Ant Inspired Routing Protocols for Wireless Sensor Networks

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Abstract- **The massive deployment of wireless sensor network (WSN) is expected to increase exponentially in all sectors of our society. Sensor networks are used in wide range of applications but finding optimal path routing is more difficult and challenging due to scalability, decentralization, resource scarcity, heterogeneity and dynamicity. Nowadays their main area of concern is based on routing protocols utilizing the concept of natural-inspired shortest path algorithm realized using Ant colony optimization (ACO). Due to the ability of ants to observe changes in networks through pheromone in order to find the optimal path routing based on swarm intelligence. In this paper, to study various efficient ant inspired routing protocols for specific scenarios to achieve particular objectives in sensor network and after that their comparison is made based on a number of aspects like energy efficiency, network lifespan, dynamic topologies, fault tolerance, data reliability and success rate.**

Keywords**-** Wireless sensor networks, swarm intelligence, ant colony optimization, optimal path routing

I. INTRODUCTION

A WSN is composed of huge low power intelligent sensors and high power sink and is typically employed in a wide spectrum of applications are remote environmental monitoring, surveillance for safety and security alert, earthquake observations, intelligent building control and object tracking [1]. Sensor networks normally operate in decentralized and distributed manner in which sensors have the capability of self-healing and self-configuration.Wireless sensors are composed of sensors, transceiver, battery and the processor for performing local processing. These sensors are capable of sensing at least one phenomenon in the environment [2]. It is tightly constrained with limited energy, memory storage, analytical and computational ability and also have low data rate as well as short range for wireless radio transmission. These tasks of sensor cause to generate a vast amount of information. The sensor has to forward this information to sink. The reporting between sensor and sink consumes energy based on the type of communication protocol, communication path and number of hops between sensor and sink. This requires finding out optimal path between sensor to sink which will be useful in efficiently forwarding data, reducing power consumption and communication overhead in sensor network [3]. In sensor networks, minimization of end-to-end delay and energy consumption is considered to be a major performance criterion, in order to provide maximum reliability and network lifetime.

II. RELATEDWORK

A.Swarm Intelligence

Swarm intelligence (SI) [4] is a relatively novel field that was originally defined as ‘‘Any attempt to design algorithms or distributed problem-solving devices inspired by the collective behavior of social insects and other animal societies”. However, nowadays SI refers more generally to the study of the collective behavior of multi-component systems that coordinate using decentralized controls and self-organization. Based on SI can be an effective approach to deal with the optimal path detection. The SI framework encompasses other popular frameworks such as Particle Swarm Optimization(PSO), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC) and etc.,

B.Ant Colony Optimization

Ant Colony Optimization (ACO) is a SI based optimization technique which is applied for solving various combinatorial optimization problems effectively and efficiently [5]. ACO is inspired from the ant behavior by use stigmergy in successfully detecting the shortest path between the anthill and the food sources.

These real life ants walking to and from a food source, deposit a volatile chemical substance called pheromone which establishes the shortest path for other members of colony to be followed [6]. While moving, ants emit pheromone over the ground and follow the path with maximum pheromone concentration. This mechanism has been proved to be an optimum way to mark paths which guide other ants and generate optimum paths from the overall behavior of the ant colony [7]. This behavior of ants has been successfully mapped in electronic devices for solving various combinatorial problems. It includes asynchronous agents or ants that produce partial solutions of the problem while traversing through different phases of the problem. While traversing, these agents follow greedy local decision policies which rely over two parameters, namely, attractiveness and trail information. Each ant while traversing through different phases of the problem incrementally produces partial solution to the problem. Search of the future ants are directed by the trail value which is updated by the ants which earlier traversed through the same path. Furthermore, an ACO algorithm involves two mechanisms which enhance the capabilities of the algorithm which are trail evaporation and daemon actions. Trail evaporation decreases the trail values overtime to abstain unlimited accumulation of trail over a specific component. Daemon actions are used to implement the centralized actions or the actions which cannot be performed by a single ant, such as update of global information [8].

In dynamic system, the ant colony algorithm works in graphs with different topologies. A graph G is a pair G = (V, E), where V consists of two nodes, namely v_s representing the anthill and v_d representing the food source. Furthermore, E consists of two links, namely e_1 and e_2, between v_s and v_d. To e_1, to assign a length of l_1 and e_2 a length of l_2 such that $l_2 > l_1$, that is e_1 represents the short path and e_2 represents the long path between v_s and v_d[9].

To introduce an artificial pheromone value τ_i for each of the two edges e_i, i = 1, 2. Such a value indicates the strength of the pheromone trail on the corresponding path. Each ant, starting from anthill (v_s), an ant chooses with probability between path e_1 and e_2 for reaching the food source (v_d). Obviously, if $\tau_1>\tau_2$, the probability of choosing e_1 is higher and vice versa. For returning from v_d to v_s, an ant uses the same way and it changes the artificial pheromone value τ_i associated to the used path as in equation (1).

$$\tau_i = \tau_i + \frac{Q}{l_i} \tag{1}$$

where Q is a positive constant parameter of the model. In other words, the amount of artificial pheromone that is added depends on the length of the chosen path (shorter path). Ants deposit pheromone on the paths on which they move. Thus, the chemical pheromone trails are modeled as in equation (2)

$$p_i = \frac{\tau_i}{\tau_1+\tau_2} \quad where\ i = 1, 2 \tag{2}$$

In nature the deposited pheromone is subject to evaporation over time. Moreover, ACO deals with a process in which decreasing in amount of pheromone deposited on every path b**y** the time is known as *trail pheromone evaporation*. To simulate this pheromone evaporation in the artificial model using equation (3)

$$\tau_i = (1 - p).\tau_i \tag{3}$$

where i = 1, 2 and the parameter *p* ε (0, 1] that regulates the pheromone evaporation. Finally, all ants conduct their return trip and reinforce their chosen path.

In ACO, ants are stochastic constructive procedures that build optimal solutions while walking on a construction graph. Such constructive search behavior makes ACO suitable for solving shortest path optimization problems [10]. Besides, ACO utilizes search experiences represented by pheromone and domain knowledge represented by heuristic information to accelerate the search process.In their journey from source to sink, ants move from node i to a neighboring node j with a transition probability P_{ij}, defined using the equation (4)

$$P_{ij}^{k}(t) = \frac{[\tau_{ij}^{\alpha}][\eta_{ij}^{\beta}]}{\sum_{l \varepsilon N_i^k}[\tau_{il}^{\alpha}][\eta_{il}^{\beta}]} \quad (4)$$

where $P_{ij}^{k}(t)$ is the probability of ant k to move from node i to node j, τ_{ij} is the pheromone value deposited on the link (i, j), η_{ij} is a heuristic value assigned to the link and α, β are weights used to control the importance given to the pheromone and the heuristic values respectively. Here $N_l(k)$ is the list of neighbors of node i visited by ant k. The pheromone value τ_{ij} on a given link depends on the likelihood that the ants pass by the link while constructing the solutions. On the other hand, the heuristic value η_{ij},depends on the calculated cost of the link. The initial pheromone value is usually set to be equal for all links. The heuristic value of the link (i,j) is the inverse of the link cost C_{ij}.

In ACO algorithm, there are many parameters such as the number of ants n, the weights α and β and evaporation rate ρ. These parameters are set at the beginning of the algorithm. The cost of each link in the network is calculated based on the cost function and fed back to the ant colony system. Every iteration, solutions are constructed by artificial ants, pheromones are updated and the best path is chosen. The pseudo code is presented in Figure 1.

```
Procedure ACO ( )
{
Input n, α, β, ρ
set ant colony configuration
set initial pheromone value and heuristic value
get ant colony optimization system based on the calculated cost matrix
i = 1
while ( i <= n)
{           r =1
            while ( r <= i)
            {
                        Reset ants
                        Construct ants' solutions
                        Apply local search
                        Update best path for i
                        Update pheromones
                        r = r +1
            }
            Choose best path for i
            i = i + 1
}
}
```

Figure 1. ACO pseudo code

III. ROUTING IN WSN USING ACO

In the last few decades many research work have been conducted by the researchers in the field of routing protocols for WSN [11]. To find shortest communication path between sensor and sink is the backbone to the routing techniques in WSN. Routing in WSN is more challenging due to the following constrains like dynamically changing network topology, communication links, mobility, failure of sensors and etc. These requirements and challenges cannot be fulfilled by classical routing protocols for sensor network. Primary routing goals of WSNs are to extend network life, prevent linking errors, data reliability and etc. As such, these routing approaches emerged as soft computing based techniques. Recently nature inspired algorithms have been explored as means of finding an efficient solution to this routing problem such as ACO [12]. ACO is a technique used for solving complex computational problems, such as finding optimal routes in networks and trying to deal with these constrains. It can help us in dynamically changing environment for setting communication paths in WSN and having characteristic like achieving global optimization through local interaction and high degree of self-organization [13].

ACO is iterative algorithm, a number of artificial ants are generated at each time and build a solution to the considered optimization problem and exchange the quality information of these solutions via communication scheme. A distributed heuristic solution like ACO routing algorithm shows many features that makes it particularly suitable for wireless sensor network:

- Algorithm is fully distributed that mean there is no single point of failure.
- The operations done in every node are simple.
- Autonomous interaction of ants, and the algorithm based on agents' synchronous.
- It is self-organizing, thus robust and fault tolerant. There is no need to define path recovery algorithm.
- Intrinsically adapts to traffic without requiring complex, and yet inflexible metrics.
- It inherently adapts to all kinds of variations in topology and traffic demand, which are difficult to be taken into account by deterministic approaches.

IV. ACO BASED ROUTING PROTOCOL FOR WSN

The ACO technique has been successfully applied to take optimal routing decisions in WSN. ACO based routing algorithm is creating artificial ants/agents in the form of data packets which are moving around in the network from one node to the other (peer to peer), updating routing tables (called pheromone table) of the nodes that they visit with what they have learned in their traversal so far. Afterwards agents selecting optimal shortest communication path from updated pheromone table. As a result, many routing techniques based on such algorithms are discussed below in the current literature.

A.Basic Ant Based Routing (BABR) for Wireless Sensor Network

Agents which are considered as ants are deployed by the source and these ants iteratively traverse through different phases of the solution and produce the partial solution to the problem. For traversing through these phases, these ants use the probabilistic approach for selection of particular route which in turn depends on the heuristic and the pheromone information. This process is repeated until the termination condition is achieved.

BABR algorithm can be described as follows

- A forward ant is generated at regular intervals from each network node with an aim to find the optimum path from the node to the destination at regular intervals.
- Each forward ant tries to reach position of the sink with equal probability by using neighboring nodes with minimum cost joining its source and sink.
- At each intermediate node a greedy stochastic policy is applied to choose the next node towards its destination.
- During the movement, the agents collect information about node identifiers, delay time and congestion status of the followed path.
- Once destination is reached, a backward ant is created which takes the same path as the forward ant, but in an opposite direction.
- During this backward travel, local models of the network status and the routing table of each visited node are modified by the agents.
- Once they have returned to their source, the agents are died.

B. Sensor Driven and Cost-Aware Ant Routing (SC)

In this approach, the performance of the forward ants equipped with sensors can smell the food and sense the most appropriate direction that the ant will go initially. In addition estimated cost of path to destination from each neighboring node and their respective probability distribution is stored by each node. This algorithm is energy efficient but (suffer from) delivered low success rate of packet and also produce misleading solutions due to obstacle or loss of visibility of the node, which proves to be biggest disadvantage of this algorithm.

C. Flooded Forward Ant Routing (FF)

FF is based on flooding of forward ants from source to sink and strongly contends that even the ants having sensors might get mislead due to loss of visibility of nodes or obstacles. There exists a situation when the sink is not known to the ants or the cost of the path cannot be estimated. In this situation a problem of wandering around the network to find the destination has occurred. Here, two methods are used to restrict the flooding process. First, an intermediate node rebroadcasts a duplicationdata packet of a forward ant and neighbor node estimates which is closer to the destination than the node it has received the ant from. Second, neighbor node waits for a random amount of time before forwarding the ant to the next hop. If, in the meantime, it receives the broadcast of the same duplication of a forward ant from one of its neighbors, the node simply drops it. FF solves this problem by using the broadcast method for routing the data packets with shorter time delays; however, the algorithm creates a significant amount of traffic.

D. Flooded Piggyback Ant Routing (FP)

Ying Zhange et alproposed the above three ant based routing algorithms for WSN [14]. FP defines a new type of ant called *data ant* which carries the forward list, whereas basic functioning of the forward ant is same as FF. FP minimizes the energy dissipation of the network while sending data packets to the destination. Data ants perform the dual task of forwarding the data along with storing the node identity which come across the path to the destination which can be later used by the backward ants. The flooding mechanism is significantly helpful in wireless networks, especially in sensor networks, where the probability of a packet loss is substantially higher compared to that of fixed networks. Despite high success rate shown by the FP algorithm but it is not energy efficient.

E.ACO-Based Quality-of-Service Routing (ACO-QoSR).

The authors Wenyu et al proposed a reactive algorithm, named ACO-QoSR uses the QoS metrics for both end to end delay and the maximum energy efficient in WSN [15]. In ACO-QoSR, whenever any sensor wishes to send data it firstly checks its routing table. If there is an appropriate path exist in its routing table then it sends the data otherwise to find a new route by initiating route discovery procedure. The routing process achieved through three phases: forward ant phase, backward ant phase and maintenance phase. In first phase, forward ants are unicast and select one neighbor node as the next hop according to the probability value which depends on the pheromone and heuristic values of the link. The heuristic information η_{ij} on the link is defined in equation (5) as the ratio between the residual energy of current node and the summary residual energy of all the neighbor nodes.

$$n_{ij} = \frac{E_{residual}(j)}{\sum_{k \epsilon N_i(k)} E_{residual}(k)} \quad (5)$$

ACO-QoSR performance has been compared with AODV and DSDV proves to be better on higher packet delivery, reduce the selected path’s delay and improve normalized energy residual ratio at the similar levels of routing overhead.

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

MO-IAR was established by Ghasemaghaei et al. is a two-phase algorithm. The first phase establishes the shortest path and the second phase provides the procedure for actual data routing. For minimizing the packet loss, proactive congestion control mechanism is adopted by the second phase.

G. Ant Chain

Ant Chain is proposed by Ding and Xiaoping Liu in 2005 and is focused on energy efficiency, data integrity and the node’s life time parameters [16]. Ant Chain is a centralized algorithm which partitions the responsibilities of sensors and the sink according to their hardware resources and relative distances with an objective of energy optimization and minimizing the transmission delay. In AntChain, identities the sensors along with their respective locations are known in advance. The sink exploits location information to calculate a near-optimal chain organization for the nodes, which is then used for efficient data transmission. Ant Chain assumes that each sensor can directly reach every other node in the network and can directly communicate with the sink. A node can be in one of the four states: sleeping, idle, receiving, or transmitting. This information is used for efficient transmission of data. AntChain is proved to be a better algorithm in comparison to its counter par*ts* LEACH and PEGASIS on the grounds of energy efficiency.

H. Energy and Delay ant-based routing protocol (E & D Ants)

The dynamic adaptive E & D Ants algorithm provides real-time data delivery service by finding a shortest path with minimum energy and delay product. This algorithm routes the packets through optimal and energy efficient paths and also avoids congested paths. Their main goal is to maintain maximization of the network lifetime and real-time data transmission services in minimum delay time by using a novel variation of reinforcement learning. Simulation results show that E & D Ant algorithm outperforms AntNet and AntChain about seven times between about the issues of routing information, routing overhead and adaptation.

V. Comparison Analysis of Ant Inspired Routing Protocols for WSN

In this paper, several ant inspired routing protocols for sensor network were investigated and compared in Table I. This table shows the comparison of various routing protocols discussed above based on some criteria such as energy efficiency, data aggregation, location awareness, route selection, and either being query based or not.

Table I. Comparison of Ant Inspired Routing Protocols for WSN

Routing Protocol	BABR	SC	FF	FP	ACO-QoSR	MO-IAR	AntChain	E&D Ants
Energy Efficiency	Weak	Strong	Weak	Weak	Strong	Moderate	Strong	Strong
Data Gathering	No	No	No	No	No	No	Yes	No
Location awareness	No	No	No	No	No	No	Yes	Yes
Route Selection	Proactive	Hybrid	Hybrid	Hybrid	Reactive	Proactive	Reactive	Reactive
Query based	No	No	No	No	No	No	Yes	Yes

VI. Conclusion

WSN consist of large sets of resource-constrained sensors. The design of effective, robust and scalable routing protocols in these networks is a challenging task. On the other hand, the relatively novel domain of swarm intelligence offers algorithmic design principles, inspired by complex adaptive biological systems that well match the constraints and the challenges of WSNs. Therefore, a number of routing protocols for WSNs have been developed in the last years based on SI principles and more specifically, taking inspiration from foraging behaviors of antcolonies. The researches done have shown that ant ACO based routing protocols can solve several problems in the area such as battery life, scalability, maintainability, minimizing delay, maximize reliability and so on. As such, ant based approaches are attracted by much researchers than other approaches.

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