

Enhanced Ant-Based Routing for Improving Performance of Wireless Sensor Network

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Abstract: Routing packets from the source node to the destination node in wireless sensor network is complicated due to the distributed and heterogeneous nature of sensor nodes. An ant colony system algorithm for packet routing in WSN that focuses on a pheromone update technique is proposed in this paper. The proposed algorithm will determine the best path to be used in the submission of packets while considering the capacity of each sensor node such as the remaining energy and distance to the destination node. Global pheromone update and local pheromone update are used in the proposed algorithm with the aim to distribute the packets fairly and to prevent the energy depletion of the sensor nodes. Performance of the proposed algorithm has outperformed five (5) other common algorithms in static WSN environment in terms of throughput, success rate, packet loss rate, energy consumption and energy efficiency. Overall, the proposed algorithm can lead to reduction of packet loss rate during packet routing and increase of network lifetime.

Keywords: Wireless Sensor Network, Ant Colony Optimization, Packet Routing, Pheromone Update Technique.

1. Introduction

Wireless Sensor Network (WSN) has become the next step in information revolution and important research areas in computer networking [1]. WSN consists of a collection of sensor nodes that can sense the changes in the environment, communicate with neighbour nodes, and perform basic computations on the collected data. WSN is widely applied in many critical applications such as healthcare, military, and environment monitoring [2]. There are various issues in WSN such as routing, node localization, node energy efficiency, time synchronization, load balancing, and security [3,4,5,6].

Routing is the main element that needs to be focused to minimize latency, minimize energy consumption of sensor nodes, maximize throughput, and maximize the network lifetime of the WSN system [7,8]. One of the main challenges in WSN is to find the optimal path to submit packets from the source node to the destination node. Optimal path discovery is the main target of a routing algorithm, where the considerations involve the energy level of sensor nodes, the distance between sensor nodes to destination nodes, and also the load of each sensor node during the submissions of packets from source nodes to destination nodes.

There are two conditions of WSN, which are static and dynamic [9]. The destination node will remain in a fixed position in a static condition. However, in a dynamic condition, the destination node will change its location, which depicts the scenario of a moving vehicle, the sensor on animals, and enemy tracking sensors. Packet routing in dynamic WSN is more difficult than static WSN because the

destination node can move in unexpected manners that will potentially lead to higher packet loss. In contrast, static WSN is prone to hotspot problems where all packets coming from the source nodes need to pass through the nodes closer to the destination node, and often this scenario may lead to faster depletion of energy on these sensor nodes.

An effective packet routing can also reduce the depletion of energy of the sensor nodes and increase the lifetime of the system [10]. However, the sensor nodes are geographically distributed in a large-scale area and have limited capabilities in terms of their processing capabilities, amount of energy, storage capabilities, and communication bandwidth that can affect the lifetime of WSN [11]. This paper proposes an enhanced Ant Colony System (ACS) algorithm that will increase the performance of WSN in terms of throughput, success rate, packet loss rate, energy consumption, and energy efficiency. The main focus of the proposed algorithm is on improving the pheromone update technique that will improve the process of finding the optimal path and exploration of the alternative path for packet submission from the source node to the destination node.

Section 2 gives an overview of the ant-based routing algorithm in WSN, while Section 3 discusses the details about the proposed ant-based routing for WSN. Experimental results are presented in Section 4 and concluding remarks are highlighted in Section 5.

2. Ant-Based Routing Algorithm in Wireless Sensor Network

Routing in WSN is categorized as a Nondeterministic Polynomial (NP)-complete problem [12,13], where it cannot be solved by an exact algorithm in a polynomial time [14]. One of the best ways to solve this kind of problem is to use approximate (heuristic) algorithms. These algorithms move from one solution to another to construct the best solution to solve routing problems in the WSN system. By using these algorithms/methods, a feasible solution can be produced even though it will not be close to the optimal solution. Bio-inspired algorithms such as Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), Genetic Algorithm (GA), and Termite Hill (TH) are categorized as heuristic algorithms.

ACO algorithm is one of the promising bio-inspired algorithms that can solve routing problems in WSN by using the chemical substances called pheromone that is used for indirect communications between artificial ants for node selection [15,16,17]. ACO is inspired from the foraging behaviour of ants, where they work together to find the shortest path between nest and food source. A chemical substance called pheromone is deposited on the ground by

ants while moving from nest to food source and vice versa. The pheromone value on the path indicates the distance between nest and food source. The path with high pheromone values is shorter than the path with low pheromone values [18,19]. Ant System (AS), Ant Colony System (ACS), Max-Min Ant System (MMAS), Elitist Ant System (EAS), and Rank-Based Ant System (RAS) [20] are variants of ACO that have been developed to solve problems in various domains. Energy-Efficient Ant-Based Routing (EEABR) algorithm was proposed by [21] with the objective to reduce energy and communication load. EEABR that is based on the AS algorithm used two types of ants, namely forward ants to explore the WSN environment in finding the optimal path to submit packets to destination nodes, and backward ants to update the pheromone value on the selected path. Probabilistic decision rules are used for the node selection process and the global pheromone update is used to encourage the optimal path to be selected in the next iteration. The global pheromone update is applied on each visited sensor node along the optimal path. The performance of the EEABR algorithm is compared with the other improved AS algorithms, which are Basic Ant-Based Routing Algorithm (BABR) and Improved Ant-Based Routing (IABR) Algorithm in three different conditions, namely static network, mobile network, and mesh network in terms of energy efficiency. However, the proposed algorithm did not consider the exploration of an alternative path to submit packets from source nodes to destination nodes. This may lead to hotspot problems on certain sensor nodes due to imbalanced packet submissions.

The study by [22] proposed an improved AS called ASW to solve the routing problems in a static wireless sensor network. They aimed to minimize the delay of the forwarding packets from source to destination nodes and to minimize the energy consumption of each sensor node. The proposed algorithm is similar to AS on how it selects the next node, but with a different pheromone updates mechanism. In ACW, different amounts of pheromone are assigned to every ant during the pheromone update activities depending on the minimum energy consumed by each ant. Experimental results showed that AS and ASW have lower delays as compared to ACS. ACS performed better than AS and ASW in terms of energy consumption. This is because ACS is more stable in a large-scale area as compared to the other algorithms.

An ant colony system-based routing algorithm for a wireless sensor network was proposed by [23]. The search angle has been proposed in this algorithm to limit the ants' search area during the node selection activities. By using the search angle approach, the nodes only broadcast their information to their neighbour in the search angle area to reduce the energy consumption of each sensor node. This approach can also increase the search speed of ants and reduce the delay of packet submission. The quantities of pheromones are different from each path, where the good path discovered by ants obtains more pheromones as compared to the others. However, the quantity of pheromones is still limited to the maximum and minimum ranges, such as the MMAS approach, to control the stagnation in WSN as well as to reduce the packet loss during transmission. Experimental results showed that the proposed algorithm performed better than the traditional MMAS algorithm in terms of delay, packet loss, and dead nodes. However, the performance of

the proposed algorithm in terms of energy consumption, energy efficiency, and throughput are not considered in the experiments.

In [16], mobile sink with the combination of ACO was introduced to improve the network lifetime in a dynamic wireless sensor network environment. An ant will be sent to the WSN environment to calculate the energy of each sensor node and to decide the next best location for the mobile sink node. The location with a high energy level of sensor nodes will be selected to move the mobile sink node, so that less numbers of sensor nodes are needed to forward the packets from source to destination nodes. Thus, it will save the energy of available sensor nodes and balance the entire WSN environment. Experimental results showed that the proposed algorithm performed better when using the mobile sink node as compared to the static sink node. In the static sink environment, the proposed algorithm worked better than TH, FF, and AODV algorithms in terms of throughput and energy consumption. However, TH performed better in terms of energy efficiency and network lifetime as compared to the proposed algorithm. The delay and success rate aspects are not considered by the proposed algorithm that may lead to stagnation and packet loss problems in WSN.

[24] proposed an algorithm that focuses on maximizing network lifetime and increasing energy efficiency of sensor nodes in WSN. The algorithm consists of a combination of a cluster technique and ACO algorithm in solving the WSN routing problem. At first, each cluster will select the best sensor node to become a cluster head by considering residual energy and distance from sensor nodes to destination nodes. ACO is used in finding the optimal path between each cluster head to the neighbour nodes and the pheromone update technique is applied on the visited path to overcome stagnation in the system. The performance of the proposed algorithm was compared to the LEACH and PARA algorithms in terms of energy consumption and number of survival nodes. Experimental results showed that the proposed algorithm worked better for both performance metrics. However, other important aspects such as latency, success rate, and throughput are not considered during the experiment, thus making the performance validation incomplete.

From all the related research works, ACS performs better in solving the routing problem in WSN as compared to the other ACO variants such as AS and MMAS. ACS also works better in several network conditions such as static, dynamic, and mobile network environments. However, more works are needed to enhance the performance of the ant-based algorithm in this application domain.

Other bio-inspired algorithms such as TH, Particle Swarm (PS), and Artificial Bee Colony (ABC) are also suitable to be used in solving routing problems in WSN. The study by [25] proposed a routing algorithm based on the behaviour of real termites on hill building which supports sink mobility to improve the performance of WSN. The main objective of the proposed algorithm is to efficiently relay all the traffic destined for the sink, and balance the network energy. The performance of the proposed algorithm was tested on static, dynamic, and mobile sink scenarios with varying speed, and compared with other state-of-the-art routing algorithms in WSN such as SC, FF, and AODV. The results of the experiment demonstrated that the proposed Termite Hill

routing algorithm performed better in terms of throughput, energy consumption, and energy efficiency. However, the proposed algorithm did not cater the hotspot problem in WSN that can reduce the network lifetime of the system.

[12] proposed a hybrid algorithm called PSOABC that combines particle swarm optimization (PSO) and artificial bee colony (ABC) to improve the QoS-based routing in WSN. In the proposed algorithm, bee colony is applied as an agent to discover the optimal path between source nodes to destination nodes. Multiple forward agents that are sent to the destination node will communicate with available sensor nodes along the path. As soon as the forward agent arrives at the destination node, it will become a reverse agent. The reverse agent will return to the source node and update the routing table, which consists of routing information. The PSO agent will be responsible to forward packets from the source node to the destination node by referring to the routing table. Experimental results showed that PSOABC performed better than the traditional PSO algorithm in terms of delay, throughput, and packet loss. Nevertheless, the proposed algorithm only focused on optimizing the path without considering the hotspot problem. This could potentially decrease the network lifetime of the system.

Based on the previous works discussed above, many researchers used bio-inspired algorithms to tackle the routing problem in WSN. However, more explorations are required to enhance the performance of the algorithm in the application domain.

3. Enhanced Ant Colony Optimization for Wireless Sensor Network

In this section, the Enhanced Ant Colony System (EACS) algorithm is proposed to improve the routing performance in WSN in terms of throughput and energy efficiency, and at the same time, trying to prevent the depletion of energy of each sensor node by reducing the energy consumption. The proposed algorithm is based on the ACS algorithm and the flow chart of EACS is shown in Figure 1 (on the last page). The proposed algorithm is inspired from the existing EEABR algorithm in terms of technique to find an optimal path to submit packets from sources node to destination nodes in WSN. However, the calculation to update the pheromone value of the selected path is further extended with the local pheromone update and a modified pheromone value formula for global pheromone update. This enhancement is essential to encourage the exploration and exploitation of ants in searching the optimal path.

EACS algorithm consists of three main elements which are probabilistic decision rule, local pheromone update and global pheromone update. The purpose of the local pheromone update is to make the most visited sensor node less attractive to the following ants as well as encouraging the exploration of other sensor nodes [26]. This approach can prevent the hotspot problem on certain sensor nodes and increase the network lifetime of WSN. On the other hand, the purpose of global pheromone update is to encourage the following ants to use the best optimal path constructed by the ants by increasing the pheromone value of each visited sensor node. The remaining energy of sensor nodes and the number of hops from each sensor node to destination node have also been considered in this proposed EACS algorithm. The

sensor node selection technique is based on probabilistic decision rule that considers the pheromone value of each sensor node and distance of the sensor node to the destination node.

An ant that is responsible to find an optimal path will be created for every packet that is submitted from the source node to the destination node. The task for the ant is to move from one sensor node to another with the aim to evaluate the best sensor node to be assigned to forward the packet. The information of every visited node is saved in a memory that is carried by the ant. The routing table will be initialized so that the ant will choose the best node based on the probabilistic decision rule. The pheromone value and remaining energy of each sensor node are considered by probabilistic decision rules to reduce the energy depletion of sensor nodes in WSN. The probabilistic decision rule is defined by:

$$P_{(r,s)}^k = \frac{[\tau_{(r,s)}]^\alpha \cdot [E(v)]^\beta}{\sum [\tau_{(r,s)}]^\alpha \cdot [E(v)]^\beta} \quad (1)$$

where $P_{(r,s)}^k$ is the probability value of ant k that chooses to move from node r to node s . $\tau_{(r,s)}$ is the pheromone value of the edge between node r and node s that is stored by the routing table. $E(v)$ is the visibility function given by $(E_{init} - E_r)$, where E_{init} is the initial energy of node s , and E_r is the remaining energy of node s . The relative importance of pheromone versus visibility is controlled by the parameters α and β . This formula encourages the selection of edge that leads to the highest energy sensor node to be used in forwarding the packets.

Local pheromone update is proposed to be performed by the forward ant to the edges that have been visited during the journey to the destination node. The exploration to the other search space can be encouraged by applying a local pheromone update to the visited edges to reduce the pheromone value. Local pheromone value also can reduce the hotspot problem in WSN by distributing packets fairly to various potential paths. The local pheromone update is performed according to the following formula:

$$\tau_{(r,s)} = (1 - \varphi) * \tau_{(r,s)} - \left[\frac{E_{init} - E_{avg}}{E_{init}} \right] \quad (2)$$

where $\tau_{(r,s)}$ is the current pheromone value of the edge, φ is the coefficient value that can control the pheromone range on each sensor node, and E_{avg} is the average energy value of sensor nodes. The forward ant is transformed into a backward ant once it reaches the destination node. The backward ant is responsible to update the pheromone trail of previous paths that are traversed by the forward ant. Global pheromone update is performed to all previously traversed nodes to increase the pheromone value so that the path becomes attractive to other ants. The number of visited nodes and amount of energy use are considered by the global pheromone update.

$$\sigma_{(r,s)} = (1 - \rho) * \tau_{(r,s)} + (\Delta \tau_{(r,s)}) \quad (3)$$

ρ is the evaporation rate value that can control the pheromone on each sensor node and influence the value of energy efficiency during packet submission. $\Delta\tau_{(r,s)}$ is pheromone value that is represented by the following formula:

$$\Delta\tau_{(r,s)} = E_{avg} * \left[\frac{N_v}{N_t} \right] \quad (4)$$

where N_v is the number of visited nodes from node r until the destination node and N_t is the total of nodes in the network. The attraction to the optimal path by the following ants can be increased through the global pheromone update.

4. Experimental Result

The proposed algorithm has been evaluated in the Routing Modelling Application Simulation Environment (RMASE), which is implemented as an application in the Probabilistic Wireless Network Simulator (Prowler). This simulator is written and run by using Matlab [27]. The performance of the proposed algorithm was compared with Energy Efficient Ant Based Routing (EEABR), Sensor-driven and Cost-aware ant routing (SC), and Termite Hill (TH) algorithms in terms of throughput, success rate, packet loss rate, energy consumption, and energy efficiency. The descriptions of the performance metrics are as follows:

- Throughput:** The number of successful packets per second arrived at the destination node from the source node.
- Success Rate:** The total number of successful packets arrived at the destination node per total number of packets sent from source node.
- Packet Loss Rate:** The total number of packets that failed to arrive at the destination node per total number of packets sent from source node.
- Energy Consumption:** The total energy consumed by sensor nodes during the experiments (Joules).
- Energy Efficiency:** Ratio of the total number of packets arrived at the destination node per total energy consumed by all sensor nodes.

All experiments were conducted using 9 (3 x 3), 25 (5 x 5), 49 (7 x 7) and 100 (10 x 10) sensor nodes in 100 seconds simulation time. Table 1 shows the simulation parameters used in the experiments. The simulation parameters are adopted from the research work of [25] except for the number of sensor nodes. The source node and destination node type can be static, dynamic, or mobile. However, for this set of experiments, the source node and destination node are set to be in static mode. The source rate is the number of packets sent per second while the destination rate is the number of requested packets per second by the destination node. Traffic data in these experiments is defined as Constant Bit Rate (CBR) where static amount of bandwidth is supplied during the experiments. The speed of transferring packets is set to 250kbps.

Figure 2 depicts the comparison between the throughput of EACS, EEABR, SC, and TH when sending packets for 100 seconds using different number of sensor nodes which are 9 nodes, 25 nodes, 49 nodes, and 100 nodes. It can be seen that the proposed EACS algorithm has the highest and about the same number of received packets when using different set of sensor nodes in all experiments as compared to EEABR, SC, and TH.

Table 1. Simulation Parameters

| Parameter | Value |
|--------------------------------|-------------------------|
| Algorithm | EACS, EEABR, SC, TH |
| Number of Nodes | 9, 25, 49, 100 |
| Source Type, Radius, Rate | Static, Random, 1, 4 |
| Destination Type, Radius, Rate | Static, Random, 1, 0.5 |
| Data Traffic | Constant Bit Rate (CBR) |
| Data Rate | 250 Kbps |
| Simulation Time | 100 seconds |

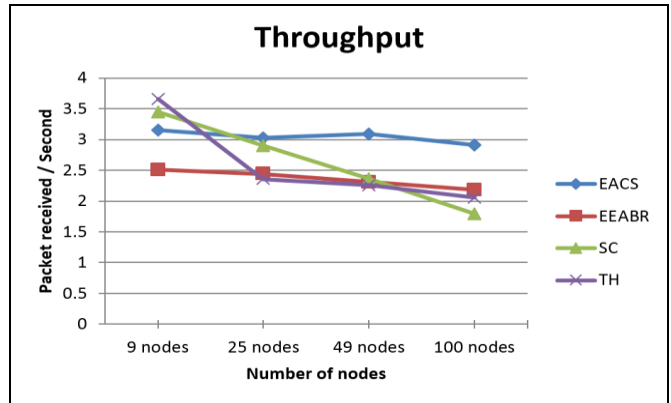


Figure 2. Comparison of throughput for different number of sensor nodes

From the results, the throughput has the same pattern as success rate where throughput is high when success rate is high as presented in Figure 3. Success rate is an important factor that needs to be considered because it shows the robustness of transmission path and quality of routing technique in ensuring the success of packet transmission.

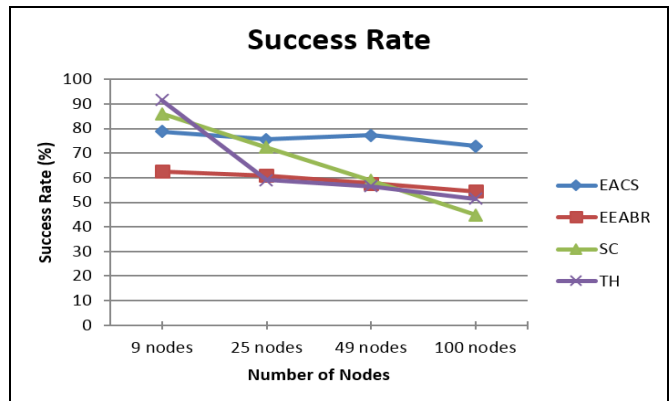


Figure 3. Comparison of success rate for different number of sensor nodes

Throughput is also influenced by packet loss rate during routing process where higher throughput is obtained for lower packet loss rate. As shown in Figure 4, packet loss rate contradicts the throughput value with EACS which has the lowest packet loss rate as compared to EEABR, SC and TH when routing packets in large number of sensor nodes (25 nodes, 49 nodes, and 100 nodes). However, for small number of sensor nodes (9 nodes), SC and TH have lower packet loss rate as compared to EACS and EEABR. This result is expected because EACS keeps track the conditions of each sensor node such as the energy level and pheromone value in determining the next node to construct close to optimal routing path that will eventually increase the throughput. Figure 5(a) shows the comparison of energy consumption for

all algorithms by using 9 nodes, 25 nodes, 49 nodes, and 100 nodes.

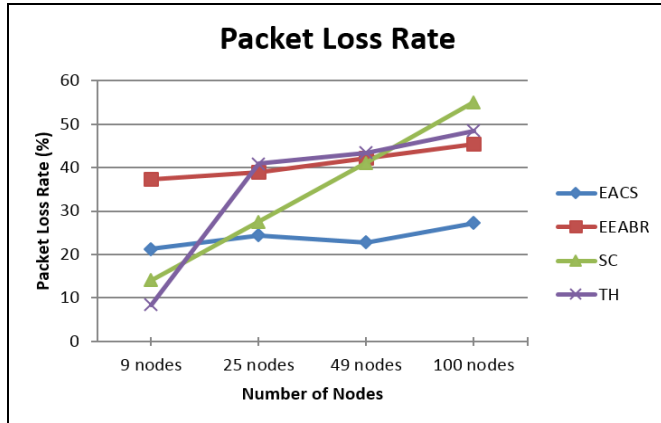


Figure 4. Comparison of packet loss rate for different number of sensor nodes

Based on the graph, TH has significant increment on energy consumption in parallel with the number of nodes as compared to other ant-based algorithms (EACS, EEABR and SC). This supports the fact that TH is only effective in small size network and requires a lot of energy to perform routing process in large size network.

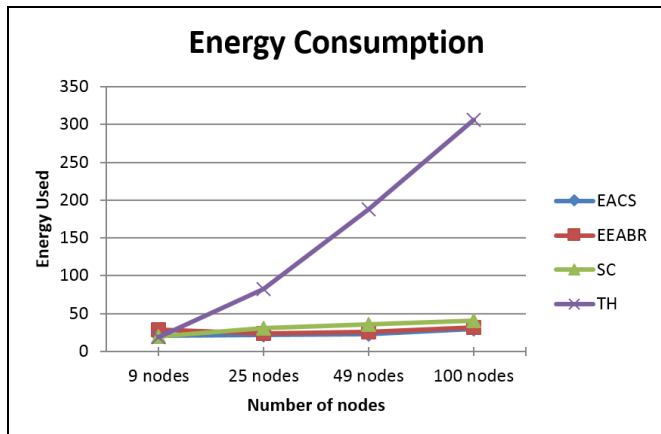


Figure 5(a). Comparison of energy consumption for different number of sensor nodes

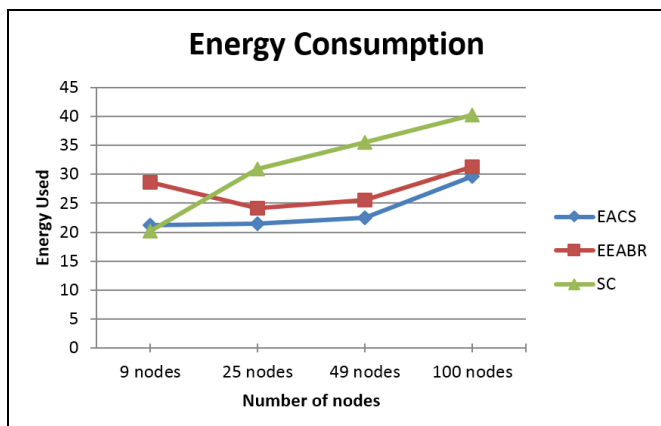


Figure 5(b). Comparison of energy consumption for different number of sensor nodes (without TH algorithm)

To further analyze the performance of EACS, comparison between ant-based algorithms (without TH algorithm) is shown in Figure 5(b). EACS has the lowest energy consumption when compared with EEABR and SC. In EACS, ants can communicate between each other by using

pheromone value to get updated condition of sensor nodes even for large size of network. At the same time, EACS considers the current energy of each sensor nodes in sensor nodes selection process. Both facts lead to lower energy consumption as the following ants can perform the node selection based on pheromone intensity and current energy instead of performing computation from the beginning.

The energy efficiency can be related to the number of received packets and the energy consumed by all sensor nodes. Figure 6 shows that EACS algorithm has the highest energy efficiency compared to other algorithms when 25 nodes, 49 nodes, and 100 nodes were used. It proved that EACS algorithm works better in large size network. On the other hand, TH has the lowest energy efficiency when the number of nodes is more than 9 nodes. This suggests that TH is not energy efficient in large size network which may lead to significant reduction of network lifetime.

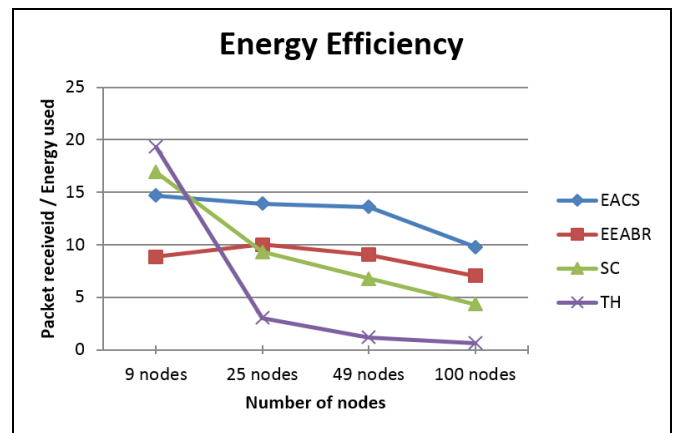


Figure 6. Comparison of energy consumption for different number of sensor nodes

Overall results showed that EACS performed better for all performance metrics as compared to EEABR, SC, and TH. EACS has the highest energy efficiency and this is reflected from the high throughput and low energy consumption. Energy efficiency is the main concern of all performance metrics because it gives the impacts to the network lifetime, the energy used by all sensor nodes, and the number of successful packets transmission in the system.

5. Conclusion

The proposed EACS algorithm focuses on improving the pheromone update technique based on the ACS algorithm. The local pheromone update is performed to increase exploration to the destination node through different edges, and the global pheromone update is performed to increase the pheromone value so that the optimal path becomes attractive to other ants. However, the experiments were only conducted in a static WSN environment. For future work, the proposed EACS algorithm can be experimented in a dynamic WSN environment and the packet priority aspect will be considered in improving the performance of WSN.

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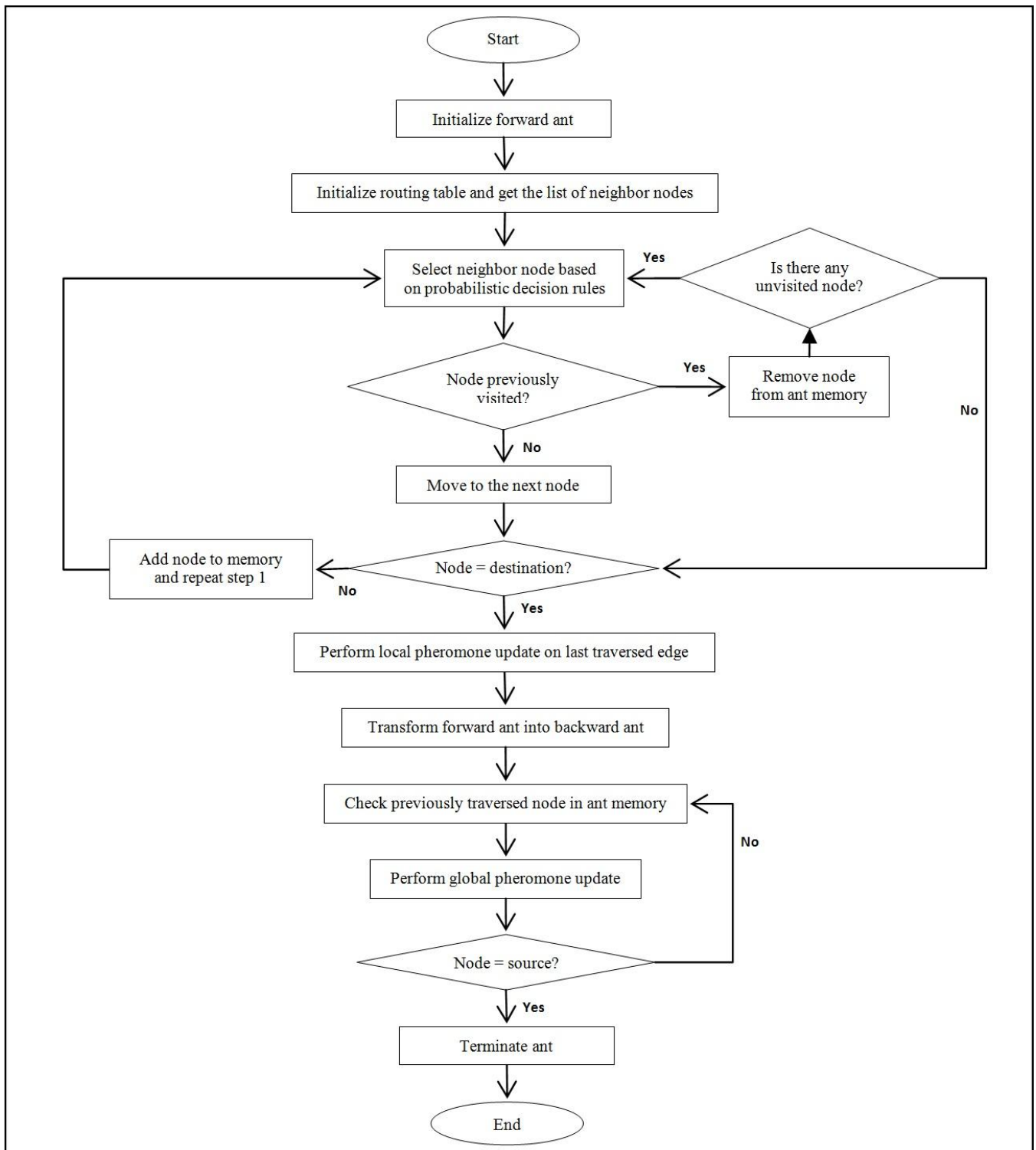


Figure 1. Flow chart of the proposed EACS