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Enhanced Aco Based Algorithm for Detection of Coverage Holes in Embedded Wireless Sensor Network

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ABSTRACT:Embedded Wireless Sensor Networks (EWSNs) coverage has become one of the most vital metrics that is directly connected to the quality of service (QoS) afforded by the Wireless Sensor Network (WSN). However, EWSNs have several challenges such as coverage maintenance, QoS provision, resource allocation and enabled widespread connectivity. Several researches have been geared towards the maximization of lifetime and efficiency of wireless sensor networks (WSNs). The review of many of such researches revealed their various shortfalls such as high communication overhead, poor quality coverage, high power consumption and time delay. To overcome these shortfalls, the algorithm developed in this work employed Ant Colony Optimization (ACO) technique to reduce system complexity and energy wastage in coverage hole detection by leveraging on the simplicity and distributed nature of the technique. The developed algorithm model was aimed at detecting coverage holes in wireless sensor networks (WSNs) which may result from improper sensor deployment, obstacles or energy depleted nodes.MATLAB software and OPNET Network simulator were used to stimulate and evaluate the efficiency of the proposed hole detection algorithm. Simulation result showed 25% reduction in number of ants required to detect 2 holes in the network compared to previous works.The developed algorithm also demonstrated that the efficiency ratio is an increasing function of the number of ants.

KEYWORDS: Ant colony, optimization (ACO), Sensor Networks (WSNs) Embedded Wireless, Sensor Networks (EWSNs), Coverage holes, Sensor nodes, Virtual Hole Angle (VHA).

I. INTRODUCTION

The tremendous progress in the field of embedded computer and sensor technology led to a new generation of wireless sensor networks known as embedded wireless sensor networks (EWSNs). Undoubtedly, EWSNs comprises of thousands of sensor nodes that are capable of performing sensing, actuating and transmitting of gathered information. Indeed, nodes in EWSNs are provided with limited resources such as battery power, memory and processing capacity together with unreliable wireless communication. Development of embedded system and technology of integration and miniaturization have produced several devices and machines with embedded ability communication and computation. Embedded system ranges from small devices such as sensors to portable devices. Complex embedded system requires the cooperation of individual components. Wireless Sensor Networks (WSNs) are products of such cooperation.

However, new class of miniature and embedded wireless devices known as motes are networked to form wireless sensor networks. Wireless Sensor Networks can be best regarded as self-organized wireless ad hoc networks which are made up of large number of support constrained sensor nodes. Applications of WSN tend to revolutionize people way of life [1]. In WSNs, the key areas of study focus are on architecture, data aggregation, operating system, communication, synchronization, hardware, deployment, security issues and localization coverage.

II. REVIEW OF RELATED WORKS

In recent years, research in the field of WSNs has gained popularity. In this section, we summarily discussed some of the related works on coverage hole detection and improved coverage quality using ant colony optimization technique. Ant colony optimization technique is one of the most thriving swarm intelligence methods use in solving combinatorial challenges. However, it is inspired by the behaviour of some ants when in search of their food. In [2], the authors proposed an algorithm for potent detection of holes boundary. Here, each node sends broadcast information to all its surrounding neighbours. In a situation where one of the neighbour nodes discovers a hole, it evaluates the distance between itself and the hole. It resends a message to the source node with the new information. The source receives all data from all nodes and set up the hole boundary region. The major disadvantage using this technique remains that all the available nodes were used to detect the boundary holes. The method consumed a lot of energy in transmitting the packets and thus, increased number of packets drop.[3] applied sentinel scheme algorithm to minimize the sleeping node detection density by outlining a new intense sleeping method. Network durability and power consumption are the key factor to be considered when calculating the detecting rate. Moreover, the coverage holes are treated by applying a triangular coverage repair process to heal the coverage hole.[4] proposed an algorithm to discover boundary holes in a particular region of interest ROI. The system of operation depends on link between each node and three other of its neighbor nodes to decide the stuck node. The stuck node is the last node to transfer the message. There are many draw backs in this method among which are: the algorithm detects holes of certain sizes only, there is tendency of large message forwarding overhead and boundary detection does not work well for large density nodes. Also, they did the boundary detection by comparing only one hop neighbour and the proposed method did not calculate the holes area.Authors in [5] proposed an ACO approach with sub-premier nodes possessing high link-gap connectivity factor. Premium node selection was based on bandwidth integrity with eternal energy factor. The simulated result achieved efficiency up to 30% when compared with previous works.Irregularity model described as quadruplet (n, R_{irr} (i), R_{th} and R_{irr} env (i)) to develop a scheme which detected holes in radio irregularity range was applied by [6]. It was observed that the proposed method detected internal holes at different levels of irregularities. 50 sensors were deployed in a field of surface area of 200m x 200m. The simulation result showed variance between irregular radio ranges based on different directions. The higher the irregularity level, the higher the variance. Therefore, as the percentage values of irregularity increases, the radio range gets more and more irregular. The proposed method by [6] discovered internal holes, but failed to proffer solution on how to repair the detected holes to optimize the network coverage. However, [7] developed ACO algorithm for coverage hole detection under radio irregularity. Minimal cycles bonded with extra nodes were obtained due to uncontrollable variations on its radio sensing range. To regain the exact minimal cycles experiencing holes, additional procedure was added to the initial proposed algorithm. With MATLAB 7.0 simulator, the result obtained showed a robust and scalable network. But, employment of extra procedure to the initial developed algorithm caused quick energy depletion, needed more ants and time consuming. Meta Heuristic Termit e Colony Optimization (TCO) approach to enhance minimal number of sensors and at the same time maximizes the covered region was proposed in [8]. A flow chart and Pseudo code were used to develop TCO algorithm and simulated with MATLAB version 7.12.0. The simulated result was compared with other metaheuristic approaches. The result yielded scalable and robust outcome, but did not put power level constraint into account. [9] developed Swarm inspired Artificial Bee Colony (ABC) in combination with Artificial Neural Network (ANN) approach for optimization of shortest path and detection of holes for repair. ABC optimized the shortest path by selecting correct fitness function, while ANN detects holes repair nodes. Their simulation resulted in energy conservation of about 23.88% when compared with previous approaches.Authors in [10] proposed hybrid or combination of Artificial Bee Colony (ABC) and Ant Colony optimization algorithms to solve a non-deterministic Polynomial (NP) and finite challenges of WSN. The combined algorithms ABCACO were divided into three parts: (i) Optimal number of sub regions (ii) Cluster head selection with ABC algorithm and (iii) efficient data transmission with ACO algorithm. They used hierarchical clustering technique for data transmission. The data was sent from member nodes to the sub cluster heads and from sub cluster heads to the elected cluster heads depending on some threshold value. The cluster head used the

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ACO algorithm to find the best path for data transmission to the base station. The result shows that ABCACO hybrid algorithm enhances the network stability by 60%, as well as improving the throughput by 30% when compared to LEACH and WSNCABC respectively.

III. METHODOLGY

This work developed an enhanced ACO based algorithm for the detection of coverage holes in embedded wireless sensor networks (EWSNs). The WSN was for water pipeline deployed to monitor leakages in the infrastructure. The sensors were static and remained fixed after deployment. Micro Electro Mechanical (MEM) accelerator sensor was connected to the pipeline. The sensor measures the surface acceleration of the pipeline as a result of the flow rate of water contained in the pipeline. Surface acceleration is generally used to deduce leakages when it occurs. A typical acoustic leak correlator has portable computers and microprocessors which analyze the signals from both transducers and discover location of leak based on the delay as well as the acoustic speed [11]. When leakage occurs, the surface acceleration changes due to change in the pressure. The sensor detects and transmits the information direct to the online server as indicated in figure 1.

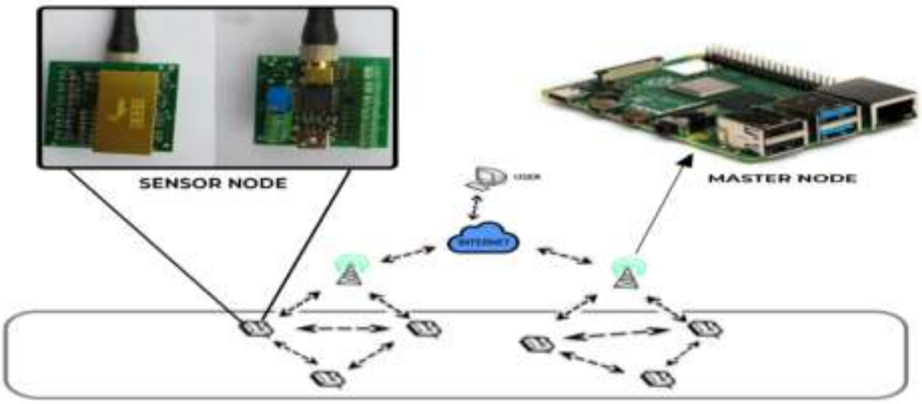

Figure 1: Circuit diagram of water pipeline sensor network(Aljuaid et al, 2020).

The MOSFETs used are (IRF3205) which act as current amplifiers and amplify the current from 1 amp to 3 amps. Two solenoids are placed on the inlet and exhaust valves the piston of the solenoid is directly connected to the valve using a rubber tubing for motion transfer. Each solenoid consists of two set of copper windings with 12 mm dia,20 turns and 8 layered both the solenoid are oppositely connected and when actuated two sets of opposite windings get magnetized ,the piston inside solenoid moves up closing the valve the alternate valve is opened. The solenoids are rigidly placed over the cylinder head with the help of wood powder and glue which turns into concrete strong upon drying up. A solenoid is simply a specially designed electromagnet. A solenoid usually consists of a coil and a movable iron core called the armature. Here's how it works. When current flows through a wire, a magnetic field is set up around the wire. The sensor node illustrated in figure 1 was designed and developed based on commercially available components. The microcontroller of the sensor node is a PIC16LF1827 microcontroller and its RF transceiver is an eRA400TRS 433 MHz transceiver. The other main component used is the sink or the master node, which is a Raspberry pi.

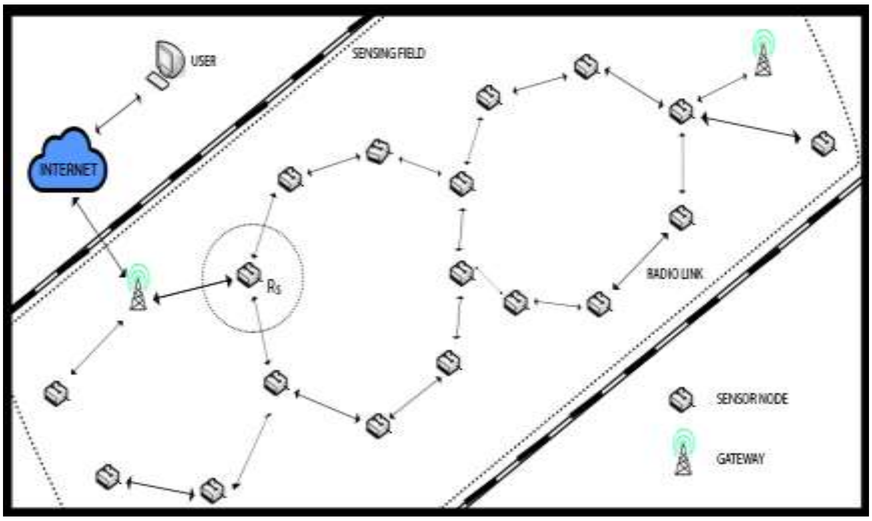

Figure 2: WSN Architecture

From the architecture shown in figure 2, the maximum sensing range of each sensor is R_s with communication range of $R_c = 2R_s$. In the developed architecture, the nodes are mapped with cycles as shown in figure 3, representing a sequence of nodes namely $S_1, S_2, \ldots, S_n$, *where* S_{i+1} is the neighbour of S_i, S_n is the neighbour of $S_1, n \geq 3$ and $\forall\, i \neq j, S_1 \neq S_j$. For any cycle that does not contain any cycle in its interior, it is called a minimal cycle.

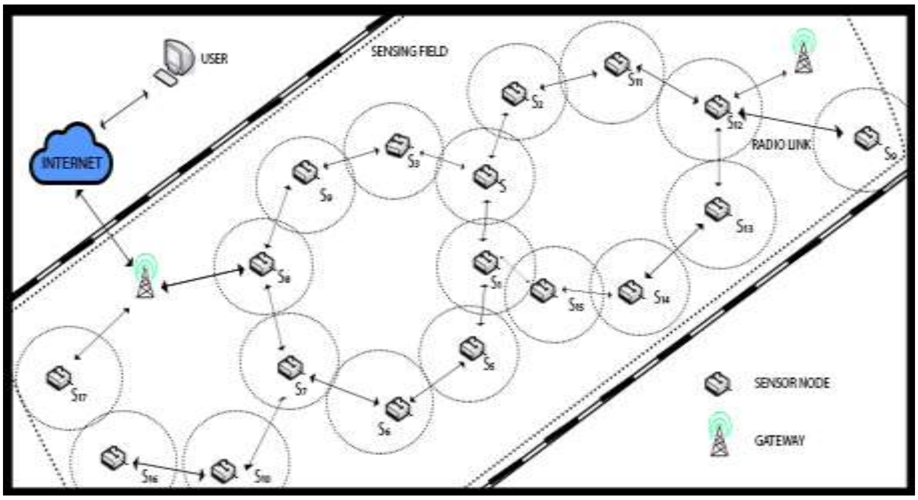

Figure 3: Cycle Illustration

In this scheme, coverage holes were and the network architecture was analyzed to identify minimal cycles. It is important to note that all angles of a minimal cycle are referred to as Virtual Hole Angle (VHA). The VHA is an oriented angle ($\widehat{S_1, S, S_2}$) as shown in figure 4 formed by two (2) edges SS_1 and SS_2, where S_1 and S_2 are two (2) neighbour nodes of node S, S_1, *and* S_2 are not themselves neighbours, and S does not have any other neighbour between S_1 *and* S_2.

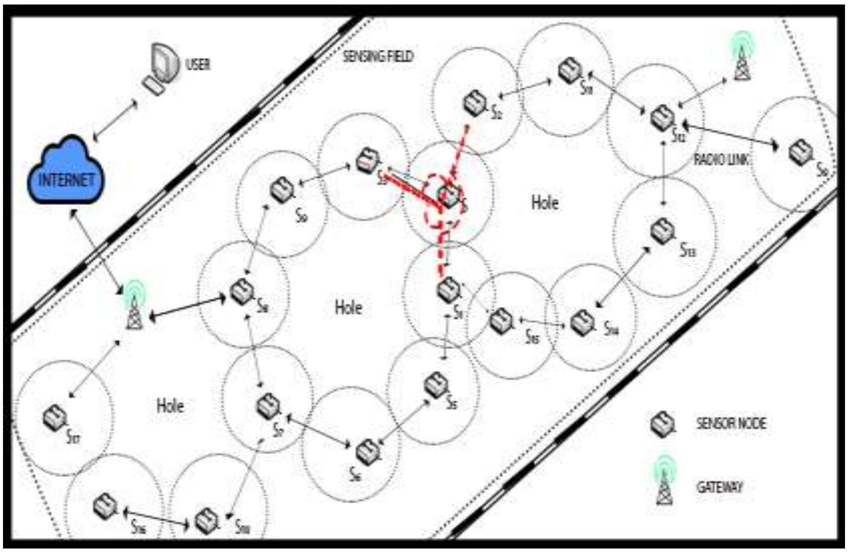

Figure 4: Virtual Hole Angle

To detect a coverage hole, it is assumed that a minimal cycle bears at least a non-hole angle taken as $\widehat{S_1,S,S_2}$. It implies that the summit S has one neighbour s', in between its neighbour nodes S_1 and S_2. Two conditions can be established here. First, S_1 or S_2 or both of them are neighbours of s'. It means that the cycle accommodates another internal cycle that differs with the minimal cycle definition. Secondly, s' is linked only to S and as a result the sequence of the node cannot be considered as a cycle being that node S will show up twice in the sequence. Hence, it is concluded that establishing or finding virtual hole angle can as well lead to identifying minimal cycles in the WSN. From figure 4, two (2) VHA are identified, which are $\widehat{S_1,S,S_2}$ and $\widehat{S_1,S,S_3}$. This also helps to establish two minimal cycles, which are: $S,S_1,S_5,S_6,S_7,S_8,S_9,S_3$ and $S,S_2,S_{11},S_{12},S_{13},S_{14},S_{15},S_1$. The described technique is employed by the Ant Colony-based algorithm.

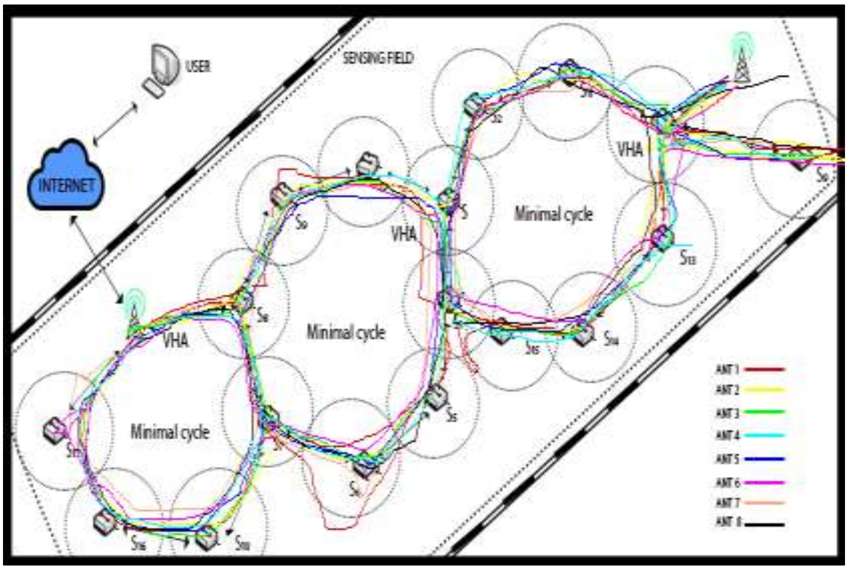

Figure 5: Simulation Image showing minimal cycle discovery using 8 ants.

In order to avert ants from loping endlessly in the same path, it was assumed that ants indicated each visited nodes as shown in figure 5. Whenever an ant makes a tour, the quality or intensity of pheromone deposit τ_{ij} on each visited edge (ij) is

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regularly updated with the formula Dhouha et al, (2017):

$$\tau_{ij}(t+1) = \tau_{ij}(t) + \varepsilon \quad (1)$$

Any time an ant visits a node, it lays a measure of pheromone at this node. The additional rate of this pheromone is equivalent to ε. Though, on every iteration, pheromone on each node melted and disappeared according to the rate P. Being that ants select nodes with big labels with greater chance, they promote nodes which are vulnerable to be part of minimal cycles. The pseudo code of the algorithm is as shown below:

Pseudo code of ACO-based hole detection Algorithm

//Algorithm to detect the hole emanating from VHA $(S_1,\widehat{S,S_2})$.
Initialize ACO parameters
Set the initial pheromone and heuristic value
presentNode $\leftarrow S$ *//Algorithm assigns summit to present node*
for t =1 to iteration // Where number of iteration is randomly assigned
    for $p = 1$ *to NodeNumber*
$\tau_p(t+1) = \tau_p(t) + \varepsilon$ *// calculate and update pheromone intensity*
end
for $\boldsymbol{A} = 1$ *to antnumber*
$R^A \leftarrow S$ *// Assign summit to tour route for each ant*
Self − assessment by each node to discover if it's summit of VHA
Each node records label value
If (node label > 1*)*
Launch ant
while (the ant **A** *has not finished it tour (has not got to the destination* **S**))
Increase pheromone intensity on node visited
determine group of Neighbors of present node Neighbor (presentNode)
determine the probability $\mathbf{P}^A$ *for all the neighbors of the present node using equation* 3.1
select nextHop Node from Neighbor (presentNode) according to $\mathbf{P}^A$
while nextHopNode belongs to R^A
update nodes visited by ant considering pheromone intensity
select nextHopNode from Neighbor (presentNode) according to $\mathbf{P}^A$
end while
presentNode = nextHopNode
$R^A = R^A \cup \{presentNode\}$
end while
update the pheromone density of all routes R^A *as stated by equation* 3.2
end for
nodes in all routes R^A *that contains the most essential quantity of pheromone*
are nodes developing minimal cycles

IV. SIMULATION AND RESULTS

Table 1: Simulation Parameters

PARAMETERS	VALUES
Surface area	$500m^2$
Number of sensor Nodes	50
Communication range (r_c)	15m
Pheromone addition/pheromone evaporation rate (ε,ρ)	0.2
Adjustable weights (α,β,θ)	0.1

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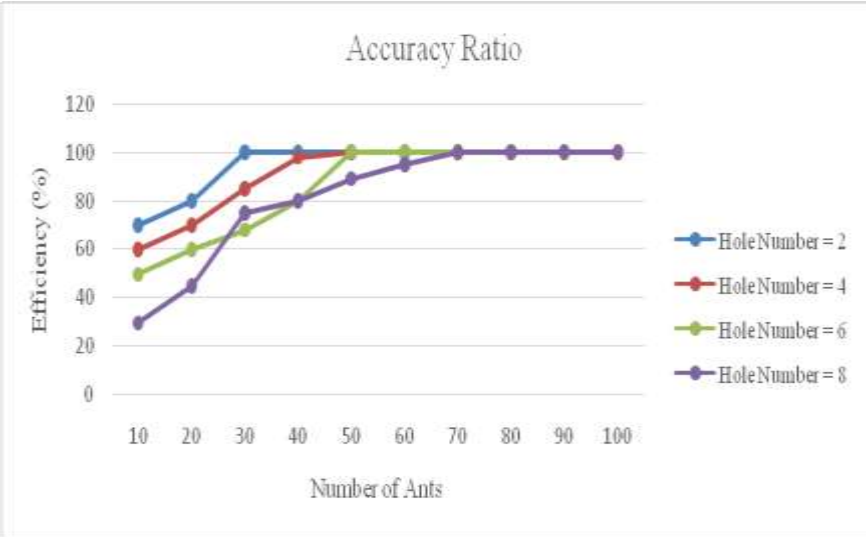

Figure 6: Simulation results of Accuracy ratio for developed algorithm

Scenario 1: Accuracy test

Under this scenario, simulations were carried out to decide the accuracy level of the developed algorithm. The accuracy ratio shows the ratio of the number of detected holes by the total number of holes in the network. The accuracy ratio determines the efficiency of the hole detection method being used. The simulation environment was designed to vary the number of holes per simulation and the amount of ants deployed to attain a high accuracy level was noted.

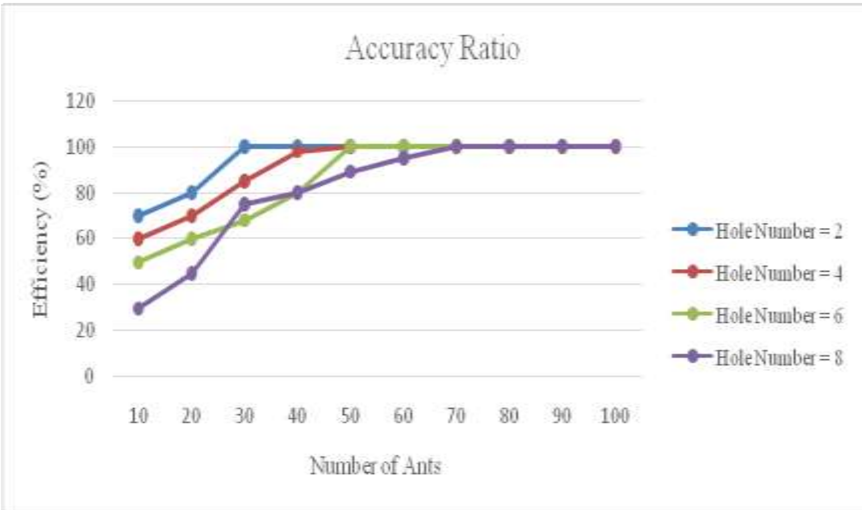

Figure 6: Simulation results of Accuracy ratio for developed algorithm

From the simulation, it was observed that the accuracy ratio or efficiency of the algorithm increased as the number of ants deployed increased. As can be seen from figure 6, the ratio is an increasing function of the number of ants and varies from 30% with only 10 ants to 100% with 70 ants for a total number of holes equal to 8. This shows that more ants will be launched by VHA nodes and more nodes of the network will be visited and marked with the ant's pheromone, hence the more boundary nodes will be discovered.

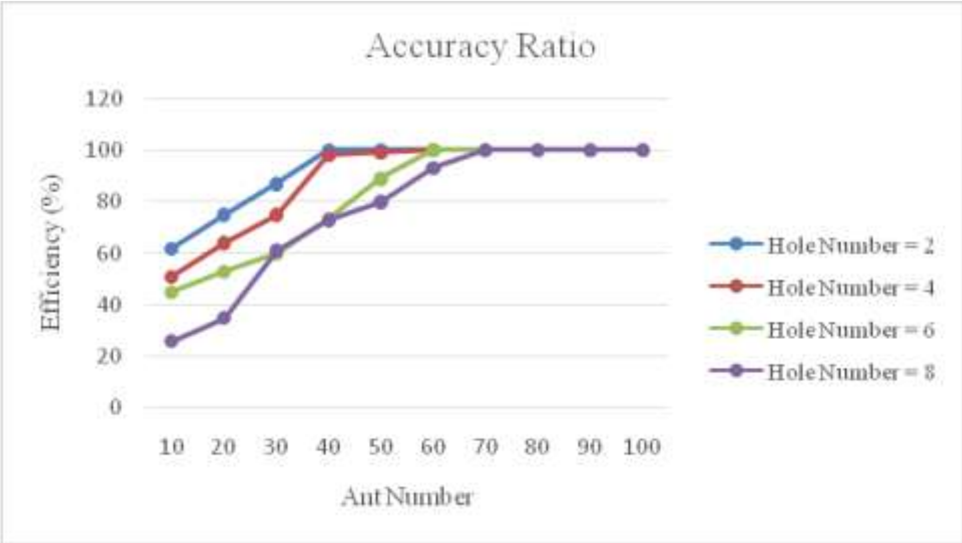

Figure 7: Accuracy ratio for the developed algorithm when compared with Dhouha, 2017.

As can be seen from figure 7, the number of ants needed to achieve 100% accuracy when the number of holes is 2 for the algorithm by Dhouha (2017) is 40, while that required by the developed algorithm in this work is 30. This shows a 25% reduction in the number of ants required to detect a hole in the network. As the number of holes are increased, it was also observed that the accuracy level of the developed algorithm exceeded that of Dhouha (2017). For instance, as at 8 holes, when about 60 ants were deployed, the accuracy level was 85% for Dhouha et al, (2017), while that of the developed algorithm was 89%. This accounts for a reduction in resource demand and promptness in mapping a minimal cycle.

Scenario2: Impact of Iterations

Iteration refers to the number of times where every VHA node will re-launch a set of ants to execute the proposed algorithm. Therefore, as the number of iteration increases, the ants will do additional work (during additional periods of time) to detect holes. Thus, they deposit additional pheromone quantity on the nodes encountering these holes.

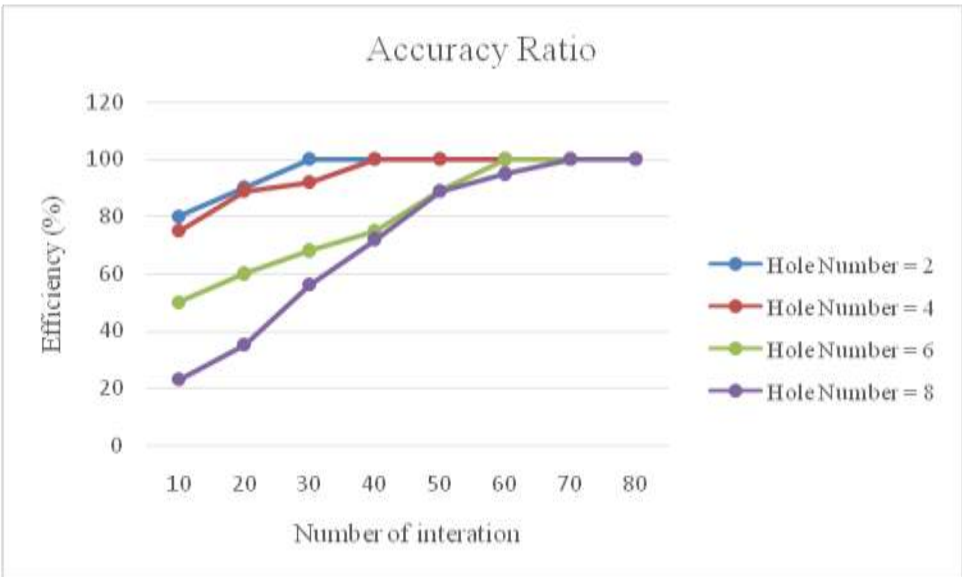

Figure 8: Accuracy ratio for developed algorithm as a function of number of iteration.

Consequently, as the number of iterations increases, the more holes are discovered and thus the efficiency ratio is enhanced. Moreover, it is important to note that the efficiency ratio is better with a smaller number of total holes. This can be explained by the fact that as more holes are scattered in the network, more time is needed to detect them all with the same number of ants (see figure 8)

Scenario3: Impact of hole length

The plot of figure 9 shows the variation of the hole detection efficiency ratio as a function of the number of ants for hole lengths ranging from 5 to 20. Simulation was carried out using a number of iterations equal to 10. It can also be seen that the efficiency ratio is an increasing function of the number of ants. For a hole length of 5, it was observed that about 20 ants were required to detect it. Moreover, when the hole length increased to 10, about 30 ants were required to detectthe hole. This establishes a relationship between the hole length and number of ants, such that the longer the hole, the more ants are required to detect its entire link.

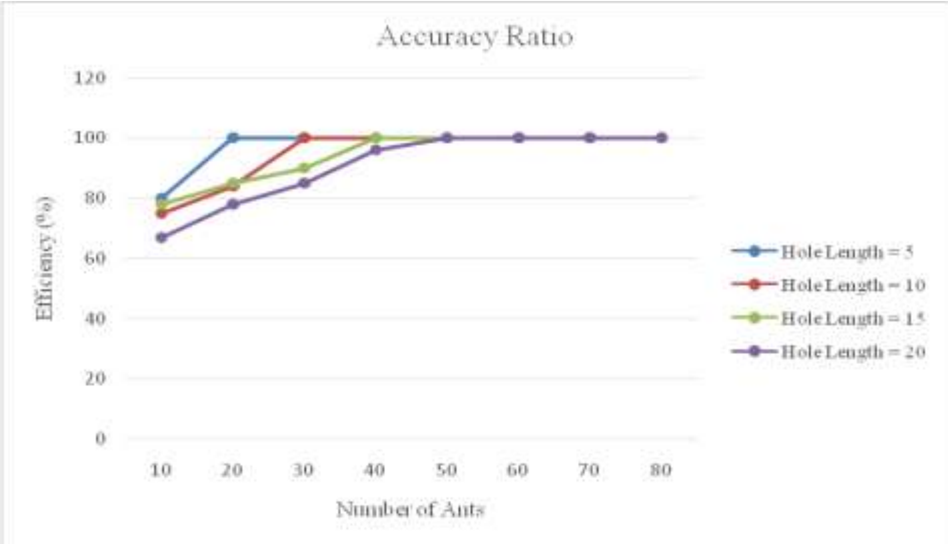

Figure 9: Accuracy ratio for developed algorithm as a function of hole length

V. CONCLUSION

Coverage quality is one of the fundamental tests for quality of service provision in wireless sensor networks (WSNs).This work has established a novel method Ant Colony Optimization (ACO) that is ideal in tackling coverage hole detection problems in WSNs for two reasons. First, ACO is a distributed technique which does not require exchange of neighborhood information. Secondly, the technique created opportunity for adjustment in the number of ants needed to detect holes irrespective of the network topology. The simulation result showed that the developed algorithm enhanced the system coverage performance compared to existing methods in terms of efficiency, robustness, reduction in resources demand and quick mapping of minimal cycles. Lesser number of ants were launched through the virtual hole angles (VHAs) to achieve efficient result. They also travelled through the shortest path, thereby saved time and energy. For further studies, these sensor nodes need to be deployed in a more complex environment such as an agricultural farmland to discover the effect of some environmental factors on hole detection for coverage quality.

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