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*Research Article*

# Energy Aware Simple Ant Routing Algorithm for Wireless Sensor Networks

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Network lifetime is one of the most prominent barriers in deploying wireless sensor networks for large-scale applications because these networks employ sensors with nonrenewable scarce energy resources. Sensor nodes dissipate most of their energy in complex routing mechanisms. To cope with limited energy problem, we present EASARA, an energy aware simple ant routing algorithm based on ant colony optimization. Unlike most algorithms, EASARA strives to avoid low energy routes and optimizes the routing process through selection of least hop count path with more energy. It consists of three phases, that is, route discovery, forwarding node, and route selection. We have improved the route discovery procedure and mainly concentrate on energy efficient forwarding node and route selection, so that the network lifetime can be prolonged. The four possible cases of forwarding node and route selection are presented. The performance of EASARA is validated through simulation. Simulation results demonstrate the performance supremacy of EASARA over contemporary scheme in terms of various metrics.

## 1. Introduction

Wireless sensor networks (WSNs) are captivating growing attention because of their merit and aptness for autonomous and unattended monitoring in large-scale applications. Examples of such applications range from terrestrial to aquatic, from earth to cosmic, from agriculture to jungle, and from home and offices to international borders [1]. Most of these applications require deployment of thousands of low-cost battery-operated tiny sensors which are expected to stay operational for a longer period. Despite considerable advancements in different aspects [2–4], network lifetime, as yet, is one of the most prominent barriers in deploying WSNs for large-scale applications because sensor nodes dissipate most of their energy in complex routing mechanisms.

Routing has been widely investigated in the context of mobile ad hoc network (MANET); however, due to unique characteristics, it is still a challenging issue in WSNs [5]. Most of the existing routing protocols either employ conventional [6–8] or nonconventional approaches [9–11]. Nonconventional approaches are based on natural systems such as bioinspired computing that is the focus of this work. In bioinspired computing, ant colony optimization (ACO) has been widely used to develop metaheuristic algorithms for combinatorial optimization problems such as asymmetric travelling salesman [12], graph coloring problem [13], and vehicle routing problem [14]. Metaheuristic algorithms such as tabu search [15], simulated annealing [16], iterative local search [17], evolutionary computation [18], and ant colony optimization [19] provide computational methods for heuristic optimization of a problem. These algorithms must be customized according to the application to find the optimal solution. For example, authors in [20] have advocated the adoption of ACO for MANETs. WSNs share some common characteristics with MANET (e.g., infrastructure less and dynamic topology); however, differences such as high node density and severe energy constraints [21] instigated us to investigate adoption of ACO for WSNs.

In dynamic changing conditions, routing in WSNs aims to deliver data from sensors to the sink in reliable and energy efficient manner. The focus is on finding the optimal path between source and destination. In our previous work [22], we have developed an analogy between foraging behavior of ants and routing process in WSNs. Routing can be handled with the help of ACO utilizing the information of neighbor discovery, routing and data transmission, and route maintenance. ACO mimics the real ant colony's foraging behavior to address the combinatorial optimization problem of finding the best path on a weighted graph. The resulting shortest route mapping determined by the artificial ants can be applied to the optimization problem of energy aware routing. Indirect communication used by social insects to coordinate their activities is called stigmergy, directing towards pheromone deposition. By exploiting the stigmergy approach (responds to new and modifies the existing environment), a number of successful algorithms in such diverse application fields of combinatorial optimization are introduced for routing in communication networks. Initially, ant agents (packet) move by following a random decision based on link and node position. Routing table is updated based on the stochastic decisions made for pheromone deposition after they reached the sink/destination node, and their decision is based on sampling the complete paths. Proactive path is selected by the ant agents so that it could affect the topology change of the nodes in a sensor network and similarly the routing. Reactive paths are then used once the routing table is updated for optimal routing of the shortest path. The resulting optimal route can be determined by the ant agents to obtain a solution of the optimization. Forward ants maintain memory of each visited node while moving towards the sink thus avoiding loops formation. The ant's internal memory helps to construct the goodness of a solution, contribute in each move, and manage feasibility of solutions. The backward moving ants retrace the path towards the source node. Figure 1 elucidates the phenomena.

The local and global pheromone are sharing help to build up the optimal solution. As far as the local pheromone information is concerned it involves the problem specific heuristic information, which is knowledge embedded in the pheromone trails involved at the beginning of the stochastic search process (ants generation, activity in search of paths, and pheromone evaporation).

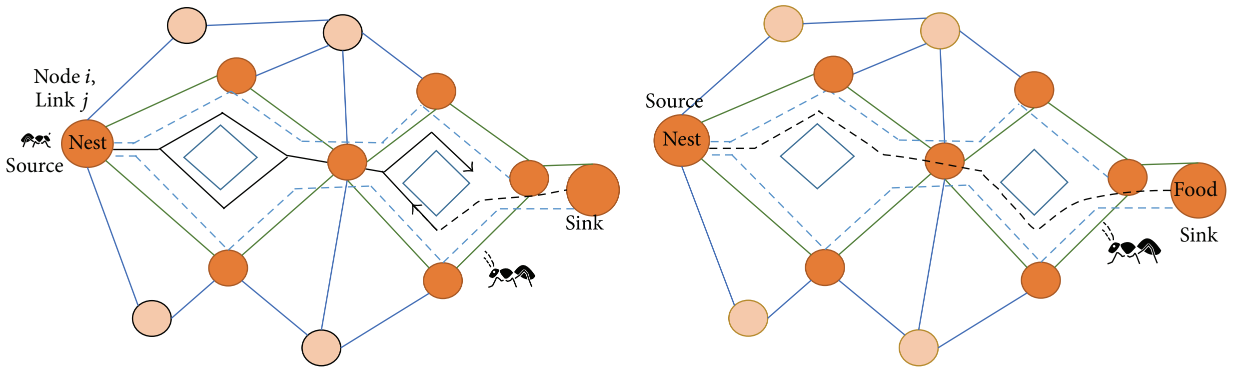
However, the global pheromone concentration information deals with the shared local pheromone value that ultimately effect the ant's decision while construction of a good solution to deposit additional pheromone information to collect useful global information. Reactive approach develops the multipath between source and destination in order to avoid link failure and robustness, but it becomes difficult when mobility among nodes causes frequent topological changes. Whereas the proactive approach is reducing the routing, overhead becomes infeasible in disruptive situations. The hybrid approach is combining both the reactive and the proactive approaches and utilizing their advantages helps to develop an optimized energy aware routing algorithm based on ACO.

The remainder of this paper is organized as follows. Section 2 describes some of the closely related works to our work. The working details of EASARA are described in Section 3. Section 4 proposed solution is discussed in Section 3 with detailed elaboration of proposed improvements in route discovery part of the baseline algorithm, simple ant routing algorithm. Also, the proficiency of EASARA algorithm over SARA algorithm in four scenarios that may arise during the forwarding node selection which are discussed is detailed in this section. Results and discussion are explained in Section 4 proceeded by conclusion in Section 5.

## 2. Related Work

Energy aware routing based on ACO has been widely investigated in the context of MANET [23, 24]. For example, ARA [25] is a reactive algorithm based on ACO that strives to reduce routing overhead. ARA consists of following three phases, that is, route discovery, route maintenance, and route failure handling. In route discovery, new paths are discovered with the help of FANT (forward ant) and BANT (backward ant). Each FANT containing a unique sequence number passes through intermediate nodes while moving data packets from a source towards the destination. Routing table entries consist of destination address, next hop, and pheromone value which is maintained by each node independently. Choosing a route among multiple paths depends on the link quality and usability. Routing paths established should be maintained (i.e., route maintenance) with the evaporation of pheromone value that indicates the quality of the link. Missing successive number of acknowledgments indicates nonavailability of a path that might be caused due to several factors such as node failure or mobility. Route failure handling deals with such situations that may call for reroute discovery, for example, finding alternative path. To conserve energy, availability of pheromone is considered while reroute is discoverd. This significantly reduces the overhead as it does not require an exchange of routing tables. However, the criterion for choosing a neighbor is not clear during route selection. Moreover, triggering a route recovery procedure based on missing an ACK may unnecessarily call for path discovery.

Similarly, AntHocNet [26] is another routing mechanism that effectively deals with network dynamics. It is comprised of four parts, that is, reactive path setup, proactive path maintenance and explorations, stochastic data routing, and link failures. In reactive path setup, each receiving node further unicasts or broadcasts the forward ants depending upon the pheromone table maintained at each node. A node only considers the first arrived forward ant that keeps the information of visited nodes on the path which helps the backward ant in backtracking. Proactive path maintenance updates exist and look for better routes. Data routing is



(a) (b)

Figure 1: Forward and backward ants. (a) Forward ant stochastically selects the path. (b) Backward ant stochastically selects the path.

Table 1: Literature based performance parameters evaluation.

| Performance parameters | ARA | ACO | SARA | AntHocNet |
|---|---|---|---|---|
| Average energy consumption | | ✗ | | |
| Node operation time | | ✗ | | |
| Packet delivery rate | ✗ | | | |
| Packet drop ratio | | | | ✗ |
| Throughput | ✗ | | ✗ | |
| End to end packet delay | | | | |
| Packet size | ✗ | | | ✗ |
| Routing overhead | | | ✗ | |
| Minimum energy | | | | ✗ |
| Energy efficiency | | | | |
| Link cost | | | ✗ | |

based on stochastic decisions for load balancing. Link failure mechanism is triggered when nodes are unable to exchange unicast or hello messages. Like AntHocNet, SARA [27] is another mechanism that optimizes the routing procedure to reduce overhead. SARA employs a new controlled neighbor broadcast (CNB) mechanism in the route discovery where one of the neighboring nodes only broadcasts the received FANT further. It further reduces overhead by employing data packets to refresh the routes of active sessions. To limit the scope of recovery (i.e., route repair phase), SARA strives to find a new link between the two end nodes of the failed path instead of establishing a new route from the source to destination. SARA pursues a broadcast search in case the recovery process remains successful. Unlike these mechanisms, the focus of our work is WSNs where node energy is a prime design consideration while making routing decisions.

Recently, a novel routing protocol based on ACO was proposed in the context of WSNs [28]. To increase network lifetime through load balancing, the proposed protocol employs a dynamic and adaptive mechanism that considers engagement of a node in data forwarding and residual energy besides data latency. The efficiency of the proposed protocol in terms of network lifetime improvement is also shown.

Table 1 summarizes the literature given in Section 2. To reduce energy consumption and prolong network lifetime, a multipath routing protocol (MRP) based on clustering and ACO is proposed in [29]. MRP picks a cluster head (CH) among nodes based on residual energy and employs ACO to determine multiple paths between a CH and sink. Several routing factors such as energy consumption are considered by the CH for data transfer while dynamically choosing a path. Most of these works do not consider WSNs dynamics such as decay in pheromone, link failures due to node mobility or dysfunction. Unlike these works, the focus of our work is different.

## 3. Energy Aware Simple Ant Routing Algorithm

As stated earlier, most applications of WSNs employ sensors with limited nonrenewable energy and routing is a major energy guzzler that shorten network lifetime. To cope with this problem, we present a reactive energy aware simple ant routing algorithm (EASARA) which is based on ACO. Unlike most algorithms, EASARA strives to avoid low energy routes and optimize the routing process through selection of the shortest path (number of hops) with more energy. EASARA mainly consists of three phases, that is, route discovery, forwarding node, and route selection. We have improved the route discovery procedure of SARA and mainly concentrate on energy efficient forwarding node selection (FNS) and route selection so that the network lifetime can be prolonged. We have described four possible cases of forwarding node and route selection. The following describes the details of EASARA.

*3.1. Route Discovery in EASARA.* Unlike traditional ACO based approaches, EASARA adopts a controlled neighbor broadcast mechanism [27] in route discovery to avoid flooding the network with FANTs. In CNB based route discovery, each sensor node broadcasts the FANT to its direct neighbors, and only one of them further rebroadcasts the FANT to its neighbors. Randomly choosing a neighbor for "rebroadcasting" may not be feasible. Therefore, EASARA adopts a probabilistic approach in picking a neighbor based on energy and link cost. The probability of a neighbor with more energy and lower link cost is higher in FANT

Table 2: FANT packet format used by EASARA.

| FANT_ID | Source | Destination | Node address | Next | N_Hop | $p_{id}$ | Average energy threshold | Ant_Val |
|---|---|---|---|---|---|---|---|---|

*rebroadcast*. First, it determines a threshold energy level based on average remaining energy of neighbor nodes that is calculated as follows. Each node continuously updates its energy and exchanges heartbeat messages with neighbors to establish and maintain a neighbor list containing updated information such as ID and energy level [30]. Suppose there are $N$ nodes in WSNs; the average energy consumption of the network is the sum of the $\Delta E_i$ divided by $N$ as

$$E_{\text{avg}} = \frac{1}{N}\sum_{i=1}^{N}\Delta E_i, \tag{1}$$

where $\Delta E_i$ is the difference between initial and final energy which can be calculated as

$$\Delta E_i = E_{\text{initial}} - E_{\text{final}}. \tag{2}$$

Since data transmission is a major energy consumer, therefore the energy consumed by each node is the sum of transmission $E_{Tx}$ and reception $E_{rx}$:

$$\Delta E_i = E_{\text{initial}} - \left(E_{Tx} + E_{rx}\right). \tag{3}$$

The energy threshold can be calculated using (4) which averages the remaining energy of all the neighboring nodes $(M)$ of a source $S$:

$$\text{Threshold energy} = E_{\text{avg}} = \sum_{i=1}^{M}\Delta E_i. \tag{4}$$

The neighbors having remaining energy greater than the threshold will become the candidates for FANT *rebroadcast*. The rationale is to engage high energy nodes in route discovery and hence improve network lifetime. Afterwards, the candidate nodes determine the link cost based on the number of times a node was previously selected for *rebroadcast*. The selection time is inversely proportional to the probability of a node to be picked in the route selection procedure. The probability $p(i, j_i, d)$ to pick a neighbor for forwarding FANT towards destination $d$ is given by (5), which is based on energy, link cost, and usability:

$$p\left(i, j_i, d\right) = \frac{C_{(i,j_i,d)} * e\left(j_i\right)}{\sum_{k=0}^{M} C_{(i,j,d)} * e\left(j_k\right)} \wedge^{C(i,j,d)} = \frac{1}{1+n}, \tag{5}$$

where $C_{(i,j_i,d)}$ represents the link cost between node $i$ to its neighbor node $j_i$ towards destination $d$. This cost is based on the number of times $(n)$ the link was previously used and on $M$, that is, the number of neighbors of node $i$; $e(j_i)$ is the energy of node $j_i$ and $e(j_k)$ is energy of node $j_k$. This *rebroadcast* of the FANT packet continues in a similar fashion until it reaches the destination. Table 2 elucidates the FANT packet used by EASARA. The rest of the route discovery procedure is similar to SARA.

Most of the fields are self-explanatory. *FANT_ID* is a unique identifier for each session and is generated by the source node. The addresses (source, destination, and node) represent the *IDs* of the source, destination, and address of the current node. The neighbor selected for *rebroadcast* is listed under *Next*. The next two fields indicate the number of hops traversed from source towards the destination on a particular path and path *ID*. *Average energy threshold* is the average remaining energy of neighbors.

### *3.2. Four Scenarios of FNS for Comparison of SARA and EASARA Algorithms.*

The depletion of node energy that has been involved in various data and control sessions causes decrease in the lifetime of network. The algorithm EASARA helps to enhance the lifetime of the network by taking care of nodes energy. If we consider nodes energy then four scenarios occur where each shows a unique case in terms of energy utilized by a node and number of times a node is selected for discovering a route. The scenario is depicted clearly in Figure 2 where a node energy usage in terms of energy units and the number of times a node is selected earlier. Nodes communicate with each other through hello packets. The routes are discovered by calculating the threshold level of energy of the neighboring nodes to select the nodes for controlled neighbor broadcast procedure where the probability of neighboring nodes is calculated. The nodes which have greater energy level and higher probability are selected. The four scenarios which arise are as follows:

(i) nodes with equal energy but different number of selection times,

(ii) nodes with variable energy and variable used number of times with less number of nodes involved in controlled neighbor broadcast process,

(iii) nodes with less energy and used less number of selection times,

(iv) nodes with more energy and used less number of times.

The algorithm details of EASARA along with the four scenarios are discussed below. Scenario depiction for the adaptation of EASARA is given in Figure 2.

### *3.2.1. Case 1: Nodes with Equal Energy but Different Number of Selection Times.*

Considering Table 7, source $S$ has two neighbors $A$ and $B$ and both are used with different number of selection times $(n)$. Previously in SARA algorithm the node with less number of selection times has a higher probability to be selected. Random decision is made if a node is used in equal number of times in SARA but in EASARA average energy is computed for node $A$ and node $B$. Average energy calculation enables to decrease the processing for nodes which are below the threshold calculated from the average energy consumption. A threshold of 6.5 units is calculated

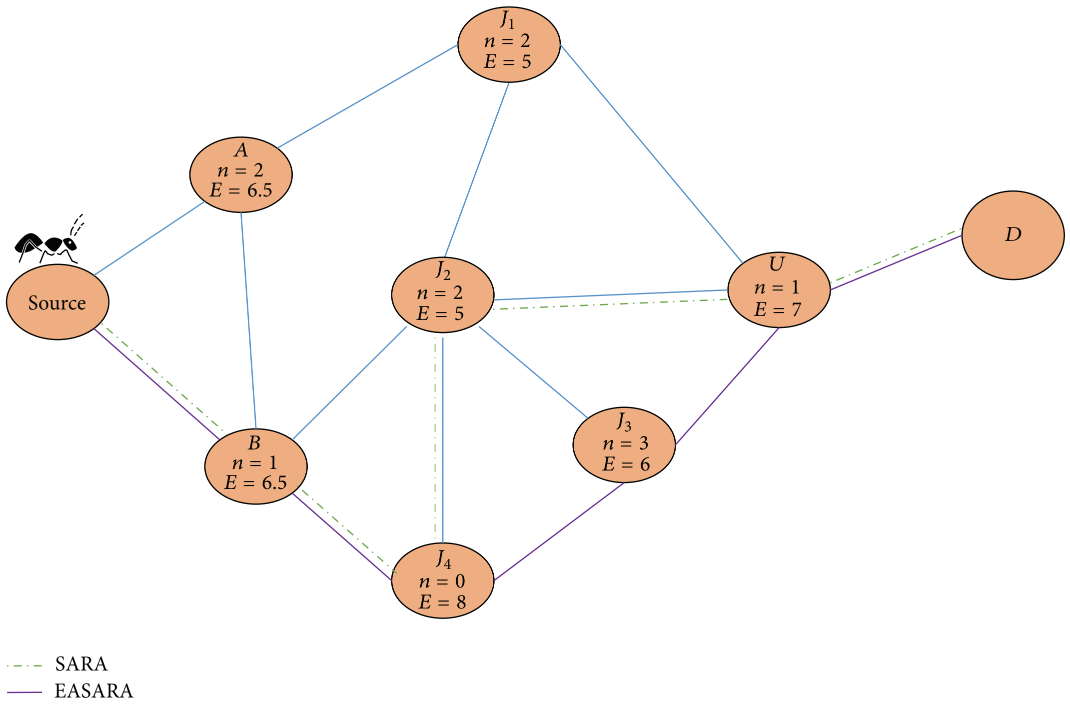


Figure 2: Scenarios depiction for adapting EASARA.

and obtained from average energy of the neighboring nodes so the node having energy greater than 6.5 is selected to participate in CNB broadcasting FANT to calculate the link cost and probability. Link cost and probability are calculated from (5). For node $A$, the link cost is 0.25 and link cost for node $B$ is 0.33 and so the probability for node $A$ is 0.43 and the probability to select node $B$ is 0.56. So node $B$ has probability decision greater than node $A$; node $B$ is selected to rebroadcast the FANT.

Table 3 shows a comparison calculation between the two algorithms.

*3.2.2. Case 2: Nodes with Variable Energy and Variable Used Number of Times with Less Number of Nodes Involved in Controlled Neighbor Broadcast Process.* Node $B$ is selected previously on the basis of higher probability and node energy. $B$ gets the energy information of its neighboring nodes; it calculates the energy threshold to be 6.5 with its three neighbors $A$, $j_2$, and $j_4$. So node $A$ and node $j_4$ can participate in CNB selected by the node $B$. The link cost of the node $j_4$ is 0.5; for node $A$ the link cost is calculated to be 0.25 and probability will be 0.28 for node $A$, and for node $j_4$ probability will be 0.71, so node $j_4$ is selected to rebroadcast the FANT among its neighbors, whereas when we compare SARA with proposed algorithm node $B$ calculates the link cost and probability for all its neighbors and only the neighbor with greatest probability will be selected to rebroadcast. EASARA makes the decision based on the average energy threshold value and calculates the probability of those nodes which are above a threshold energy level. Table 4 explains case 2.

*3.2.3. Case 3: Nodes with Less Energy and Used Less Number of Selection Times.* $J_4$ calculates the energy threshold to be 5.5; it selects $j_3$ node for calculating its link cost only. The link cost and probability is 0.2 and 1, respectively, whereas in SARA algorithm the nodes with less number of selection times are selected due to their higher probability among their neighbors irrespective of the fact that the node has less energy, and due to its number of less selection times it participates in the route discovery procedure without knowing the left energy level of the node. It may cause the network to have dead nodes which affects the network lifetime.

As the mobility in the network and four sessions are under consideration, this case occurs as a node is involved in a number of processes. Similarly in EASARA, only the node(s) in neighbor that will have energy above the threshold level is selected, so node $J_4$ only calculates the probability and link cost of that node whereas in SARA algorithm all neighbors link cost and probability will be calculated so processing energy will be consumed for each node. Table 5 gives an extended understanding to this scenario.

*3.2.4. Case 4: Nodes with More Energy and Used Less Number of Times.* This case resembles SARA algorithm initial session case when all the nodes have equal energy and link cost and probability will be calculated to have a load balance among the network nodes. Now $j_3$ node calculates the energy threshold to be 6 nodes for its two neighboring nodes $u$ and $j_2$; node $u$ is selected to calculate link cost to be 0.25 with probability 1, which ultimately reaches the destination; dissimilarly it reaches destination node. But in EASARA as

Table 3: Case 1 route discovery comparison for SARA and EASARA.

| | EASARA | SARA |
|---|---|---|
| Neighbor set | $S \rightarrow A\ (E = 6.5)$<br>$S \rightarrow B\ (E = 6.5)$ | $S \rightarrow A$<br>$S \rightarrow B$ |
| Link cost | $A$: $n = 2$;<br>$C(s, A, d) = 0.25$<br>$B$: $n = 2$;<br>$C(s, B, d) = 0.33$ | $A$: $n = 2$;<br>$C(s, A, d) = 0.25$<br>$B$: $n = 2$;<br>$C(s, B, d) = 0.33$ |
| Probability | $P(s, A, d) = 0.43$<br>$P(s, B, d) = 0.56$ | $P(s, A, d) = 0.43$<br>$P(s, B, d) = 0.56$ |
| Average energy threshold | 6.5 | — |
| Number of nodes in CBR | 2 ($A$, $B$) | 2 ($A$, $B$) |
| Conclusion | Node $B$ is selected with greater probability based on energy and the less number of times it is used. Node $B$ energy is 6.5. | Node $B$ is selected based on less number of time used |

Table 4: Case 2 route discovery comparison for SARA and EASARA.

| | EASARA | SARA |
|---|---|---|
| Neighbor set | $B \rightarrow A\ (6.5)$<br>$B \rightarrow j_2\ (5)$<br>$B \rightarrow j_4\ (8)$ | $B \rightarrow A$<br>$B \rightarrow j_2$<br>$B \rightarrow j_4$ |
| Link cost | $A$: $n = 2$;<br>$C(B, A, d) = 0.25$<br>$j_2$: $n = 2$;<br>$C(B, j_2, d) = 0.25$<br>$j_4$: $n = 2$;<br>$C(B, j_4, d) = 0.5$ | $A$: $n = 2$;<br>$C(B, A, d) = 0.25$<br>$j_2$: $n = 2$;<br>$C(B, j_2, d) = 0.25$<br>$j_4$: $n = 2$;<br>$C(B, j_4, d) = 0.5$ |
| Probability | $P(B, A, d) = 0.28$<br>$P(B, j_4, d) = 0.71$ | $P(B, A, d) = 0.25$<br>$P(B, j_2, d) = 0.25$<br>$P(B, j_4, d) = 0.5$ |
| Average energy threshold | 6.5 | — |
| Number of nodes in CBR | 2 ($A$, $j_4$) | 3 ($A$, $j_2$, $j_4$) |
| Conclusion | Node $j_4$ is selected due to the less number of times it is selected but more processing nodes are involved in calculating the probability of the link. | Node $j_4$ is selected based on the number of times a node is selected and the energy of the node energy of $j_4$ is 8. |

shown in Table 6, only one node is selected based on energy threshold value for being further selected as the forwarding node as SARA calculates link cost and probability for each neighboring node.

Four cases have been discussed in it: firstly, if the node's energy in neighbors is used equally but with variations in their link cost, that is, number of times a node is used in the network. Secondly, the nodes are used more but energy consumption is less as compared to neighboring nodes; thirdly the weaker neighbor cannot participate in calculating the link cost and probability to reach destination and the fourth case is the less the link cost is and the less the energy consumption will be. This will help to discover the paths where more energy efficient nodes update their energy level at each step to enhance the lifetime of the network.

*3.3. Route Selection Criteria and Procedure.* Once the routes are discovered, they are selected on the basis of a number of hops, energy of the node, and pheromone concentration. When multiple routes are discovered using a controlled neighbor broadcast then the route is selected on the basis of probability procedure. The route selection in EASARA differs from SARA algorithm. Two different metrics are used for the best shortest path selection. The only difference lies in the fact

Table 5: Case 3 route discovery comparison for SARA and EASARA.

| | EASARA | SARA |
|---|---|---|
| Neighbor set | $j_4 \rightarrow j_2$ (5)<br>$j_4 \rightarrow j_3$ (6) | $j_4 \rightarrow j_2$<br>$j_4 \rightarrow j_3$ |
| Link cost | $j_2$: $n = 2$;<br>$C(j_4, j_2, d) = 0.25$<br>$j_3$: $n = 3$;<br>$C(j_4, j_3, d) = 0.2$ | $j_2$: $n = 2$;<br>$C(j_4, j_2, d) = 0.25$<br>$j_3$: $n = 3$;<br>$C(j_4, j_3, d) = 0.2$ |
| Probability | $j_2$: $n = 2$;<br>$C(j_4, j_2, d) = 0.25$<br>$j_3$: $n = 3$;<br>$C(j_4, j_3, d) = 0.2$ | $P(j_4, j_2, d) = 0.55$<br>$P(j_4, j_3, d) = 0.44$ |
| Average energy threshold | 5.5 | — |
| Number of nodes in CBR | 1 ($j_2$) | 2 ($j_2, j_3$) |
| Conclusion | Node $j_2$ is selected on the basis of the less number of times it is used. | Node $j_3$ is used due to less energy consumption and the fact that the processing energy consumption of other nodes decreases. Energy of $j_3$ is 6. |

Table 6: Case 4 route discovery comparison for SARA and EASARA.

| | EASARA | SARA |
|---|---|---|
| Neighbor set | $j_3 \rightarrow u$ (7)<br>$j_3 \rightarrow j_2$ (5) | $j_2 \rightarrow j_1$<br>$j_2 \rightarrow U$<br>$j_2 \rightarrow j_3$ |
| Link cost | $U$: $n = 1$; $C(j_3, u, d) = 0.5$<br>$j_3$: $n = 2$; $C(j_3, j_2, d) = 0.25$ | $j_1$: $n = 2$;<br>$C(j_2, j_1, d) = 0.33$<br>$j_3$: $n = 3$;<br>$C(B, j_4, d) = 0.25$<br>$U$: $n = 1$;<br>$C(j_2, u, d) = 0.2$ |
| Probability | $P(j_3, u, d) = 1$ | $P(j_2, u, d) = 0.42$<br>$P(j_2, j_1, d) = 0.32$<br>$P(j_2, j_3, d) = 0.25$ |
| Average energy threshold | 6 | — |
| Number of nodes in CBR | 1 | 3 |
| Conclusion | Node $u$ is selected on the basis of the less number of times it is used. | Node $u$ is selected based on the energy consumption and number of times a node is used with energy. Energy of $u$ is 7. |

that now the routes are selected on the basis of nodes that have a particular energy threshold plus the number of time a node is selected. Number of hops from source to destination and the other pheromone level present in the link between nodes. SARA uses the hop distance, and the pheromone value as metrics whereas EASARA introduces another metric in route selection criteria which are node energy and number of hops:

$$p(u, ji, d) = \frac{\varphi(u, j_i, d)}{\sum_{k=0}^{k=M} \varphi(u, j_k, d)},$$

$$\varphi(u, j_i, d) = \frac{(\text{ph}(u, j_i, d) + 1)^F}{e^{\text{nh}(j_i, d)}},$$

$$\varphi(u, j_i, d) = \frac{(\text{Energy}(u, ji, d))^{1/2}}{e^{\text{nh}(j_i, d)}}, \tag{6}$$

where the probability of the route selection between node $u$ and $j_i$ is dependent on the link cost $\varphi$ where $M$ is the number of adjacent nodes. The link cost is calculated based on pheromone value between the nodes and number of hops. The pheromone value tells the fact that each node tracks the amount of pheromone on each neighbor link. A packet passes through the link between the nodes $u$ and $j$; the pheromone intensity ph increases by a factor $\alpha$. $T_i$ is the time when a packet crosses the link and increases pheromone level and

TABLE 7: Pheromone description.

| Pheromone intensity and its effects | $\alpha$ | $\zeta$ |
|---|---|---|
| Pheromone intensity will increase slowly, and paths become unstable | Too small | Too large |
| Pheromone intensity will decrease slowly, and paths become stable | Too large | Too small |

TABLE 8: Simulation parameters.

| Parameters | Values |
|---|---|
| Simulation time | 100 s |
| Simulation area | 1000 $m^2$ |
| Number of nodes | 104 |
| Packet size | 512 bits |
| MAC type | 802.11 b |
| Packet rate | 16 Packets/sec |
| Node speed | 0 $ms^{-1}$–10 $ms^{-1}$ |
| Receiving range | 100 m |
| Propagation model | Two ray ground |
| Mobility model | Random way point |
| Traffic | FTP |
| Node initial energy | 20 J |
| $T_x$ energy | 0.003 J |
| $R_x$ energy | 0.001 J |

$t$ is the time in which a packet crosses the link recently. $\zeta$ is time when the pheromone decreases. $\gamma$ is the pheromone decrease intensity. The $\alpha$ and $\zeta$ are used to optimize the link pheromone availability. The pheromone increasing intensity $\alpha$ and decreasing intensity $\zeta$ values are adjusted to tune the route availability based on the pheromone intensity. Table 7 gives the summary of this pheromone description.

## 4. Results and Discussion

For performance evaluation of our proposed algorithm, EASARA, with existing protocol SARA. We used NS-2.31 simulator by considering simulation parameters as shown in Table 8. All the environmental parameters of both algorithms are same. The performance metrics which are used to evaluate the performance of both algorithms in route discovery and route recovery phenomena are as follows:

(i) transmitted packets per node,

(ii) received packets per node,

(iii) total number of packets per node,

(iv) energy consumption:

  (a) per node,

  (b) per selected path,

  (c) total network,

  (d) route recovery.

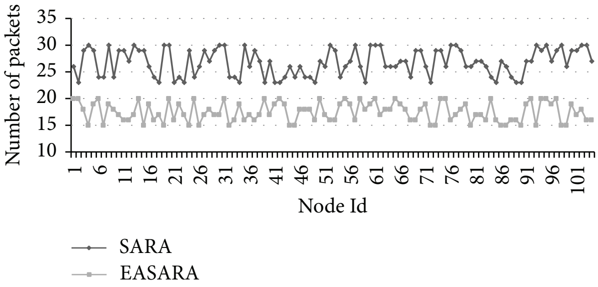


FIGURE 3: Number of packets transmitted per node.

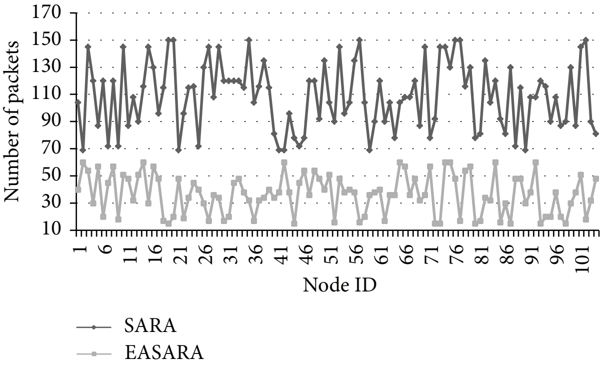


FIGURE 4: Number of packets received per node.

Initial results during simulations for randomly selected paths for the proposed route discovery and route recovery procedure are presented. We have started the analysis based on the characteristics of typical sensor node architectures such as in receiving and transmitting the control packets during route discovery procedure. It helps to identify the various factors that affect system lifetime.

Figure 3 shows the packets transmitted per node where SARA has more value compared to EASARA. When any node in route discovery procedure communicates with its neighboring nodes for FNS, it generates packets called control packets. The average energy calculation of the neighboring node before controlled neighbor broadcast procedure helps to involve less number of nodes in link cost and probability calculations. This reduces the number of transmission packets among the nodes. The number of control packets that are transmitted during the route discovery procedure is analyzed in Figure 3. Also, the comparison of both competing algorithms in the number of received control packets during the route discovery procedure is depicted in Figure 4. That shows almost the same result of better performance of EASARA over SARA as shown in Figure 3.

Route discovery packets, route recovery, and route maintenance packets in the routing algorithm depict more overhead of the protocol. Overhead is exponentially related to the number of interacting nodes. Increase in control packets

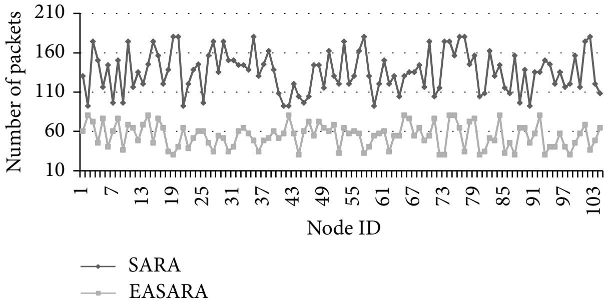


Figure 5: Total number of packets entertained per node.

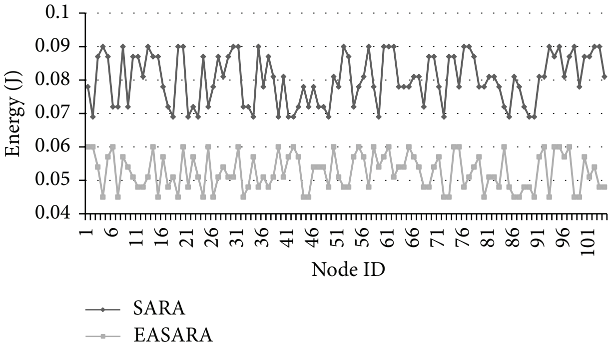


Figure 6: Energy consumption per node during packet transmission.

reflects in the form of decrease in the bandwidth available for the data packets to transfer among the nodes and to reach from the source to destination. This results in less reliability of data transmission. Same is the case that happened in the working of SARA which is using more control packets in route discovery, route recovery, and route maintenance processes. Hence, more energy is consumed per network node as is shown in the Figure 5.

Control packets are the primary source of energy consumption. Energy consumption by the node during the transmission of control packets is shown in Figure 6 which justifies the above facts that less number of packets transmitted between intermediate nodes for route discovery procedure is an effective way to save energy.

This is favored most in the situations where the nodes are mobile and distributed in the network area. SARA utilized more control packets for route discovery, so more energy is consumed per node as compared to EASARA by involving less number of nodes.

Similarly, Figure 7 shows performance of the node on the energy consumption while receiving control packets. The EASARA outperforms SARA algorithm, that is, the reflection of more entertainment of control packets by SARA compared to the proposed solution.

This is again demonstrated in Figures 8 and 9 in another way by figuring out the total energy consumption per node and of the overall network during the route discovery phenomenon, respectively.

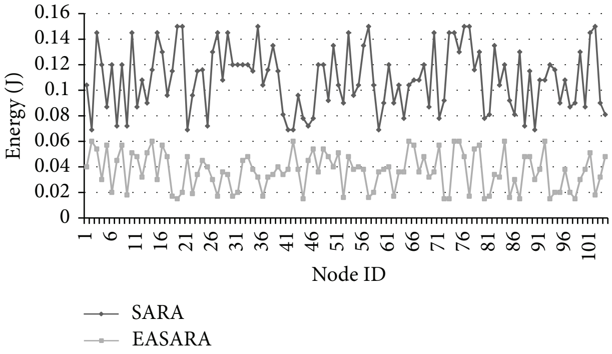


Figure 7: Energy consumption per node during packet reception.

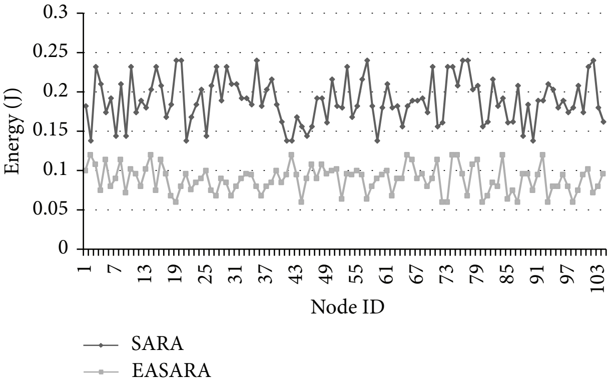


Figure 8: Total energy consumption per node during entertainment of packet.

Forwarding node energy consumption is calculated against five randomly selected paths during the simulation. From Figure 10 it is intuited that EASARA gives a better result than SARA. The reason of this improved performance is the reduction of energy consumption at each node during the set up phase as fewer transmissions occur in EASARA as compared to SARA, less transient nodes are involved in controlled neighbor broadcast and probability calculation, and less node to node delay from the overall packet energy from source to destination occurs.

In SARA, the route recovery process involves two phases. First the nodes recovery process is initiated locally by looking at the neighbor table entry. If it is not present then the node initiates the forward node selection. In another case if it fails then the source node initiates a route discovery procedure. SARA solves the link congestion problem already. We have taken the case of 5 randomly selected paths where a link break occurs and the node cannot find a node in its neighbor table and it calculates the probability of the next forwarding node to be selected. The path selection using the probability function that is based on the link cost and energy helps in reduction of overall energy consumption. That appears in the form of betterment in EASARA as compared to that of SARA. Our aim is to make the route discovered energy-aware so that the lifetime of the network can be increased, whose

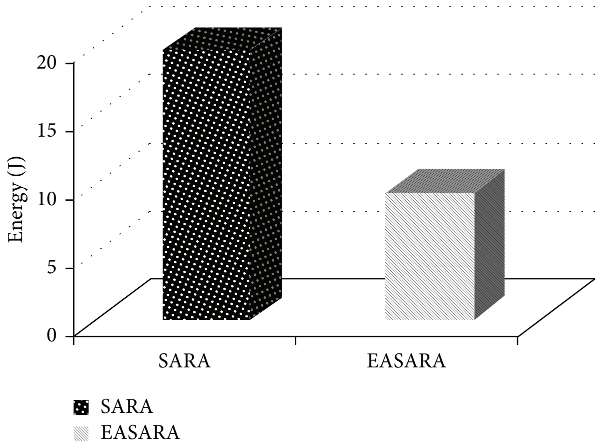


Figure 9: Total energy consumed.

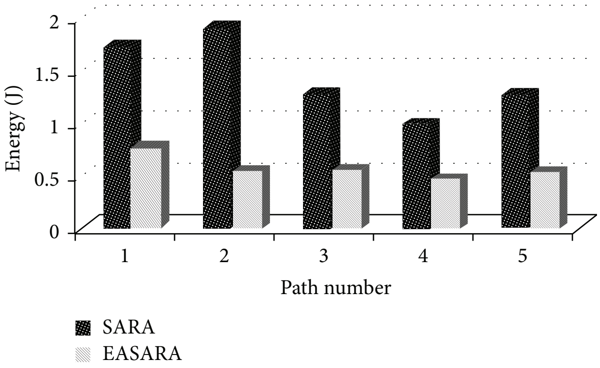


Figure 10: Energy consumption during selection of forwarding node.

achievement is depicted based on empirical results in Figure 11.

## 5. Conclusion

This paper has presented EASARA, an energy aware simple ant routing algorithm, to improve WSNs lifetime. EASARA is a reactive scheme based on ant colony optimization. To cope with limited energy problem, EASARA strives to avoid low energy routes and optimizes the routing process. EASARA mainly consists of three phases, that is, route discovery, forwarding node, and route selection. EASARA strives to avoid low energy nodes in route discovery and engages nodes with higher energy as forwarders. Moreover, it prefers to choose high energy routes with least hop count path to improve network lifetime and minimize delay. The four possible cases of forwarding node and route selection were also discussed. The performance of the EASARA was validated through simulation experiments. The experimental results validated the effectiveness and efficiency of EASARA compared to contemporary scheme in terms of various performance metrics. This scheme can also be used in M2M, in IoT, and in extension various cyber physical systems (CPS) [31–35], apart from the fact that a sensor based Big data will also benefit from such energy aware technique.

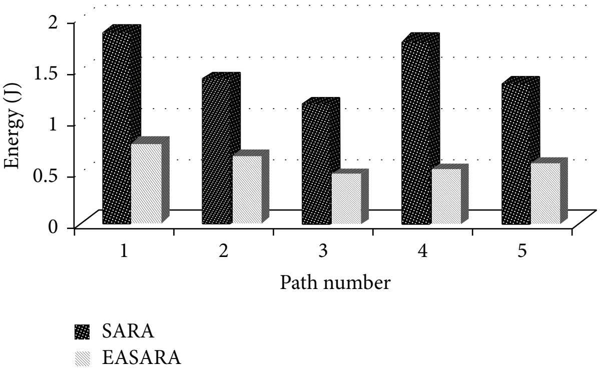


Figure 11: Energy consumption during route discovery process.

## Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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