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Routing Protocols for Wireless Sensor Networks Based on Swarm Intelligence: A Review

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Abstract--- In the last few decades, wireless sensor networks have attracted many researchers towards it. One of the main areas of researchers is evolving routing protocols for wireless sensor networks. Routing protocol based on Swarm intelligence is a subcategory of routing protocols. It is relatively an innovative field. This approach analyse the behaviour of many components which makes a system and these components communicate with each other in decentralized manner and also are self-organized. Their natural system inspires them and these protocols show the properties of being robust, ascendable, and adaptive. These three properties are the key properties in term of network routing, and mainly routing in wireless sensor networks. Because of this, in the last few decades, swarm intelligence based protocols have been developed particularly which are influenced from the exploring behaviour of ant colonies. In this paper, a survey of swarm intelligence based routing protocols for wireless sensor network is presented.

Keywords--- Wireless sensor networks (WSNs), Swarm Intelligence (SI), Energy Efficiency, Routing, Ant colony optimization (ACO).

I. INTRODUCTION

A wireless sensor network (WSN) commonly contains numerous low power, low cost, and multifunctional sensor nodes that are deployed in a region of interest. These sensor nodes are very tiny and are furnished with sensors, radio transceivers and embedded microprocessors. Sensor nodes are used to monitor many physical parameters or conditions for example light, sound, humility, pressure, temperature etc. Sensor nodes are furnished with a battery which provides it energy. Later analog to digital convertor which converts the signal sensed by the node. After that micro-controlling processor process the signal. There is a memory to store the data which is sensed by the sensor node and then the signal is transferred with the help of radio to the base station. These wireless sensor nodes are generally known as motes. They are deployed in a large area and are capable to interact with the environment. These motes can be static or they can be mobile. The mobility of nodes depends on the need of the application for which the network is created. WSNs have wide range of applications. Some of them are habitat monitoring, health care, vehicle tracking system, building surveillance and many more. In WSNs, from the point of view of the processing of information, data aggregation and then use it for statistical inference can be conceived in a number of ways that results in to different network architectures. In [1] compressed sensing (CS) technique is applied to compress the data. The problem of minimum energy compressed data aggregation (MECDA) is described and then its time complexity is calculated which comes out to be NP complete. Then two solution techniques are also given to find the optimal and near optimal aggregation trees. Simulation results show that by applying CS to the network for data aggregation results in prominent improvement in energy efficiency.

Reference [2] proposes Velocity Energy-efficient and Link-aware Cluster-Tree (VELCT) scheme for data collection in WSNs which implements cluster scheme with the help of data collection nodes. This scheme effectively reduces the problem of coverage distance, mobility, delay, traffic, tree intensity and end to end connection. In this the data collection tree is created and the data collector node doesn't participate in sensing the data. These nodes only collect the data which is sensed by the nodes from the cluster head and then send it to sink node.

In WSNs, routing protocols are required as in mobile ad hoc networks (MANETs). But in WSNs more emphasis is on energy efficiency and also nodes are usually static and the network is comparatively larger than MANETs. WSNs are usually data centric while MANETs are address-centric.

There are so many routing protocols which are proposed for WSNs based on energy efficiency, optimization, etc. But in this paper we are discussing routing protocols which are based on swarm intelligence based system. This is a sub-category of routing protocols. It is inspired from the behaviour of various biological species and the intelligence of various insects. In this paper we will discuss some prominent protocols.

Swarm intelligence (SI) ([3], [4], [5]) is a relatively innovative field that was generally defined as any try to construct algorithms or distributed problem-solving devices influenced by the joint behaviour of social insects and other animal societies [3]. In SI we study the joint behaviour of multi-component system which are self-organized and communicate in fragmented manner. Swarm intelligence is basically a type of artificial intelligence which is based on the joint behaviour that is made up of a population of simple agents communicating locally with one another and with their conditions. Although there is no centralized control as mentioned earlier, the agents communicates locally by some simple methods with other agents that results in a global pattern to emerge. The systems can be seen in nature, including glow-worm

swarm, bird flocking, ant colonies etc. And among them ant colony is of great importance. The same process has also motivated the evolution routing algorithms which are based on SI for WSNs. In fact, the exploring behaviours of ant colonies, and also of bee colonies inspire the design of most of these algorithms. The main principle trailing this fact lies in the examination that in actual the routing problem is solved by these insect societies, as a joint unit. They need to establish and discover paths that can be used by the other insects to adequately proceed backward and forward from their habitat to find sources of food. These ants usually explore and then find their paths with the help of the communications among a large number of relatively simple ones that finds sample paths and inform others about their characteristics using a variety of communication schemes, including direct communication (e.g., waggle dance in bees) and indirect communication (e.g., pheromone-mediate communication in ants). The exploring behaviours of these insect colonies are robust to losses of individuals, fully distributed, expandable and adaptive to environmental variations.

A. Ant colony and general principal of ACO for routing.

Basic working is explained by following steps:-

1) In the ant colony system, a colony of artificial ants is used to formulate solutions govern by the pheromone trails and doubtful information.
2) Motivation behind ant colony system is the exploring behaviour of real ants.
3) This behaviour facilitates ants to find the shortest paths between food sources and their habitat.
4) Initially, ants search the area which surrounds their habitat in a random manner. As soon as an ant finds a source of food, it ranks the quantity and quality of the food and carries some of it to the nest.
5) During the return trip, the ant deposits a pheromone trail on the ground based on the ranking of food.
6) The quantity of deposited pheromone will guide the other ants to the food source.
7) The indirect conversation between the ants via the pheromone trails allows them to find the shortest path between their habitat and the food sources.
8) This performance of real ant colonies is accomplished in artificial ant colonies in order to solve problems.
9) In the ant colony system, the pheromone trails are simulated via a parameterized probabilistic model called the pheromone model.

Survey paper [6] provides various routing protocols based on swarm intelligence and also the taxonomy of routing protocols explained below:-

B. Taxonomy of routing protocols

Authors of ([7] [8]) classified the protocols in four categories which are Data-centric, Location based, Hierarchical, Network and QoS-aware protocols. In Data-centric, sink node sends the queries to the regions from where it needs the data and then the sensor nodes located at that region sends the sensed data to the sink. Data centric uses aggregation of data in transferring of data. The various coding techniques are also used to minimize the data bits. In Location based some protocols needs location information of sensor nodes. The information about the respective location of the sensor nodes is needed so as to calculate distance between them. By implementing this technique the number of transmissions can be reduced which ultimately leads to power consumption. In Hierarchical, sensor nodes arrange themselves in groups also known as clusters. Cluster head is elected from each cluster. And they forward the sensed data of the sensor nodes of their respective clusters to the sink node. Reference [9] extends this classification which is described below:-

1) Single path and multipath routing: Routing protocols can be single path or multi path. In single path, all possible paths or only one path may be explored and at the end only one i.e. best path is chosen. But in case of multipath information about multipath is stored in the routing table and is used when the primary path fails.

2) Reactive, Proactive and hybrid routing: In reactive routing sensor node sense and sends the data whenever it receives a query from the sink node. In proactive routing data is send periodically by the sensor nodes. Hybrid uses both. Generally proactive scheme is energy consuming.

3) Source and next hop routing: In the source routing, source node itself mention the path information with the packet. Intermediate nodes have to check the next hop and then forward the data to the mentioned one. In [10] next hop routing data packet contains information about only the destination node and at each intermediate node packet is transferred according to the local routing table of that node. Source node routing prevents loop problem.

4) Flat and Hierarchical Routing: In flat routing all the nodes are viewed at a single level. Data can be transferred between any two arbitrary pairs while in hierarchical routing nodes are divided into clusters and cluster head is selected for each cluster and also the cluster heads can be a part of another cluster. Every node forwards the data to its cluster head. Cluster head forwards the data to that node with the help of another cluster head.

5) Data-Centric and Address Centric: In [11] data centric every node need not to have a unique identity. This scheme is applies only when it is not feasible to assign unique id to all node. This scheme is also known as content centric. In address centric routing, unique id is required. In this routing scheme, source node knows to whom it is sending the data. Here, receiver node's ID is necessary whereas in data centric main concern is on data.

6) Best Effort and QoS Aware Routing: Protocols that don't provide any guarantee in terms of the quality e.g. delay, delay jitter, packet losses etc are called as best effort. Whereas routing protocols which provide these types of services are called as QoS aware routing protocols.

7) Distributed and Centralized Routing Protocols: In centralized approach, all the route maintenance and discovery maintained by sink node or base station. This approach is a single point failure. But in distributed route maintenance and discovery is maintained by the nodes itself. This scheme is more robust to failures.

8) Event-Driven and Query Based Routing: In event driven, data is send when any event is occurred e.g. if temperature rises from a particular value then information is send. Whereas in query based data is send by the nodes in response to the specific query send by the destination.

9) Fault tolerance: Packets may be lost in the path due to many reasons like node failure, loops etc. Protocols which are robust to these changes are termed as fault tolerant protocols. Multipath is a technique that may be used to provide fault tolerance.

10) Energy aware routing: As we know that sensor nodes are equipped with limited amount of energy. It is very important to utilize the energy of the sensor nodes very efficiently. The protocols which consider the residual energy in selection of next node are called as energy aware routing protocols.

II. LITERATURE SURVEY

In [12] sensor nodes arrange themselves in groups which are generally known as clusters. Then a node is elected as a cluster head (CH). CHs are selected from each cluster and the sensor nodes pass the data to the CH of their respective clusters. In this way the information is forwarded in this. Disadvantage of [12] is that CH's deplete their energy faster than other nodes which results in unbalanced energy consumption. Because CH's have to pass the sensed data collected from every sensor node in its cluster to the sink node. To solve the disadvantage [12], authors of proposed an algorithm [13]. In this residual energy is also considered in selection of CH's.CH rotation takes place in it. This means same sensor nodes are not elected as CH's again and again. This leads to balanced energy exhaustion of the sensor nodes in the network. Most [14] of the energy of sensor nodes is exhausted in upholding the event packets of other sensor nodes to a BS. So, they deplete their energy soon not just because they sense data and forward it, also they forward the data of other sensor nodes. The solution for this is the deployment of mobile data collectors (DC) in the network. They can move anywhere in the network and then collect the sensed data from the sensor nodes and pass them to the sink or base station. Their only purpose is to forward the sensed data. These mobile data collectors also aggregate the data and sometimes itself act as a base station. The important aspect is reliability. Data packets should reach with reliability to the base station. This ([13], [15]) discuss the reliability constraint in terms of multiple paths. Same data packets are sending by multiple paths instead of taking single one. References ([16], [17]) discuss in terms of multiple copies. In this multiple copies are sent by single path or multiple paths to achieve reliability. This [7] is a survey paper in which classical and swarm intelligent based protocols are compared on basis of various parameters. According to this swarm intelligent based protocols are also very good in increasing lifetime of the network. A survey paper [18] which compares swarm intelligence based protocols based on different parameters like load balancing, fault tolerant, energy aware etc. In paper [6] coverage is the priority. Some applications need full coverage. In this the sensor node deployment scheme is given which tells how to deploy the sensor nodes to achieve the full coverage. The purposed scheme helps in achieving the full coverage and also enhances the network lifetime.

Data aggregation is very important concept. It saves the energy and hence increases network lifetime. In [19], authors have proposed a scheme according to which data is aggregated at every intermediate node to reduce the number of messages which flows in the network. In this, this is done with the help of ant colony optimization. Ants explore all the possible ways from source node to sink node and construct data aggregation tree with the help of pheromones. The amount of pheromones is sufficiently large to guide the ants.

Here are some protocols which depend on swarm intelligence:

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

In [20] authors proposed that ants have initial estimate in terms of number of hops as in the same way as biological ants have capability of smelling the food at the beginning of the routing process so that ant will approach the smell in order to find the path. Also each node has the probability distribution and it stores the estimated values of the cost from its each neighbour to the destination. However, this may mislead the ant due to presence of any obstacle.

B. Flooded forward ant routing (FF)

According to [20] protocol ants are flooded in the network in search of the path. This is done whenever there is no estimation is present initially (SC). In that case SC becomes a basic ant algorithm. That's why flooding of ants is done in the network. If the search is successful then the forwarded ants releases the backward ants and the updates the routing tables of each ant. This method is preferable when particular destination is not known.

C. Flooded piggyback ant routing (FP)

Reference [20] includes FP which brings a new ant species to forward ant's names as data ants. These ants are also carrying data with them. These are flooded in the same manner as in FF, the only difference is this that they also carry data with them so that in the discovery of the path data can also be delivered to the destination. Energy is utilized efficiently in this way. Backward ants do the same work as in FF and that path is used whenever data has to be send again.

D. Energy efficient ant based routing (EEABR)

Reference [21] describes EEABR which is another technique which is based on ant colony optimization metaheuristic. In this technique ants carry the id of the previous node from where it comes. Every intermediate node stores the id of the previous node, ant id and set the timer. Whenever it receives any forward ant then it looks in its table. If it finds the ant id

with same previous node then the loop is detected and it doesn't forward that ant. If loop is not detected then it forwards it. If destination is found then backward ants are generated.

E. Bee Sensor

In [22] authors proposed a technique named as Bee Sensor. This technique is energy efficient, scalable and increases network lifetime. In this three additional agents are present apart from forward and backward ants named as packers, foragers and swarms.

Packers receive data from the upper layer, foragers used to transfer the data to sink node and swarms bring back foragers from sink node to source node. This technique is reactive, event-driven and uses multipath scheme.

F. Ant Chain

Ant Chain, proposed by Ding and Xiaoping Liu [23] is energy efficient and its aim is to increase the network lifetime with help of data integrity. In this with help of ACO optimal bi-directional chain is achieved. According to this technique sensor node can be in one of the four states: sleeping, idle, receiving, or transmitting. In route setup phase, sink node sends the setup message to all the nodes and the nodes which are active at that time reply with their location and id. Then the sink node with the help of certain algorithm solves this TSP problem and identifies a near optimal chain. The chain information is broadcasted into the network. Then the node which is at the head of the chain picks the data from the source node and then transfers it to tail node in the chain which in turn sends to the base station.

G. Ant-based service-aware routing protocol (ASAR)

ASAR, proposed by Sun et al. is a QoS aware routing protocol and is efficient for multimedia applications. In these two different operating modes having different QoS requirements are proposed by the authors of [24].

First one is query driven mode which includes two services D-service which is data service and S-service which is stream service's-service is not tolerant to errors but tolerant to delay. D-service has opposite QoS requirements.

Second one is event-driven mode which includes R-service. R-service is strictly reliable and also tolerant to delays.

H. Self-organizing data gathering for multi-sink sensor networks (SDG)

Kiri et al. [25] proposed a cluster-based data gathering scheme named as SDG mainly focused on reliability and scalability in WSN's. In this scheme sink node generates agents called as backward ants on proactive basis and send to each node in the network. Then the sensor node stores the id of sink node. In this multiple sink nodes are considered. If one fails then another one can act as a sink node.

I. Jumping ant routing algorithm (JARA)

JARA, proposed by [26] is combination of reactive and proactive schemes. It speeds up the discovery of route and also reduces the overhead in route discovery process. It assumes that every node has its own zone and inside its zone it knows the path to every node in the same zone so it focuses on inter-zone communication which is done by ACO. It combines the advantages of zone routing protocol (ZRP) and ant routing algorithm for mobile ad-hoc networks (ARAMA).

J. ACO-based quality-of-service routing (ACO-QoSR)

ACO-QoSR, proposed by cai et al. [27] is a reactive protocol focuses both on energy efficiency as well as delay. It focuses on finding the path with the help of ACO so that delay is less than some bounded value D and also the residual energy of the path must be above from some residual value. Whenever any node wants to send data it firstly looks into its routing table. If it finds the appropriate path then it sends the data otherwise route discovery process is initiated.

K. Ant aggregation (Ant agg.)

Ant aggregation proposed by Mirsa and Mandel in 2006 [28], argues the fact that if the multihop communication combines with inbuilt aggregation method then it can significantly increases the network lifetime. In this the ants helps in making an aggregation tree which is a NP-hard problem. Ant's tries to find the closest path to the destination or it finds the path to the nearest aggregation node or terminates.

L. Pheromone based energy aware Directed Diffusion (PEADD)

PEADD is a variant of direct diffusion and is proposed by Zhu [29]. In this the paths with higher residual energy levels is selected again. Pheromone level is higher on that path which has higher residual energy. The algorithm uses same process each time node wants to send the data.

M. Probabilistic, Zonal and Swarm-inspired system for Wildfire Detection (PZSWiD)

Ramachandran et al. [30] have proposed PZSWiD which is ACO inspired cluster based algorithm. It performs two functions. First function is to send the response if sink queries. Second is to send the data in emergency or if any event happens. For example, an emergency event can be triggered when temperature rises from a certain value.

N. Many-to-One Improved Ant Routing (MO-IAR)

MO-IAR, introduced by Ghasemaghaei et al. [31], works in two phases. In first phase route discovery happens with the help of forward and backward ants then in second phase actual data is send. In data sending phase congestion control

techniques are employed to avoid congestion. In this every node knows the location of every other sensor node and also of sink node. Whenever a new node comes in the network it broadcasts HELLO message in the network to tell its id and location to other nodes.

O. Energy-delay ant-based routing (E-D ANTS)

E-D ANTS proposed by Wen et al. [32] focuses on reducing the delay in data packets. In these ants discovers the path and maintains a stack of residual energy level and also of delay experienced by them in discovering the path or hop to hop movement. Simulation results show that they help in increasing the network lifetime.

P. Data aggregation ant colony algorithm (DAACA)

In DAACA proposed by Chi et al. [33], energy efficiency is focus for the enhancement of network lifetime. In this a family of protocols which are data aggregation and ant colony based are proposed. They are called as data aggregation ant colony based algorithms (DAACA). The main emphasis is on energy efficiency. This algorithm works in three phases which are initialization, packet transmission and operation on pheromones. In initialization phase routing table of every sensor node is randomly initialized then in packet transmission phase data is transferred and then operation on pheromones is done.

Q. Elitist Strategy based DAACA (ES-DAACA)

In [33] Chi et al. improves the DAACA by introducing one more factor MP_{cost} in calculating the value of pheromones. This factor calculates the cost from source node to that current node.

R. Maximum & Minimum based DAACA (MM-DAACA)

This is further an improved version given by Chi et al. in [33]. In this the value of pheromones is limited by the lower and upper value. If pheromones are not limited in the range then some paths own higher probabilities than others. To eliminate this range is necessary.

S. Ant Colony System Based DAACA (ACS-DAACA)

In [33] Chi et al. introduces ant colony system in data aggregation algorithm. Probability of selection of unselected sensor nodes can be increased by local pheromone updating technique. Also ACS-DAACA will generate more aggregation paths as compared to MM-DAACA and therefore global optimal solution is more likely to achieve.

T. Bee-Sensor-C

Bee-Sensor-C [34] is an improved version of Bee-Sensor. This protocol is multipath, reactive and event driven. Bee-Sensor-C is hierarchical unlike Bee-Sensor. This protocol uses clustering scheme to transfer data. Bee-Sensor-C works in three stages named as cluster formation, multipath construction and then transmitting the data. In first stage when any event is detected then the sensor nodes which are involved in sensing the event forms a cluster. In this an extra agent is present called as HiveHeader. HiveHeader's major responsibility is to claim if any sensor node wants to be CH. CH is chosen on the basis of first declaration. Sensor node which declares in the beginning becomes CH. In second stage multipath are constructed in better way than Bee-Sensor. Then in third stage data is transmitted. Simulation results show that this protocol provides efficient results in terms of energy efficiency.

U. Particle Swarm Optimization Protocol for Hierarchical Clustering in Wireless Sensor Networks (PSO-HC)

Clustering topology is very efficient for scalability in the network and also in maximizing the network lifetime. In protocol [35] energy efficiency is achieved by minimizing the active CHs at same time. This protocol sends the data in rounds and each round consists of two phases. These two phases are named as set-up phase and steady-state phase. In setup phase every sensor node broadcasts its ID and residual energy with hello packets. In this way neighbour table is updated by every sensor node. In steady-state phase every sensor node is allotted time slot for sending the data. Every sensor node is allowed to send the data in allotted time slot only. After that the sensor node enters in sleep state to save the energy.

V. Two-tier particle swarm optimization protocol for clustering and routing in wireless sensor network (TPSO-CR)

In [36] authors propose a protocol which increase the packet delivery rate, consumes energy efficiently and also increase the network coverage. In this protocol firstly CHs are elected on the basis of coverage and residual energy. After selecting CHs a tree is created which connects these CHs to the base station. After that, setup phase starts. In this phase every sensor node broadcasts its ID, residual energy and its neighbour routing table to sink node. Then base station configures the network and then broadcasts the packet containing network configuration. Then time slots are allotted to every sensor node and every sensor node transmits the data in allotted time only.

III. COMPARATIVE ANALYSIS OF ROUTING PROTOCOLS BASED ON SWARM INTELLIGENCE.

In this section the comparative analysis of routing protocols based on SI is presented. Table 1 represents the analysis of various routing protocols based on swarm intelligence.

Table 1. Comparative analysis of routing protocols based on SI.

Routing protocols		Characteristics									
		Single (SP) or multipath (MP).	Reactive (RE), proactive (PR) or Hybrid (HY).	Source (S) or next hop (NH).	Flat (FL) or hierarchical (HC).	Data-centric (D) and address centric (A).	Best effort (BE) and QoS aware (QoS).	Distributed (DB) and centralized (CE).	Event-driven (ED), query based (Q), periodic (P)	Fault tolerate (Y/N).	Energy aware (Y/N).
1.	SC[20]	MP	HY	NH, S	FL	A	BE	DB	ED	Y	N
2.	FF[20]	MP	HY	NH, S	FL	A	BE	DB	ED	Y	N
3.	FP[20]	MP	HY	NH, S	FL	A	BE	DB	ED	Y	N
4.	EEABR [21]	MP	PR	NH	FL	A	BE	DB	ED	Y	Y
5.	Bee Sensor [22]	MP	RE	NH	FL	A	BE	DB	ED	Y	Y
6.	ASAR [24]	MP	PR	NH, S	HC	A	QoS	DB	ED	Y	Y
7.	Ant Chain [23]	SP	RE	NH	HC	A	BE	CE	Q	N	N
8.	SDG [25]	MP	PR	NH	HC	A	BE	DB	ED	Y	Y
9.	ACO-QoSR [27]	MP	RE	NH, S	FL	A	QoS	DB	ED	Y	Y
10.	JARA [26]	SP	HY	NH, S	HC	A	BE	DB	ED	N	N
11.	PEADD [29]	MP	RE	NH	FL	D	BE	DB	Q	Y	Y
12.	Ant-agg. [28]	MP	PR	NH, S	FL	A	BE	DB	ED	N	N
13.	MO-IAR [31]	MP	PR	NH, S	FL	A	BE	DB	ED	Y	N
14.	PZSWiD [30]	SP	RE	NH	HC	D	BE	DB	ED,Q	Y	Y
15.	E-D ANTS [32]	MP	RE	NH, S	FL	A	QoS	DB	ED	Y	Y
16.	DAACA [33]	SP	PR	NH	FL	A	BE	DB	P	Y	Y
17.	ES-DAACA [33]	SP	PR	NH	FL	A	BE	DB	P	Y	Y
18.	MM-DAACA [33]	SP	PR	NH	FL	A	BE	DB	P	Y	Y
19.	ACS-DAACA	SP	PR	NH	FL	A	BE	DB	P	Y	Y
20.	Bee-Sensor-C [34]	MP	RE	NH	HC	A	BE	DB	ED	Y	Y
21.	PSO-HC [35]	SP	PR	NH	HC	A	BE	DB	P	N	Y
22.	TPSO-CR [36]	SP	PR	NH	HC	A	BE	CE	P	N	Y

IV. CONCLUSION

Swarm intelligence based routing protocols is very effective technology in wireless sensor networks. In this survey, we have reviewed routing protocols based on swarm intelligence used in wireless sensor networks and how they can be applied for finding the optimal route to send the data in wireless networks. These approaches mainly focus on data aggregation and thus increases network lifetime by using energy efficiently. A detailed comparison of these routing protocols based on characteristics like single path/multipath, source/next hop, flat/hierarchical, Data centric/address centric, best effort/QoS aware, distributed/centralized, event driven/query based, fault tolerant, energy aware and type of protocol is also presented.

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