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iACO: A Bio-inspired Power Efficient Routing Scheme for Sensor Networks

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Abstract— **An efficient and effective routing scheme plays an important role in improving the network throughput of Wireless Sensor Networks (WSNs) under the major constraint of power consumption. This paper proposes an energy efficient routing algorithm inspired from nature colonial scheme, its implementation and validation are also described in this paper. Details of the algorithm and its testing procedures are included. The proposed model is validated through simulations, demonstrating the network performance measurements such as delay, throughput and packet loss have been improved as a promising outcome.**

Keywords- Wireless Sensor Networks (WSNs), Biologically Inspired System, Ant Colony Optimisation (ACO), Swarm Intelligence (SW)

I. Introduction

Wireless Sensor Networks (WSNs) have drawn considerable attention recently in network research community [1-2], [14-15]. It potentially enlists our daily life with such characteristics as pervasive computing, ubiquitous communication and monitoring, which enables to establish on-demand interactions with data devices, services and applications without spacial and time limitations. Portable wireless communication devices, microprocessors as well as communication protocols and wireless techniques such as WiMAX, Wireless Mesh Networks make the desired above functions of WSNs possible. Specifically, WSNs consist of a number of sensor devices, which are normally inexpensive, portable, having communication and limited computational power.

The sensors are interconnected to each other via the network grid. Routing schemes play an important role in maintaining efficient data communications across this network grid. Specifically, routing algorithms are required to consider the constraints of sensors such as limited energy supply, limited computational power. There are a number of routing protocols that have been proposed so far, such as Low Energy Adaptive Clustering Hierarchy (LEACH), Data-centric SPIN and Direct diffusion. LEACH relies heavily on the regular routing structure, which cannot flexibly adapt to changeable network environment. While the Direct diffusion does not build up a regular routing structure and SPIN even does not maintain a structural hierarchy at all, even no state information. These protocols cannot satisfy the practical requirements with these disadvantages under various circumstances. In fact, two major aspects that a routing scheme should consider are (1) energy efficiency and (2) self-healing. As such, a self-governed bio-inspired routing scheme is proposed in this paper. This algorithm is designed to solve the packet routing problem with minimal energy consumption for each hop communication and aims to maximise the lifetime of nodes in the network. Meanwhile, the new self-healing algorithm well reduce the possibility of node failures and satisfy the need for various levels of dynamic packets routing when routing decisions can be made locally at each node.

The remainder of the paper is organised as follows: Section II reviews the background of the new bio-inspired scheme initiated by the swarm behavior. Section III presents the new routing algorithm details including algorithmic steps, and its implementation details. Simulation results of the new algorithm are presented in Section IV. As a validation experiment, the performance analysis shows the efficiency of our proposed routing scheme that potentially to small sized networks in WSNs. Finally, we emphasises the contribution of this paper and future work

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II. Proposed Ant Colony Biological Model

A. *Proposed iACO Algorithm*

We apply the metaphor of ant food foraging behavior into network routing system. As stated in the literature, ant colony optimization metaheuristic (ACO) was first systematically introduced by Dorigo in 1992 in his PhD dissertation [6]. ACO is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs. They are inspired by the behavior of ants in finding paths from the colony to food. The early attempts of biological researches on ants were conducted by Dorigo and Gambardella [7] for routing in wired and wireless mobile environments.

In addition, Stutzle and Hoos proposed MAX-MIN ant system, namely MMAS, it is an improvement version of ACO. MMAS differs from standard ACO in that (i) only the best ant adds pheromone trails, and (ii) the minimum and maximum values of the pheromone are explicitly limited [8]. Agassounon [9], [10] proposed interesting work based on ACO to solve information retrieval and resource allocation issues. A good review of available ACO basis, models and new trends can be found in Oscar's work [11].

ACO algorithms can be applied to find the near-optimal multihop routing path in mobile ad hoc networks, namely AntHocNet, the experimental results indicate AntHocNet algorithm outperforms the other popular Ad hoc On-Demand Distance Vector Routing (AODV) algorithm in terms of *end-to-end delay* and *delivery* ratio. Related problems such as load-balance and routing in computer networks are also investigated in the work by Hsiao et. al, by use of ACO [12]. In sum, performance comparisons between ACO-based algorithm and other routing algorithm show better performance by use of ACO metaheuristics.

The most important feature of ACO metaheuristic is inspired from the *stigmergy,* which mimics the indirect communication behaviors adopted by social insects. The proposed algorithm, called iACO, especially for WSNs, each packet are regarded as an individual ant, communicating with each other via "pheromone" values stored in each wireless sensor node's pheromone table.

As shown in Figure 1, three main steps are included in the flowchat of the proposed iACO algorithms for the routing scheme of WSNs. In brief, the steps include (1) Generate local solutions based on the path (i,j) selection probability; (2) Pheromone update; (3) Decision making.

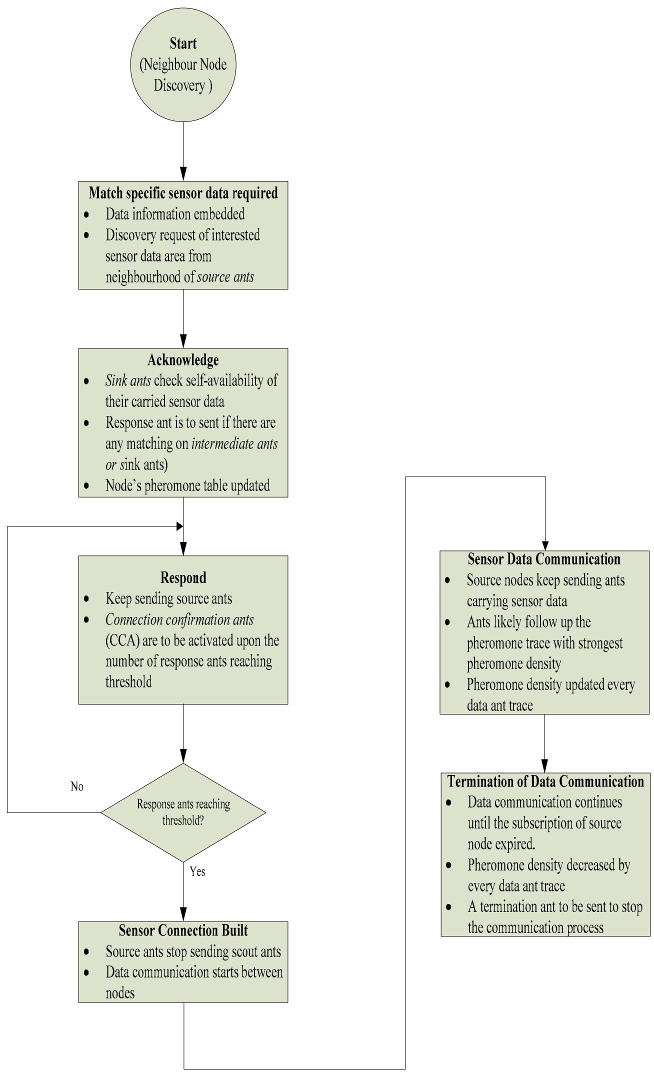

Figure 1. iACO Algorithm

III. ROUTING ALGORITHM IN WSNs

Suppose the ant is randomly placed on node i , the probability of an ant k choosing the next adjacent node j is as depicted in Equation 1. And the pheromone table helps to choose the next neighbor in the process.

$$P_{ij} = \begin{cases} \dfrac{[\tau(i,j)]^{\alpha} \cdot [\eta(j)]^{\beta}}{\sum_{u \notin M_k} [\tau(i,j)]^{\alpha} \cdot [\eta(j)]^{\beta}} & if\ j \notin M_k \\ 0 & \text{otherwise} \end{cases} \qquad (1)$$

where P_{ij} = probability of packet going from node i to j,

τ (i,j) = pheromone level in the table of node i for node j,

η (j) = energy level of node j,

M_k = identifier of every visited node,

α = parameter that denotes pheromone level,

β = parameter that denotes energy level heuristics.

Two categories of ants are in use, they are termed as forward ants and backward ants. We adopted this concept from the relating work of ant algorithm routing such as T-ant, antNet [2] and EEABR [3]. We further develop the definitions as used in the literature. The forward ants are defined as the ants that are sent from the source. The forward ants will carry the information such as (1) the required sensor type, (2) the sensor region of interest, (3) the data rate and (4) the time period of the interest. More details can be seen in table I where both categories of ants are described in functions.

A. Parameters and variables formatted in the packet of the experiment are described here in Table I. The header and data are carried by each packet. The packet is sent from source node, taking the form as backward and forward ants.

TABLE I. USE OF PACKET (FORWARD AND BACKWARD ANTS)

Forward Ant Dispatched from Data Source	
Name	*Description*
	Header
source	Node name or address of where ants go from
destination	Node name or address of where the ant was sent
antType	Forward
antID	Floating point data variable, unique to each ant
	Data
sensorType	Sensor Type of Source Node
location	Location co-ordinates of Source Node
sensValue	The data value taken from the source node sensors
Hop	The number of nodes which the ant has traversed
timestamp	Timestamp of when the forward ant was created

Backwards Ant Dispatched from Data Source	
Name	*Description*
	Header
source	Node name or address of where ants go from
destination	Node name or address of where the ant was sent
antType	Backwards
antID	Floating point data variable, same as the forward ant which it transformed from
	Data
sensorType	Sensor Type of Source Node
location	Location co-ordinates of Source Node
sensValue	The data value taken from the source node sensors
Hop	The number of nodes it took for the forward ant to reach data source
ΔT	The amount which the pheromone levels should be increased by
timestamp	Timestamp of when the backward ant was created

B. Pheromone table: presents semantics required for pheromone trail and neighbour nodes as listed in Table II.

TABLE II. SEMANTIC STRUCTURE OF PHEROMONS TABLE

Pheromone Table	
Name	*Description*
neighbour i	Address/Unique ID of Neighbour i
neighbourLocation i	Location of Neighbour i (Coordinates)
pherLevel i	Pheromone Level of Neighbour i
neighbour j	Address/Unique ID of Neighbour j
neighbourLocation j	Location of Neighbour j (Coordinates)
pheromoneLevel j	Pheromone Level of Neighbour j
neighbour n	Address/Unique ID of Neighbour n
neighbourLocation n	Location of Neighbour n (Coordinates)
pherLevel n	Pheromone Level of Neighbour n

C. Description of Data Structures in C++ syntax

In this section, we describe how the pheromone table, ant table and multi-hop counters are described in C++ syntax as below.

```
1. Pheromone Table for Traces

Typedef unordered_map<unsigned short,
Double > PheromoneTable;

2. Ant Table for Nodes

Struct AntType   // Structor of Ant Node Table
{
Double antID;
Unsigned short previousNode;
Unsigned short nextNode;
};
Typedef unordered_map<unsigned short, …>AntNodeTable

3. Multi-hop Ant Searching Mode
Typedef unordered_map<unsigned short,
Unsigned short>multiHopSearching;
```

Figure 2. Syntax Description of Data Structure in Use

D. Pheromone Update:

Pheromone plays an important role in searching for a suitable node. In our algorithm, only the pheromone along our successfully recorded paths (usually more than one) is intensified, instead, pheromone in those incomplete paths evaporates. The pheromone increases and reductions will influence the searching process in next iteration. We adopt the conventional ACO pheromone update rule as:

Intensify pheromone: an absolute amount of pheromone $\Delta\tau_{i,\ j}^{k} > 0$ is added to the existing pheromone values on the paths completed by k -th ant

$$\Delta\tau_{i,\ j}^{k} = \begin{cases} \frac{Q}{Z_{\min(k)}} if \ (i,\ j) \in T_k \\ 0 \qquad if \notin T_k \end{cases} \tag{2}$$

Where T_k are the paths having been traversed by k -th ant. Q is a constant. More research on Q value have been done in Dorigo [6].

- Evaporate pheromone: pheromone on the edges of incomplete traversing paths is reduced in order to minimize the chances of being selected by other ants.

$$\tau_{i,\ j} = (1-\rho)\times\tau_{i,\ j} \qquad \forall i,\ \ j \in [1:52] \tag{3}$$

where $\rho \in [0,\ \ 1)$ is the pheromone evaporation rate. $\tau_{i,\ j}$ is the current pheromone density on the trail $a(i,\ \ j)$.

Mutate pheromone update process: In order to increase the convergence speed of the algorithm, we combine the *mutation* parameter into our pheromone update rules, where the concept of *threshold* is also involved. The mutation parameter in our algorithm is partly based on *Best-worst Ant Colony Algorithm* (BWACA) as well as *Max-min* Ant system.

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IV. EXPERIMENT

A. Simulation Platform and Configuration Parameters

The simulation is conducted on the platform called Castalia network simulator [5]. Being a specially designed network simulator, Castalia contains models for realistic wireless channels, MAC layers, radio, physical sensor and resource management. Moreover, it contains modules that can simulate the different functionality and behaviours of wireless sensors and hence is regarded as a good simulation of the real behaviour in the research society for WSNs [4].

The most commonly used algorithm for routing label witched Paths (LSPs) is the min-hop algorithm [13] The nature of this algorithm has been adopted by many routing protocols. Therefore, it is reasonable to compare our proposed algorithm with min-hop algorithm.

To evaluate two algorithms, the same metrics are to be applied. We define the following parameter metrics are in use in the simulation.

1) *Energy consumption*
2) *Delay*
3) *Throughput*

The following mathematical equations quantitize and measure these metrics.

Energy Consumption is measured as depicted in Eqn 1:

$$\text{Energy Consumption} = \frac{\left(\frac{\text{Total Energy}}{\text{Number of Nodes}}\right) - \text{Idle Energy per node}}{\text{Number of packets received}} \qquad \text{(Eqn 1)}$$

Delay is measured and obtained by calculating the difference of timestamps of the packet from the sending to receiving as described in Equation 2.

$$\text{Delay} = \text{TimeRecieved} - \text{TimeSent} \qquad \text{(Eqn 2)}$$

Throughput measures the quantities of packets that were sent against the quantities of packets that were received by the sink node as described in Equation 3.

$$\text{Throughput} = \frac{\text{Packets sent by source}}{\text{Packets received by sink}} \qquad \text{(Eqn 3)}$$

With regards to these metrics, Figure 4 and 5 depict the comparison view of *energy consumption* and *delay* exhibited by various node density levels. As shown, the small number of nodes would not make a signicant impact on the energy consumption and delays. When the interactive nodes increasing till 145, an energy peak occurs, and new routing algorithm proposed in iACO consumes less 1/3 energy than min-hop algorithm though the similar curve trend is observed. For the larger network, this difference tends to be more significant.

As shown in Figure 4, the impacts of delays for algorithms are trivial, though the iACO routing produces a slightly less delays than the min-hop.

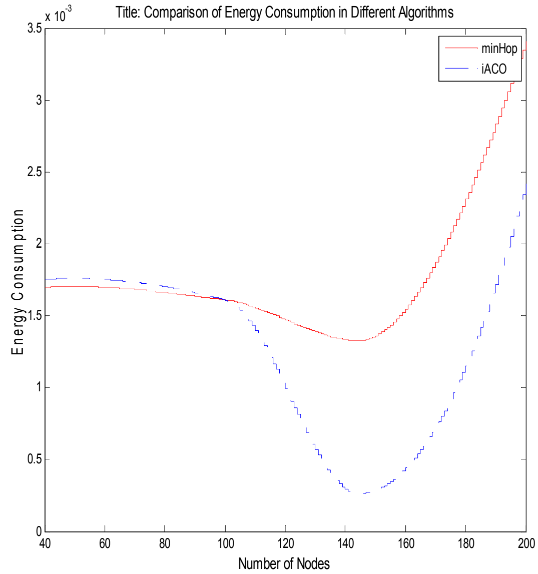

Figure 3. Comparison of Energy Consumption of Ant Population Levels

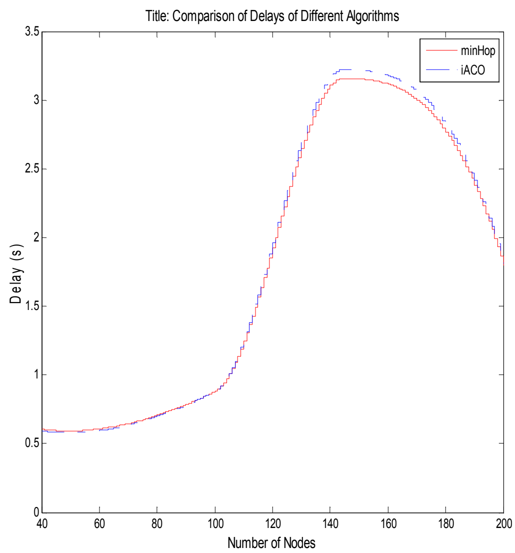

Figure 4. Comparison of Delays between Two Algorithms

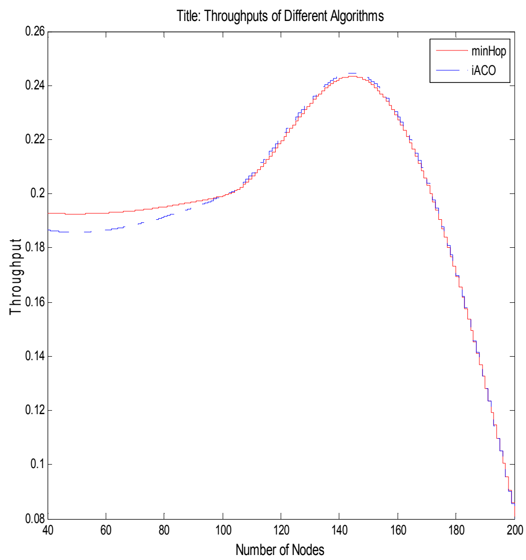

Figure 5. Comparison of Throughputs between Two Algorithms

With regards to the throughput, as shown in Figure 5, when the number of nodes increase till 145, there are not much differences between min-hop algorithm and iACO algorithm. The experience data and literature prove it is difficult for the traditional ACO achieve the marginal performance as min-hop routing scheme. The proposed iACO demonstrated the similar performance in this regard, so it can be regarded as a good improvement.

Figure 5, 6 and 7 shows the impacts of various node densities towards energy consumption, delays and throughput. It is shown there is an obvious effect on the efficiency of various node densities, but it seems not a linear relationship. There is a few optimal node densities at which the lowest energy consumption is observed. Similarly, it comes to the delay in Figure 7 and throughput in Figure 8. Specifically, the density is 0.005 when the minimum delay occurs, but the maximum delay occurs when the density is 0.1. This is also the case for throughput.

In particular, the minimum energy consumption, maximum throughput and minimum delay appears to start occurrance when the network has 50 nodes. The current good results are well compliance with the expected network size less than 100.

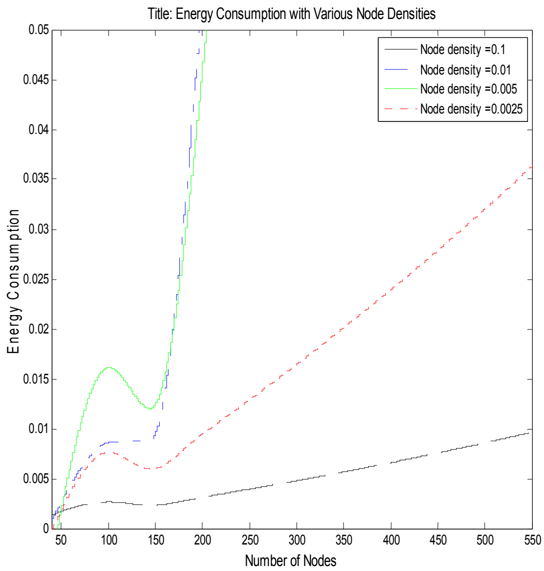

Figure 6. Energy Consumption with Various Node Densities

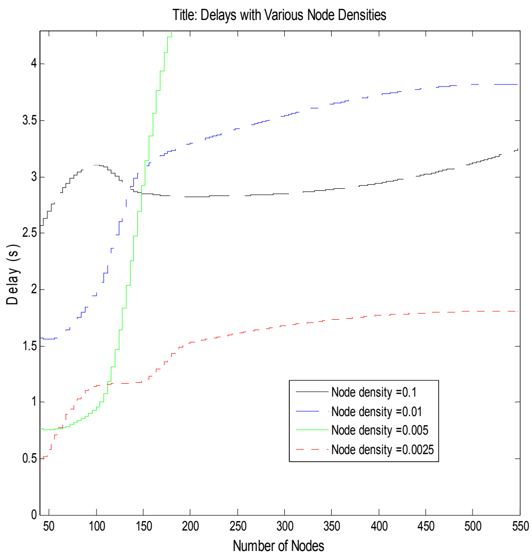

Figure 7. Delays with Various Node Densities

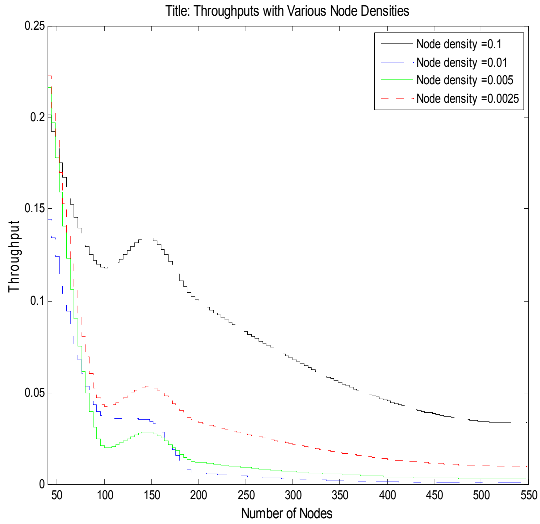

Figure 8. Throughputs with Various Node Densities

V. Conclusion and Future Work

In this paper, a reliable, nature-inspired routing algorithm called *iACO* for sensor networks is presented. The algorithm is partly based on the efficient *Max-Min* algorithm and it is suitable for flexible structure of wireless sensor networks. This new routing scheme performs generally not worse than other standard routing algorithm, and in some occasions, it outperforms than min-hop algorithm. More work in the future includes conducting more performance comparison work with other sensor network routing algorithms, and identify, validate the best parameters configurations for the proposed algorithm under various network environment to guide real productive practices in the networking industry.

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