the nodes update their solution using the experience of the global leader. The global leader learning phase the agent having the best fitness sis selected to be the global leader. The following stages of the algorithm deals with comparing the solutions of the global and local leader nodes with certain thresholds to check if there is a need to divide the cluster to sub clusters to increase computational efficiency. A flowchart of the algorithm can be found in Figure 5.

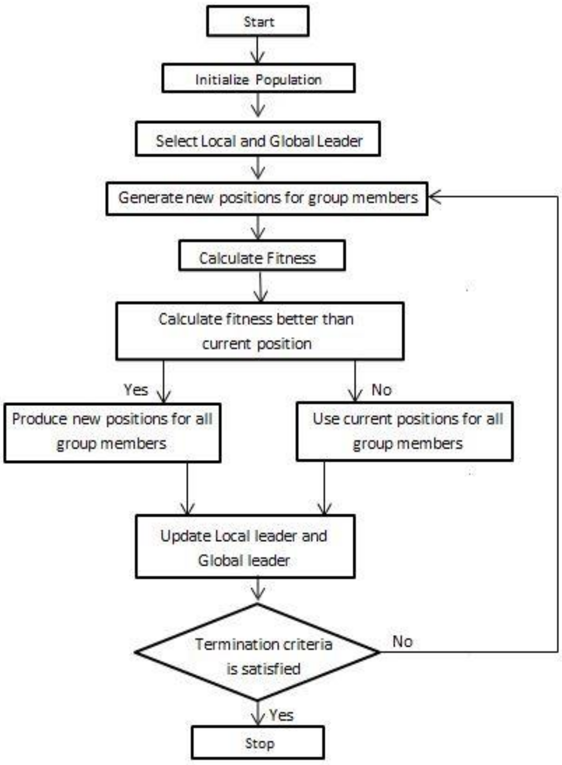

Figure 5. Flowchart of Spider Monkey Optimization Protocol

The SMO initializes with a uniformly distributed population and then explores for optimal solutions by updating their positions using self-experience. The SMO algorithm is good in exploration and exploitation of local search space and requires lesser computation time than conventional algorithms.

4. Design Challenges in Wireless Sensor Networks

Wireless sensor networks (WSN) and Mobile Ad-hoc networks (MANET) though look similar can be distinguished on many features. Firstly, specific traffic patterns like many to one (convergence-cast) and one to many (multi-cast) trees are present in WSN and not in MANET. Secondly, sensor nodes in wireless sensor networks have high operational constrains to resources, such as less memory, limited battery power, small bandwidth links etc. Thirdly, in WSN each sensor node can continuously generate a redundant quantity of data, therefore there is a higher need of data aggregation at various levels in the network to detect and filter out excessive data, which would increase the in network traffic. In the subsequent section the specific design challenges of wireless sensor networks will be discussed one by one as follows:

4.1 Computation and Memory Requirements

The agents in wireless sensor networks are tiny computers equipped with CPU's with low processing power and have limited on board memory and so the routing algorithms developed need to have minimal processing overhead in order to have an efficient execution of functionalities.

4.2 Automaticity and Self-Organization

A wireless sensor network is a dynamic network; during its time of operation many nodes might become non-operational whereas many new nodes would be added to the network. The routing protocol used must be proactive, in such a dynamically varying network it must be adaptive enough to able to sustain the long term availability of essential network services.

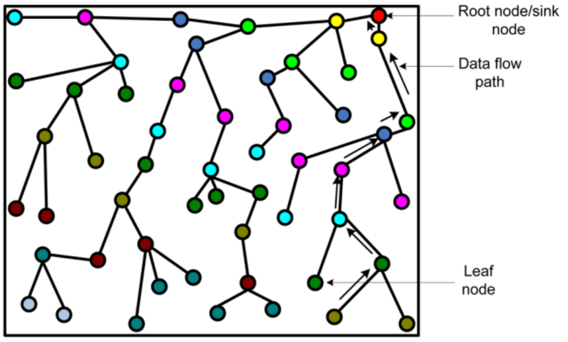

Figure 6. A Self Organized Wireless Sensor Network

4.3 Energy Efficiency

Sensor nodes also have limited battery power and so efficient power utilization is a critical aspect in wireless sensor networks to support longer network operational time. A routing protocol is thus expected to:

1) Minimize the number of transmission involved in data delivery and route discovery.
2) Data forwarding in the protocol must be done in multi paths so that the energy expenditure of all nodes is uniform throughout the process.

4.4 Scalability of network

Wireless Sensor Network applications usually deploy thousands of sensor nodes in a dense distributed pattern over a test bed. The nodes in this dense network have short communication ranges resulting in high failure rates due to signal interference. Thus a routing protocol must be resilient to challenges from intensive radio interference and unpredictable failures in long paths of data forwarding.

4.5 Security of data in network

Security of data is a stiff challenge in WSN. Unauthorized access due to inadequate security of network may violate QoS negotiations. Due to the nature of data broadcasting in wireless sensor networks, it potentially results in more exposure of data. As the physical channel of communication is inherently insecure, there is a need for data routing protocols developed to be security aware.

5. Conclusion

Wireless Sensor networks comprise of large sets of nodes with limited resources, which makes the design of an efficient, robust and scalable routing protocol a very challenging task. Swarm Intelligence offers algorithmic design principles inspired by social interactions of complex biological systems, that well match the constrains and challenges of Wireless Sensor networks. In this paper the author has presented an extensive survey of the Swarm intelligence based algorithms developed for data routing in wireless sensor networks. The bio inspired data routing models for data routing lacks contributions from two opposite domains. On one hand, mathematical models must always complements simulation based studies and on the other hand simulations should be done to proceed to hardware

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implementations, as simulations only account for a very little of the challenges faced when working with real test beds. The author strongly believes that we will witness a large diffusion of Swarm Intelligence based solutions for routing in wireless sensor networks once researchers commit themselves to the use of sound experimentation for their study.

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