A Survey: Swarm Intelligence based Routing

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Abstract

Designing multi-hop protocols and implementing algorithms for wireless sensor networks (WSNs) is an area of research. The concept of swarm intelligence(SI) presents various protocols suitable for field of WSNs and the intelligence of nature inspired techniques like that of bees proves to be an inspiration for working of nodes in different areas of applications. In this paper, we discuss the routing methods, SI, compare various classical and swarm intelligence based routing protocols for wireless sensor networks.

Keywords: Artificial Bee Colony(ABC), Wireless Sensor Networks(WSNs), Swarm Intelligence(SI)

I. INTRODUCTION

Wireless sensor networks (WSNs) consisting of multiple collaborative sensor nodes have been widely applied in the field of medical, industrial, and military applications [1,2]. WSNs can provide users with the ability to record, observe, and react to an event or a phenomenon in a specific environment. And WSNs are expected to play an even more important role in the next generation network to sense the physical world. WSNs can provide users with the ability to record, observe, and react to an event or a phenomenon in a specific environment. And WSNs are expected to play an even more important role in the next generation network to sense the physical world [3,4]. WSNs have many characteristics that differ from conventional wireless networks [5]. The sensor nodes in WSNs typically have limited resources in terms of battery supplied energy, processing capability, communication bandwidth, and storage. Routing is a very important function to achieve efficient communication in the design of WSNs [7] and has been shown to significantly impact the energy efficiency and consequently the lifetime of WSNs [8]. The sensor nodes in WSNs sense the surrounding environment and deliver the measured data to a central base station or the sink through the routing process. Nevertheless, the design of routing protocols in WSNs is a challenging task as a result of their inherent characteristics mentioned above. An applied routing protocol in WSNs should ensure the minimum of the energy consumption and hence maximization of the lifetime of the network [9]. That means that it not only aims for energy efficiency but also aims for energy consumption balance. In addition, an ideal routing protocol should be scalable and resilient to meet the requirements of WSNs. Micro-Electro-Mechanical Systems (MEMS) have led to the development of small sensor nodes equipped with logic functions, sensing and communication capabilities. When sprayed in a target area, they form a communication network that can sense, communicate and even react to control the environmental conditions. This makes WSNs suitable for a range of applications in diverse real world civil and military applications – target field imaging, intrusion detection, weather monitoring, security and tactical surveillance and disaster management. Routing in WSNs has been a challenging task primarily because of limited processing, communication and energy resources available at a sensor node [25]. Consequently, routing protocols must be designed with low processing complexity and minimum communication overhead. Since the sensor nodes mostly operate in pervasive environments with no user intervention; routing must be done through distributed and decentralized controllers at each node, which on the basis of local and partial information should be able to self-organize to take adaptive routing decisions in response to changing external environment.

II. ROUTING METHODS

Recent research has proven that both multipath and clustering communication are very efficient routing methods in WSNs. Routing is the process of selecting best paths in a network. In the past, the term routing also meant forwarding network traffic among networks. However, that latter function is better described as forwarding. Routing is performed for many kinds of networks, including the telephone network (circuit switching), electronic data networks (such as the Internet), and transportation networks.

A. Clustering

Clustering has been widely used to extend the network lifetime and achieve network scalability. Data from different sources in cluster are aggregated by reducing redundancy with the purpose of minimizing energy consumption in transmission. LEACH [11,17] is a representative clustering algorithm for WSN. LEACH forms clusters by using a distributed algorithm. However, it is not friendly in a large network deployment. The authors in [12] design a power-efficient and adaptive clustering hierarchy protocol (PEACH). In PEACH, cluster formation is performed by using overhearing characteristics of wireless communication to avoid additional overheads. Cluster analysis itself is not one specific algorithm, but the
general task to be solved. It can be achieved by various algorithms that differ significantly in their notion of what constitutes a cluster and how to efficiently find them. Popular notions of clusters include groups with small distances among the cluster members, dense areas of the data space, intervals or particular statistical distributions. Clustering can therefore be formulated as a multi-objective optimization problem. The appropriate clustering algorithm and parameter settings (including values such as the distance function to use, a density threshold or the number of expected clusters) depend on the individual data set and intended use of the results. Cluster analysis as such is not an automatic task, but an iterative process of knowledge discovery or interactive multi-objective optimization that involves trial and failure. It will often be necessary to modify data preprocessing and model parameters until the result achieves the desired properties. Clustering algorithms are generally classified as hierarchical clustering and partitional clustering [19–21]. Hierarchical clustering groups data objects with a sequence of partitions, either from singleton clusters to a cluster including all individuals or vice versa. Hierarchical procedures can be either agglomerative or divisive: agglomerative algorithms begin with each element as a separate cluster and merge them in successively larger clusters; divisive algorithms begin with the whole set and proceed to divide it into successively smaller clusters [22,23]. Partitional procedures that we concerned in this paper, attempt to divide the data set into a set of disjoint clusters without the hierarchical structure. The most popular partitional clustering algorithms are the prototype-based clustering algorithms where each cluster is represented by the center of the cluster and the used objective function (a square-error function) is the sum of the distance from the pattern to the center [24].

B. Multipath mechanism

In multipath mechanism, two or more paths are established from source to destination [10]. Multipath routing can distribute the forwarding of the data packets across multiple paths so that all nodes can utilize their batteries at a comparable rate, which contributes to prolonging the network lifetime and achieving load balance.

III. SWARM INTELLIGENCE (SI)

Swarm intelligence (SI) has been considered in the routing issue of an WSN. Social insect communities such as ants and honey bees have many desirable properties in the WSN. These communities are formed with simple, autonomous, and cooperative organisms that are interdependent for their survival [6]. Despite the lack of centralized control, social insect communities are able to effectively coordinate themselves to achieve global objectives. Their labour division is clear and can be adaptively Adjusted according to the colony requirements or environment changes in an unpredictable world. The characteristics described above are necessary and desired in the context of sensor networks, especially for the design of routing protocols in WSNs. Bio-inspired mechanisms are considered more robust as they provide interesting solution for routing due to their inherent features. Honey bee colonies have recently emerged as a source of inspiration for the optimization of time-varying, dynamic, and multi-objective problems [7]. Some researchers have paid much attention to the foraging behavior of bee swarm and utilize it in designing the routing protocol in last decade. Such systems may be composed of simple nodes working together to deliver messages, while being resilient against changes in its environment. Nevertheless, to the best of our knowledge, limited number of bee-inspired routing protocols for WSNs have been reported in [8–10]. Moreover, these existing works have not considered the integration of clustering technique, multipath mechanism, and bee-inspired mechanism in solving routing problem for WSNs. Swarm intelligence is an emerging area in the field of optimization and researchers have developed various algorithms by modeling the behaviors of different swarm of animals and insects such as ants, termites, bees, birds, fishes. In 1990s, Ant Colony Optimization based on ant swarm and Particle Swarm Optimization based on bird flocks and fish schools have been introduced and they have been applied to solve optimization problems in various areas within a time of two decade. However, the intelligent behaviors of bee swarm have inspired the researchers especially during the last decade to develop new algorithms. This work presents a survey of the algorithms described based on the intelligence in bee swarms and their applications. The term swarm is used for an aggregation of animals such as fish schools, birds flocks and insect colonies such as ants, termites and bee colonies performing collective behavior.

The individual agents of a swarm behave without supervision and each of these agents has a stochastic behavior due to her perception in the neighborhood. Local rules, without any relation to the global pattern, and interactions between self-organized agents lead to the emergence of collective intelligence called swarm intelligence. Swarms use their environment and resources effectively by collective intelligence. Self-organization is a key feature of a swarm system which results global level (macroscopic level) response by means of low-level interactions (microscopic level). Bonabeau et al. (1999) interpreted the self-organization in swarms through four characteristics:

1. Positive feedback is a simple behavioral “rules of thumb” that promotes the creation of convenient structures. Recruitment and reinforcement such as trail laying and following in some ant species or dances in bees can be shown as examples of positive feedback.

2. Negative feedback counterbalances positive feedback and helps to stabilize the collective pattern. In order to avoid the saturation which might occur in terms of available foragers, food source exhaustion, crowding or competition at the food sources, a negative feedback mechanism is needed.

3. Fluctuations such as random walks, errors, random task switching among swarm individuals are vital for creativity and innovation. Randomness is often crucial for emergent structures since it enables the discovery of new solutions.

4. Multiple interactions occur since agents in the swarm use the information coming from the other agents so that the information and data spread to all network.
A. Bees in Nature

A very interesting swarm in nature is honey bee swarm that allocates the tasks dynamically and adapts itself in response to changes in the environment in a collective intelligent manner [16]. The honey bees have photographic memories, space-age sensory and navigation systems, possibly even insight skills, group decision making process during selection of their new nest sites, and they perform tasks such as queen and brood tending, storing, retrieving and distributing honey and pollen, communication and foraging. These characteristics are incentive for researchers to model the intelligent behaviors of bees. Before presenting the algorithms described to use intelligent behaviors and their applications, behavior of the colony is explained below:

i. Queen bee - Queen bee can live several years. She is the only egg-laying female who is the mother of all the members of the colony. The queen usually mates only once in her life and she fertilizes for two or more years by the sperms stored in the mating. After consuming the sperms, she produces unfertilized eggs and one of her daughters is selected as a queen in order to keep on egg-laying. A laid egg hatches into larva, pupate, adult bee, respectively [3].

ii. Drones - Drones are the fathers of the colony, in other words drones are male bees. They are produced from unfertilized eggs, queens and workers produced from fertilized eggs which are fed differently as larvae. They never live more than 6 months. There are several hundred of drones in the colony in summer times. The primary task of a drone is to fertilize a new queen. Drones die after they mate with the queen [3,15].

iii. Workers - They collect food, store it, remove debris and dead bees, ventilate the hive and guard the hive. Workers make the wax cells in which the queen lays eggs and feed the larvae, drones and queen by special substance or secretion of their salivary glands. The tasks of a worker bee are based on its age and the needs of the colony. In second half of her life, she works as a forager by initially leaving the hive for short flights in order to learn the location of the hive and the environment topology. They live for 6 weeks during summer times and 4–9 months during the winter times [15].

iv. Mating Flight - The queen mates during her mating flights far from the nest. A mating flight starts after a dance performed by the queen bee. During the flight the drones follow the queen and mate with her in the air. A drone mates with a queen probabilistically according to queen’s speed and fitness of the queen and the drone. Sperm of the drones will be deposited and accumulated in the queen’s spermatheca to form the genetic pool of the potential broods to be produced by the queen [3,15].

v. Foraging - the foraging behavior of each individual bee and what types of external information (such as odour, location information in the waggle dance, the presence of other bees at the source or between the hive and the source) and internal information (such as remembered source location or source odor) affect this foraging behavior. Foraging process starts with leaving the hive of a forager in order to search food source to gather nectar. After finding a flower for herself, the bee stores the nectar in her honey stomach. Based on the conditions such as richness of the flower and the distance of the flower to the hive, the bee fills her stomach in about 30–120 min and honey making process begins with the secretion of an enzyme on the nectar in her stomach. After coming back to the hive, the bee unloads the nectar to empty honeycomb cells and some extra substances are added in order to avoid the fermentation and the bacterial attacks. Filled cells with the honey and enzymes are covered by wax [15].

vi. Dance - After unloading the nectar, the forager bee which has found a rich source performs special movements called “dance” on the area of the comb in order to share her information about the food source such as how plentiful it is, its direction and distance and recruits the other bees for exploiting that rich source. While dancing, other bees touch her with their antenna and learn the scent and the taste of the source she is exploiting. She dances on different areas of the comb in order to recruit more bees and go on to collect nectar from her source. There are different dances performed by bees depending on the distance information of the source: round dance, waggle dance, and tremble dance. If the distance of the source to the hive is less than 100 meters, round dance is performed while the source is far away, waggle dance is performed. Round dance does not give direction information. Incase of waggle dance, direction of the source according to the sun is transferred to other bees. Longer distances cause quicker dances [3,15].

vii. Task Selection - A honeybee colony needs to divide its workforce so that the appropriate number of individuals are allocated for each of the many tasks. Bees are specialized in order to carry out every task in the hive. However, there is a controversy about which factors have roles on the specialization of bees, such as their age, hormones (internal factors), individual predisposition coming from their genetic determination and also the allocation of tasks can dynamically change. For example, when food is drought, younger nurse bees will also join to foraging process. Depending on the swarm intelligent behaviors of a bee swarm noted above, several approaches have been introduced and applied to solve problems. In the following section, these approaches and their applications are summarized [3,15].

viii. Nest Site Selection - While deciding nest site selection, bees pay attention on some issues such as the size of cavity to hold combs, tightness of the cavity, weather conditions and the construction time. The most important issue is that
giving a unified decision in all swarm without conflicts. In order to achieve this task, many scout bees working in parallel explore for potential nests sites and share their information about the explored sites with the other scout bees by dancing. From all alternatives, the best is selected by means of the various coalitions of scouts by attracting others via waggle dances of which the strength is proportional to the site quality. A scout prefers the other site that is advertised by dances only if the advertised site is a worthy site after inspecting the site. Inspection progress provides shifting to poor sites [3].

ix. Navigation - Forager bees use a map-like organization of spatial memory for homing, food source search flights. This organization is based on the computations of two experienced vectors, or on viewpoints and landmarks. There are two perspectives of which one certainly true is not known. First one is that bees use stimuli obtained during their flights. The second one is that they encode the spatial information in their dances into their map-like spatial memory [3].

B. Abbreviations and Acronyms

Swarm intelligence (SI) is the collective behavior of decentralized, self-organized systems, natural or artificial. A wireless sensor network (WSN) (sometimes called a wireless sensor and actuator network) are spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc.[15,16] and to cooperatively pass their data through the network to a main location.

C. Equations

The intelligent behaviour infers the knowledge about the randomness of swarm particles, error, fluctuations, and the positive and negative feedback of the swarm intelligence and the how the balance is maintained [2,3,4].

$$\Theta^* = \arg \min_{\theta \in \Theta} f(\theta) = \{\theta^* : f(\theta^*) \leq f(\theta), \ \forall \theta \in \Theta\},$$

where $\theta$ is an $n$-dimensional vector that belongs to the set of feasible solutions $\Theta$ (also called search space). In PSO, the so-called swarm is composed of a set of particles $P=\{p_1, p_2, ..., p_K\}. The position of a particle corresponds to a candidate solution of the considered optimization problem, which is represented by an objective function $f$. The PSO algorithm starts by generating random positions for the particles, within an initialization region $\Theta \subseteq \Theta$. Velocities are usually initialized within $\Theta$ but they can also be initialized to zero or to small random values to prevent particles from leaving the search space during the first iterations [2]. For Onlooker bee, the formula for calculating choice of food source is

$$v_{ij} = x_{ij} + \Omega_{ij} (x_{ij} - x_{kj})$$

(3) where $k \in \{1, 2, ..., EB\}$ and $j \in \{1, 2, ..., Z\}$. For scout bee the operation can be in terms of formula:

$$x_i^j = x_{min}^j + rand[0,1](x_{max}^j - x_{min}^j)$$

(4)

A global optimization problem can be defined as minimizing the objective function $f(x^*)$:

$$f(\vec{x}^*), \vec{x} = (x_1, x_2, ..., x_i, ..., x_{n-1}, x_n) \in \mathbb{R}_n$$

(5)

IV. RESEARCH GAPS

1. With the formation of CC-HEED, a few of the nodes are left and are not part of hexagonal shapes and have to act as individual nodes which can lead to wastage of energy [13].

2. More work need to be carried out on sensor node mobility since it has an impact on overall working of the wireless sensor network [14].

3. Clustering with ABC algorithm on routing of networks including mobile nodes and effect of noisy channels needs to be analyzed [15].

4. The scalability of bee Sensor networks needs to be validated for very large scale networks of real sensors rather than virtualization [16].

5. Multipath routing is in terms of the techniques but not in context to application field which will have an impact in real time scenario [17].

V. COMPARISON OF ROUTING PROTOCOLS

In this paper, we compare the performance of six swarm based routing protocols in WSNs: EEABR (energy-efficient ant-based routing protocol), SC(sensor-driven and cost-aware ant routing), FF(flooded forward ant routing), FP(flooded piggybacked ant routing), Beeesensor, BABR(basic ant-based routing), and classical routing protocols; AODV(ad-hoc on-demand distance vector) routing, MCBR-AST(message-initiated constrained based routing - adaptive spanning tree), MCBR-RTRS(message-initiated constrained based routing - real-time search routing), and MCBR-CFR(message-initiated constrained based routing - constrained flooding routing) using the metrics shown in Table 1. The performance of swarm intelligence(SI) based protocols is promising in terms of energy efficiency. Further, only a few of classical routing protocols perform well in terms of energy efficiency, as it can be seen from the table. MCBR-CFR and AODV performs below expectation, while MCBR-AST and MCBR-RTSR performs quite well.
### Parameters

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<th>Beesensor</th>
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### REFERENCES


