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Review

A survey on swarm intelligence based routing protocols in wireless sensor networks

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In the last decade, wireless sensor networks have attracted many researchers. One of the main topics adopted by researchers studying on wireless sensor networks is developing routing protocols for wireless systems. Routing protocol development deals with problems such as complexity, scalability, adaptability, survivability and battery life in wireless systems. Routing protocols grounded for wireless systems are developed in order to solve these problems. In this paper, we briefly discussed especially, swarm intelligence based routing protocols for wireless sensor networks.

Key words: Wireless sensor networks, swarm intelligence, routing.

INTRODUCTION

Wireless sensor networks (WSNs) are such networks which comprise numerous small scale sensors that communicate via wireless channels (Çakiroğlu et al., 2010). Current developments in wireless communications and digital electronics make it possible for sensor units to be designed with low power consumption, small size and short range communication capabilities. WSN architectures, including a lot of processing sensors having such properties, provide significant advantages on classical sensor systems (Al-Karaki and Kamal, 2004). A typical sensor network is composed of a region under observation, sensor nodes, base station and task allocator nodes (Freeman, 2004).

Large-scale sensor networks can be deployed to and around the measured region in applications. Each sensor unit is randomly distributed to the region; therefore it is impossible to determine the exact location of the sensors. In such applications, self organization and adaptive collaboration among sensors become key properties to provide survivable structure in the network level (Karaki and Kamal, 2004). Collaboration and self organization among sensor units allow network to route physical information from the observed environment to the base station via multi-hop routes. The features such as low costs of the WSN nodes deployed into inaccessible regions and long life without any maintenance enable sensor networks to be used in a wide range of application areas. WSNs application areas can be classified into military, environmental and medical applications.

Primary routing goals of WSN systems are to extend network life and prevent connection errors that emerged from the use of intensive energy management techniques (Ökdem and Karaboğa, 2007). Therefore, there is no way to use classical routing approaches in WSNs and there is need for new routing approaches. As such, these routing approaches emerged as swarm intelligence based schemes (Appleby and Steward, 1994).

Social insect colonies such as ants and honeybees have complex collective behavior and decentralized management structure (Di Caro and Dorigo, 1998; Saleem et al., 2009). These properties have resemblances with parallel, dynamic and distributed systems such as computer networks. Several researchers studied these insects to devise high performance routing protocols (Di Caro, 2004). This paper lends itself to give brief information about swarm intelligence based routing protocols developed for WSNs. In this work, several swarm intelligence based routing protocols were investigated and compared. Comparisons are performed in terms of some criteria such as energy consumption, scalability and so on.

FACTORS OF THE ROUTING PROTOCOL DESIGN

WSNs were first deployed by military applications, and

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later, civilian applications such as Internet and other network technologies were pursued. In Figure 1, a typical wireless sensor network system can be seen. Civilian applications can be exemplified as environmental and species monitoring, agriculture, production and healthcare, smart home, etc. WSNs may consist of heterogeneous and mobile sensor nodes. The scale and density of a network varies depending on the application. As such, a routing protocol is demanded in order to route sensed data. Due to structural difficulties of WSNs, routing protocols work differently than wired networks such as Internet. Some issues need to be considered when a new routing protocol is being developed (Ökdem and Karaboğa, 2009).

Energy

Sensor nodes have limited energy. They can exhaust their limited energy when performing tasks such as computations and transmitting information in a wireless environment. As such, active lifetime of a sensor node has a strong dependence on its battery lifetime (Akkaya and Younis, 2005). In a multihop WSN, every node has two functions: receiver and transmitter. Network topology is highly dynamic as a constituent of the sensor nodes' battery that is exhausted. Depending on this dynamism, routing process should be reconfigured and routing algorithm is needed to be highly adaptable.

Scalability

Scalability is a significant property of a routing protocol since sensor applications may have thousands of sensor nodes. In other words, the number of sensor nodes deployed in the sensing area may be in the order of hundreds, thousands or more and therefore routing algorithms must be scalable enough to respond to events. Abstraction and simplification mechanisms are demanding, in that such a large amount of data is decreased to manageable size.

Data assembly

Sensor nodes can generate and transmit trivial data and this can cause huge traffic over wireless sensor network. To prevent this, similar packets from multiple nodes can be merged and hence transmission number can be reduced (Heinzelman et al., 2000).

Network life span

Across various applications, the necessary life span of a specific sensor network may range from some hours to several years. As such, the necessary lifetime has a high impact on the required degree of energy efficiency and robustness of the nodes (Ökdem and Karaboğa, 2009).

Fault tolerance

The failure of sensor nodes such as blockage due to lack of power, physical damage, or environmental interference must not affect the overall network task. In case of these failures, routing protocols are able to generate new routes to the data collection base stations (Krishnamachari et al., 2002).

Latency

Latency is also considered as an important factor influencing routing protocol design. Latency in a WSN is an expression of how much time it takes for a packet of data to get from one designated sensor point to the base station, whereas latency in a sensor network is measured either one-way (the time it takes for the source to send a packet to the destination receiving it) or round-trip (the one-way latency from source to destination, including the one-way latency from the destination back to the source). Besides one-way and round-trip latency, data aggregation and multi-hop relays can also cause data latency, Figure 1 (Al-Karaki and Kamal, 2004).

Deployment

Layout of sensor nodes may vary depending on the area under observation and it has effects on routing performance. Deployment of any sensor node can be performed in predetermined places. In contrast, in self-organizing systems, the sensor nodes are spread randomly in the form of shaping an infrastructure in an ad hoc manner (Rommer and Friedeman, 2004).

Quality of service (QoS)

The quality of service (QoS) is about service excellence that is required by the specific application. Depending on the application domain, it can be the length of life span, data reliability, energy efficiency, location-awareness and collaborative-processing, which affect the selection of routing protocols for that application (Al-Karaki and Kamal, 2004).

Data delivery models

In a typical sensor network, data are flooded from the sensor nodes to the sink or base station. Depending on the application of the sensor network, the data delivery

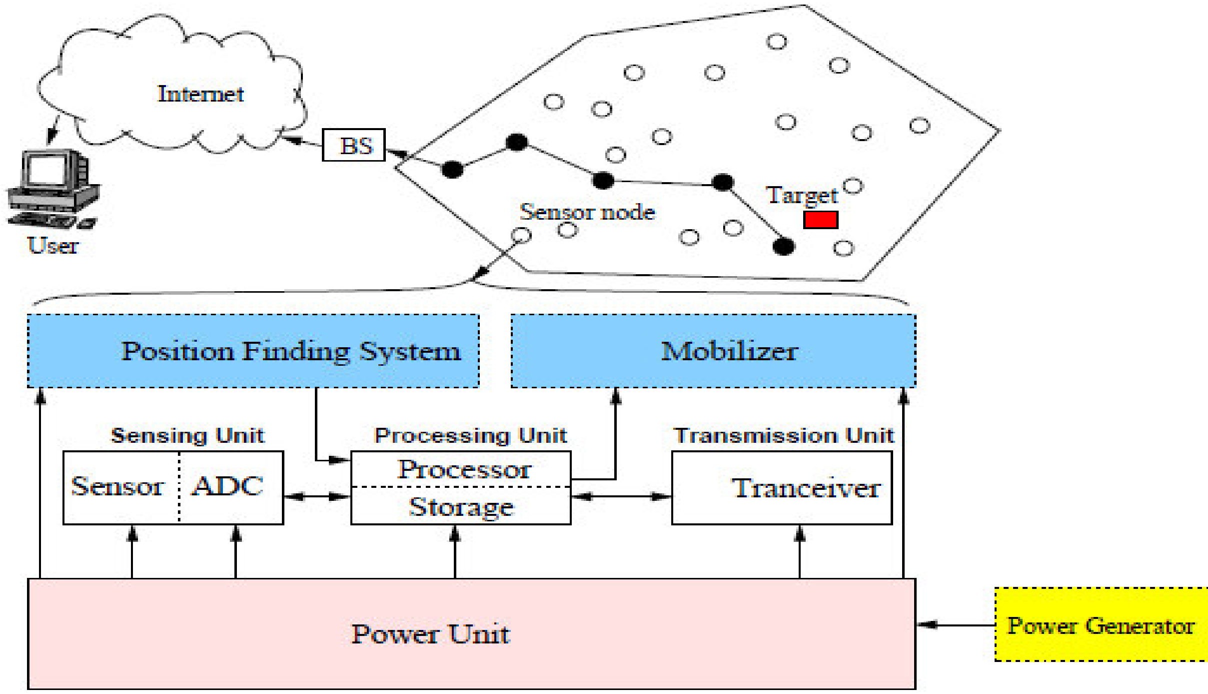

Figure 1. The components of a sensor node (Karaki and Kamal, 2004).

model can be continuous, event-driven, query-driven and hybrid (Biradar et al., 2009). In the continuous model, every node transmits the data periodically, while event-driven model runs the event in a triggered manner (that is, data are sent on occurrence of an event). Query-driven model initiates the data on query of the sink and hybrid model uses all three models.

Operating environment

Depending on the requirements of the applications, sensor nodes can be deployed to oceans, woods and inside of a building or different areas. As such, varying environment has effect on the routing protocols.

SWARM INTELLIGENCE BASED ROUTING PROTOCOLS FOR WIRELESS SENSOR NETWORKS

Here, a brief literature for swarm based routing protocols is given to WSNs (Dorigo, 2001). Swarm based routing protocols are classified into three categories: Ant based, bee based and slim based (Figure 2).

ACO based routing protocols

The ant colony optimization (ACO) based routing scheme has been inspired by operating principles of ants foraging behavior (Bonabeau et al., 2000), allowing an ant colony to perform complex tasks such as nest building and foraging (Dorigo et al., 1999; Schoonderwoerd and Holland, 1999).

Energy-efficient ant-based routing (EEABR)

EEABR is developed by T. Camilo in 2006 and a new communication protocol for WSNs called energy efficient ant-based routing algorithm (EEABR), which is based on the ant colony optimization (ACO) (Camilo and Carreto, 2006).

In every node, a data structure stores ant information, whereas the routing table stores the previous node, the forward node, the ant identification and a timeout value. When a forward ant is received, the node looks at its routing table and searches the ant identification for a loop. If the ant identification is not found, the node stores the necessary information, restarts a timer and forwards the ant to the next node.

If ant identification is found, the ant is eliminated. When a node receives a backward ant, it searches its routing table to find the next node, where the ant must be sent to. The timer is used to delete the record that identifies the backward ant, if ant does not reach that node within the time defined by the timer.

Experiments in the paper (Camilo and Carreto, 2006), including comparison with the basic ant-based routing algorithm (BABR) and the improved ant-based routing

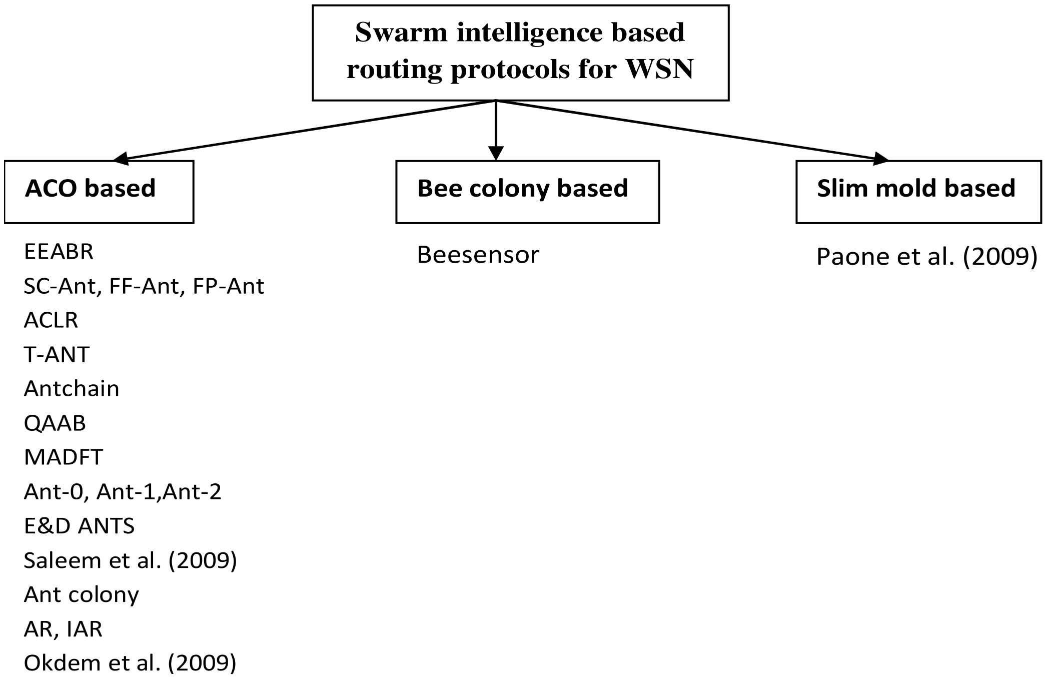

Figure 2. A taxonomy of routing protocols for fixed telecommunication.

algorithm (IABR) are performed in ns-2 network simulator.

Sensor-driven and cost-aware ant routing (SC-Ant), flooded forward ant routing (FF-Ant) and flooded piggybacked ant routing (FP-Ant)

Sensor-driven and cost-aware ant routing (SC)

In this approach, the performance of the forward ants is increased with sensors to sense the best direction that the ants will go initially. In addition to storing the probability distribution, each node estimates and saves the cost to the destination from each of its neighbors (Zhang et al., 2004).

Flooded forward ant routing (FF)

The approach is based on flooding of the ants to the route packets' destination. In case destination is unknown at the beginning, or in case the cost cannot be estimated, ants continually explore the area. This approach uses broadcasting functionality in wireless sensor networks (Zhang et al., 2004).

Flooded piggybacked ant routing (FP)

Flooding in wireless network is complex, dynamic and a highly distributed task. FP approach brings a new ant species to forward ants namely data ants carrying the forward list. In contrast, control of the flooded forward ants are treated same as in FF for flooded data ants (Zhang et al., 2004). Comparisons of these three algorithms to 'antnet' are done in 'pursuer and evader' application.

Ant colony optimization-based location-aware routing (ACLR)

ACLR is developed by Xiaoming Wang in 2008 as a new communication protocol (Wang et al. 2008) for WSNs called colony optimization-based location-aware routing (ACLR), which is based on the ant colony optimization (ACO) (Tilak et al., 2002).

The logic behind the algorithm is as follows: an ant selects its next-hop to a subset of the set of node's neighbors, instead of its whole neighbors which guarantees that the data packets are delivered toward the sink node avoiding the loops. Algorithm proposes a formula to estimate transition probability with which ants select their next hop nodes. In order to determine the amount of the pheromone deposited by an ant, algorithm uses a model and also proposes a novel scheme to evaporate the pheromone on the different segments of a certain route according to the residual energy and the location information of nodes, so that it increases the diversity of the solutions found by ants.

Comparisons between basic ant routing (BAR), sensor-driven cost-aware ant routing (SCAR), flooded piggybacked ant routing (FPAR) and IAR are performed in OPNET modeler.

T-ANT

T-ANT is developed by S. Selvakennedy in 2006 and adopts two-phase clustering process involving the cluster setup and steady state phases. T-ANT uses two methods: variance estimation and clustering methods (Selvakennedy et al., 2006). In clustering method, a CH election ant is deployed. In case of node initialization, sink deploys a number of ants (that is, control messages). As such, ants can trespass the network limited to its time-to-live (TTL) value. When an ant arrives at a node, the next node is randomly chosen hence routing is probabilistic. Comparisons with TCCA and m-LEACH are done in a discrete event simulator.

Ant-chain

Ant-chain is developed in 2005 (Ding and Liu, 2005) and is focused on energy efficiency, data integrity and the node's life time parameters.

Ant colony optimization is in the form of a chain. As such, the chain data are broadcasted for wireless sensor nodes' routing. Three different chain schemes are supported for different states of WSNs data gathering: the bi-direction ant-chain which is self-adaptive in small topology changes, the simple uni-direction ant-chain which is developed for limited data gathering rounds and the query chain which is used to collect data from the node in focus. After obtaining chain type and information, node runs independently for data gathering. Simulation experiments including comparisons to Pegasis and Leach are performed in ns-2 network simulator.

QAAB

QAAB routing algorithm is developed in 2006 based on GAF protocol (Sun et al., 2006). In this approach, virtual grids are formed using node's positions obtained by GPS system (Figure 3). After creation regions by GPS, a rational network is built by which any communication can be performed.

The self organization of the nodes in the same region is based on several rules. There are five types of the total nodes such as source node (event), destination node (sink), queen ant node (interface node with Internet), principal node (monitor or agent of a group) and normal member node. Comparison with SPIN algorithm is performed in GloMoSim 2.0 network simulator.

MADFT

MADFT is developed by Juan et al. (2007) using ACO (ant colony optimization) to solve any cast network problem. As such, it is a sensational sink selection algorithm.

Same ways are applied to other ACO based algorithms, in that MADFT assigns ants to source nodes. Then the resultant route is formed by one of the ants from other ants search close to the previous discovered route's point. MADFT uses probabilistic routing, calculated from pheromones and costs, in order to find the minimum total cost path. Hence, the algorithm is based on several rules that ants follow. These rules are defined in Juan et al. (2007). Simulation experiments are done in comparison with CNS and GIT. Thus, simulator is written in C++.

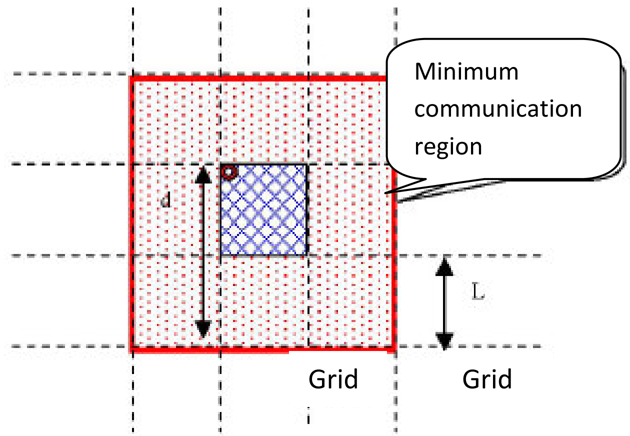

Figure 3. Splitting the region into several grids.

Ant-0, Ant-1 and Ant-2

To solve the data aggregation tree problem, algorithms are developed by Liao et al. (2007). The approach emphasizes the data aggregation which is important in energy constraint wireless sensor networks. To do this, it is important to reduce the number of messages exchanged between intermediate nodes in the network. The study proposes the solution about the problem of constructing data aggregation tree in a wireless sensor network for a group of source nodes to send sensory data to a single node. Swarm intelligence system allows the exploration of search space in determining data aggregation. Ants will search for possible paths from the source to the sink node. In this approach, low-latency paths are built between sources and sink nodes. Then, data aggregation tree is constructed by the accumulated pheromone. For example, in Figure 4, there is no data aggregation between Source 1, 2 and sink. Aggregation node G can be discovered and two routing paths can be established in the case of the two paths' search regions that could be extended individually. These two paths are shown with dashed lines in Figure 4. Simulation

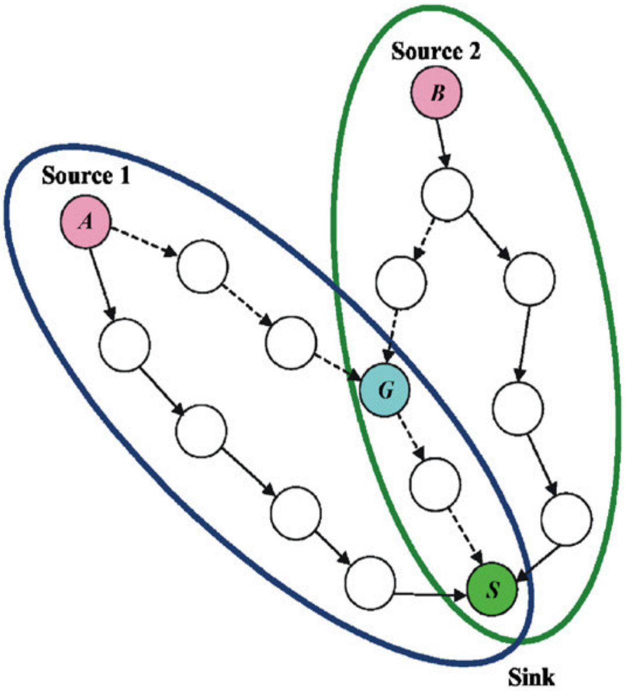

Figure 4. The aggregation node identification process (Liao et al., 2007).

experiments, including DD and GIT comparisons and results have shown that algorithm can reduce significant energy costs.

E and D ants

This approach is developed to minimize the time delay in transferring a fixed number of data packets for the sake of the energy constrained (Wen et al., 2008). In this study, a novel EnergyxDelay model based on ant algorithms is proposed and called “E and D ants” for short. The lifetime maximization of the network and real-time data transmission services are the main features of the developed algorithm. E and D ants algorithm is compared to other ant-based routing algorithms like ‘ant-net and ant-chain’ about the issues of routing information, routing overhead and adaptation, and as such, simulation experiments are done in OPNET. Results show that E and D ants algorithm outperforms ant-net and ant-chain about seven times better.

A self-optimized multipath routing protocol

This approach is focused on parameters such as energy level, delay and velocity which are considered in this study (Saleem et al., 2009). These parameters are optimally configured and routes are organized for WSNs.

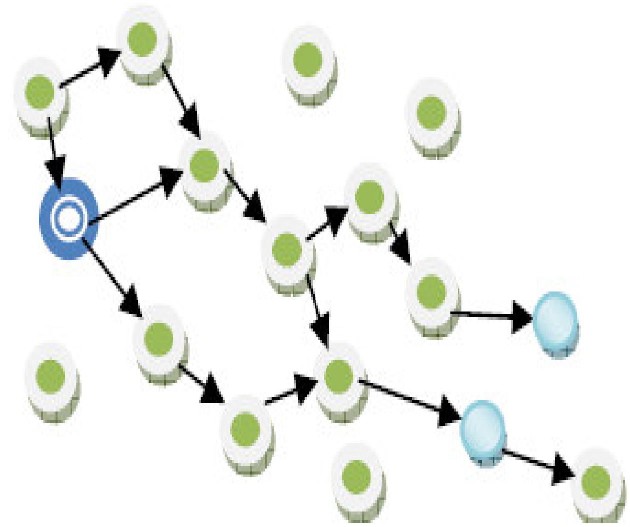

Figure 5. Approach can support single path and multipath routing (Saleem et al., 2009).

The developed approach has multipath capability to avoid congestion in WSNs, resulting in maximizing the data throughput rate and minimizing the data loss. Simulation experiments are performed in ns-2 network simulator. In Figure 5, both single-path and multi-path routings are shown.

Ant colony

This approach is focused on energy balance, end to end latency and network lifetime issue by taking less hop numbers into consideration and choosing the nodes with less pheromone as the next hop. Energy balance is an important performance characteristic in wireless sensor networks (Wang and Lin, 2008).

Presented experiments show that this approach is better than the directed diffusion routing protocol both in end-to-end delay and global energy balance and can effectively balance the global energy consumption and prolong the network lifetime. Comparison experiments with DD are performed in JiST/SWANS network simulator.

AR and IAR

AR and IAR are developed by GhasemAghaei et al. (2007) as a biologically-inspired swarm intelligence-based routing algorithm, which is suitable for sensor networks. The developed ant routing algorithm also meet the enhanced sensor network requirements, including energy consumption, success rate, and time delay. Comparisons are made with SC-Ant, FF-Ant, FP-Ant and ant-net in Java-based simulation environment.

Routing in wireless sensor networks using an ant colony optimization (ACO) router chip

A novel routing approach using an ant colony optimization algorithm is proposed by Ökdem and Karaboğa (2009) for wireless sensor networks consisting of stable nodes. Solution phases are handled in four phases.

First, node fragments the packet into several parts in order to send data to different paths. To confirm data delivery, it uses acknowledgement messages. In case of lack of acknowledgement message, that packet is re-sent on a different path.

Secondly, nodes' battery life is also considered in routing. The nodes having greater energy level are more preferable so that the average network life is increased.

Thirdly, a new routing mechanism is developed based on ants.

Lastly, network remains survivable even if nodes are highly mobile. Stages are established and the data transmission is done using these stages. The developed approach is also embedded to a small sized hardware component called a router chip. Tests are done in MATLAB parallel discrete event based platform and comparisons are performed with EEABR.

Bee colony based routing protocols

These protocols are inspired from honeybees foraging behaviors. The routing in computer networks has several resemblances with honeybees (Farooq, 2009). Honeybees in particular have mechanisms for WSNs such as self organization and division of labor. There are a few routing protocols for WSNs, inspired from bees.

Bee-sensor

Saleem and Farooq (2007) implemented bee-hive routing protocol for wireless sensor networks which is developed originally for wired networks (Paone et al., 2009). Bee-hive is developed by inspiration of scout-recruit system of honeybees (Karaboga and Akay, 2009).

Developed by Saleem and Farooq, bee-sensor is an algorithm based on the foraging principles of honey bees with an on-demand route discovery (AODV). Approach has three types of bee agents. These are packers, scouts and foragers bees. Packers locate appropriate foragers for the data packets at the source node, while scouts are responsible for discovering the path to a new destination. Foragers have a major function carrying the data packets to a sink node.

This approach is based on the interactions of scouts and source routing by which small forwarding tables are built during the return of a scout. Comparison experiments are performed with FP-Ant, EEABR and AODV in ns-2.

Slime mold based routing protocols

Slime mold term is used for heterotrophic organism regarded as a fungus and is unicellular. There is a strong resemblance between such unicellular organisms, colonies such as ants and wireless sensor networks. As already mentioned before, a wireless sensor network can be viewed as a "colony" of sensor nodes. These nodes are simple, with limited capacity and scarce resources, and can react autonomously. As such, they are able to perform simple tasks (GhasemAghaei et al., 2007). Nonetheless, there are some works based on the slime mold behaviors.

A multi-sink swarm-based routing protocol for wireless sensor networks

Paone et al. (2009) proposed a routing protocol for wireless sensor networks. Self organization, fault tolerance and environmental adaptation are demanding properties for WSNs, and social colonies have these mechanisms. The protocol is inspired by slime mold organisms. These organisms can organize themselves in clusters via pheromone generation and evaporation functions. Similarly, the developed algorithm organizes data traffic towards multiple sink nodes using gradient concept and shows autonomy and fault tolerance. The proposed protocol is examined in OMNET++ network simulator for performances, while the signaling overhead and the adaptation properties to environmental changes or nodes faults are examined using simulation techniques. In Figure 6, phases are shown in signal processing manner.

COMPARISON OF THE ROUTING ALGORITMS

Here, routing algorithms are compared in terms of energy efficiency, scalability, data gathering, network lifetime, fault tolerance, packet delivery latency, success rates and used simulator characteristics. Table 1 shows the results.

CONCLUSIONS

Together with emergence of WSN networks, new routing approaches are required since networks are highly dynamic and distributed. When the literature was investigated, it was obviously seen that routing protocols for WSNs were implementations from wired networks. The researches done have shown that swarm intelligence based routing protocols can remove at least one or several problems in the area such as battery life, scalability, maintainability, survivability, adaptability and

Table 1. Comparison of routing protocols.

Routing protocols	Energy efficiency	Scalability	Data gathering	Network lifetime	Fault tolerance	Packet delivery latency	Success rates	Simulator	Swarm based
T-ANT	Strong	Strong	Very strong	Strong	Weak	Weak	Weak	A discrete-event simulator	ACO
Ant-chain	Strong	Weak	Strong	Very strong	Weak	Weak	Weak	NS2	ACO
QAAB	Very strong	Weak	Weak	Strong	Weak	Weak	Weak	Glomosim 2.0	ACO
Paone et al.	Strong	Weak	Weak	Weak	Very strong	Weak	Weak	Omnet++	Slime mold
ACLR	Very strong	Weak	Weak	Weak	Weak	Strong	Weak	Opnet	ACO
MADFT	Strong	Weak	Weak	Weak	Weak	Weak	Weak	C++	ACO
Ant-0, Ant-1 and Ant-2	Very strong	Weak	Very strong	Weak	Weak	Weak	Weak		ACO
E and D ants	Strong	Weak	Weak	Weak	Weak	Strong	Weak	Opnet	ACO
K. Saleem	Strong	Weak	Weak	Weak	Weak	Strong	Weak	NS2	ACO
SC-Ant	Very strong	Weak	Weak	Weak	Weak	Weak	Weak	The Pursuer Evader Game (Peg)	ACO
FF-Ant	Weak	Weak	Weak	Weak	Weak	Very strong	Weak	The Pursuer Evader Game (Peg)	ACO
FP-Ant	Weak	Weak	Weak	Weak	Strong	Weak	Very strong	The Pursuer Evader Game (Peg)	ACO
Ant colony	Strong	Weak	Weak	Strong	Weak	Strong	Weak	Jist/SWANS	ACO
Okdem et al.	Strong	Weak	Weak	Weak	Weak	Weak	Weak	Matlab	ACO
AR, IAR	Strong	Weak	Weak	Weak	Weak	Very strong	Very strong	Java-based simulation	ACO
EEABR	Very strong	Weak	Weak	Strong	Strong	Weak	Weak	NS2	ACO
Beesensor	Very strong	Weak	Weak	Strong	Strong	Very strong	Weak	NS2	Bee colony

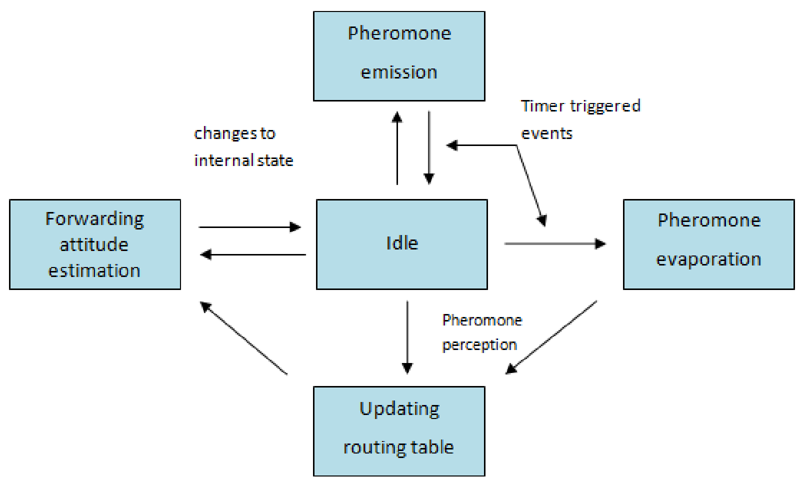

Figure 6. Signaling process phases (Paone et al., 2009).

so on. As such, ant based approaches are attracted by much researchers than other approaches.

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