International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 11 Issue 2 ǁ February 2023 ǁ PP. 239-246

Coverage Hole Detection in Embedded Wireless Sensor Network Using ACO Based Technique: Comparative Architecture

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Abstract
In this work, an ACO based algorithm was developed for coverage hole detection for embedded WSN. The algorithm employed communication information collected by ants as they trail the sensing field to map coverage holes. The developed method required the creation of simulated test environments that were as close to real-life conditions as possible. To demonstrate the robustness of the algorithm, two different WSN architectures were considered. The first WSN architecture was a water pipeline, while the second was a farm land for precision agriculture. The two architectures were simulated to compare leakage detection as a function of hole length. The performance of the developed algorithm was analyzed under diverse conditions. MATLAB software and OPNET Network simulator were applied for this simulation.To validate the results obtained, the performances were compared with an already existing design by [1]. The accuracy ratio test was used to evaluate the accuracy level of the developed algorithm under different conditions. The results obtained showed 25% reduction and 15.3% reduction of the amount of ants needed to map the coverage holes in the first and second WSN architectures respectively when compared with [1].
KEY WORDS: *Ant colony optimization (ACO), Coverage holes, Embedded Wireless Sensor Networks (EWSNs), Sensor nodes, Wireless Sensor Networks (WSNs), Virtual Hole Angle (VHA).*

Date of Submission: 10-02-2023 Date of acceptance: 21-02-2023

I. INTRODUCTION

The growth of embedded system, technology of integration and miniaturization of sensors have yield several devices and equipments with embedded capability of communication and computation.Complex embedded system demands the cooperation of separate components into performing a particular function. Wireless Sensor Networks (WSNs) are products of such cooperation. Wireless Sensor Networks (WSNs) can be best described as self-organized wireless ad hoc networks which comprise large number of supported limited sensor nodes. In WSNs, the fundamental bases of research are on architecture, communication, data aggregation, deployment, operating system, localization coverage, synchronization andsecurity issues. Evolution of WSN originally received boost by military applications such as battlefield surveillance and later advanced in numerous applications like healthcare, systematic health monitoring, traffic control, home automation etc. Greater number of these applications requires complete coverage and reliable connectivity [2]. For instance, during border surveillance, sensors are randomly scattered via airdropping even on the border line. This causes a limitation in the coverage area and the result creates detectable holes. Sensors can be sprayed on machines, roads and walls etc. for monitoring vehicular movements, tracing of job flows in factories and offices, monitoring of supply chain in smart companies. Each node in a sensor is furnished with different sensors, radio transceiver, power source (battery) and a microcontroller. Wireless sensor networks (WSN) have spatially distributed sensors with one or two sink nodes (base stations) [3]. A sensor node can provide duel functions as data source or data router, while sink node collects data from sensors [4].

Also, sensor nodes use battery as source of power supply. Rapid power depletion experienced by sensors nodes lead to appearance of number of holes. To handle coverage problems in WSNs, holes is required to be detected, located and be healed or optimized in an efficient manner. It can be accomplished by finding out nodes surrounding boundaries of the hole.When coverage holes are detected, it can either be mitigated or utilize the information to optimize the performance of the existing routing procedure [5].

II. RELATED WORKS

A lot of research works done in this area had tried to solve coverage holes problems with several proposed detection approaches. These schemes can be classified in three categories: geometry, statistical and topological bases.

The geometry approaches usevoronoi diagram for perfect hole detection in WSNs which makes them to be deterministic in nature. In statistical method, nodes in wireless Sensor Networks are presumed to be joined by probability distribution. On the other hand, topological approach uses connectivity information to detect nodes that enclose boundaries. Typically, topological method does not need geographical information, but can have high packet overhead. Packet overhead in this scenario is caused as a result of exchange in neighborhood information [6]. In [6], the authors described the sensor network on communication graph which is plotted to identify hole boundary nodes. The plotted communication graph could be analyzed based on a given algorithm to detect the number of holes and their locations too.

[7] used Rips complex homology theory to design a wireless sensor network and developed connectivity-based algorithm for discovering boundary cycles of non-triangular k-coverage holes. The k-coverage algorithm work in two parts; I-coverage hole detection and coverage degree reduction. Boundary cycle of I-coverage holes are discovered in I-coverage hole section. But in the coverage degree reduction sector, free covering subset of nodes for the covered area is detected. These nodes are put in dormancy state to reduce of the coverage degree of the target area by one. The simulation result showed that over 95% of non-triangular – coverage holes could be perfectly detected with this algorithm.

[8] presented a distributed solution for boundaries and hole detection in wireless sensor Networks with the use of node connectivity information and evaluated distance between nodes. It was achieved in four key phases: Node discovers its coverage neighbors and gather their information, node communicates with its neighbors to know if its sensing range is wholly covered by the sensing ranges of its neighbors, boundary node connects with each other and finally a boundary sub-graph among boundary nodes is put up and classified either as an interior or an exterior boundary. The simulation result showed that the proposed algorithm was efficient with improved energy and as well reduces the number of boundary nodes.

[9] identified coverage-hole based on the concept of Delaunay Triangulation (DT) and Empty Circle property. The hole-area was evaluated using inner Empty Circle (IEC) property which enhanced the existing Empty Circle (EC) property. The results proved that the IEC technique was much accurate compared to the traditional EC technique in hole-identification, coverage hole number, hole-area estimation and hole-discovery time.

[10] evaluated a wireless sensor network where mobile sensor nodes are randomly used over a two-dimensional region. Coverage hole healing algorithm was applied to maximize and detect coverage holes based on Delaunay triangulation. Its simulation result demonstrated on effective edge over previous approaches such as VFA, VEDGE and HEAL because the total sensor nodes moving distance is reduced.

[11] studied hybrid sensor network using Delaunay theory to estimate static sensor coverage holes, evaluate the number of assistant mobile sensors and calculate the positions of assisted mobile nodes in each triangle. Finally, mobile sensors go in to heal the coverage hole. The experimental result shows it as a simpler technique and also gave room for quantitative evaluation of number range of assisted sensors compared to previous works.

III. METHODOLGY

In this section, we developed an improved algorithm to compareleakage detection and monitoring in wireless sensor networks (WSNs) using two variable environmental settings. Sensor nodes were deployed in two different environments (water pipeline and a more complex environment such a precision agricultural farmland) to monitor leakages. The sensors when deployed are static and fixed. Micro Electro Mechanical (MEM) accelerator sensor was connected to the pipeline. This sensor measures the surface acceleration of the pipeline as a result of the flow rate of water contained in the pipeline. Surface acceleration is used to deduce leakages when it occurs. A typical acoustic leak correlator has portable computers and microprocessors which analyze the signals got from both transducers and discover location of leak based on the delay as well as the acoustic speed [12]. When a leak occurs, the surface acceleration changes because of the change in pressure. Hence, the sensor detects that and transmits the information direct to the online server indicated in figure 1[13].

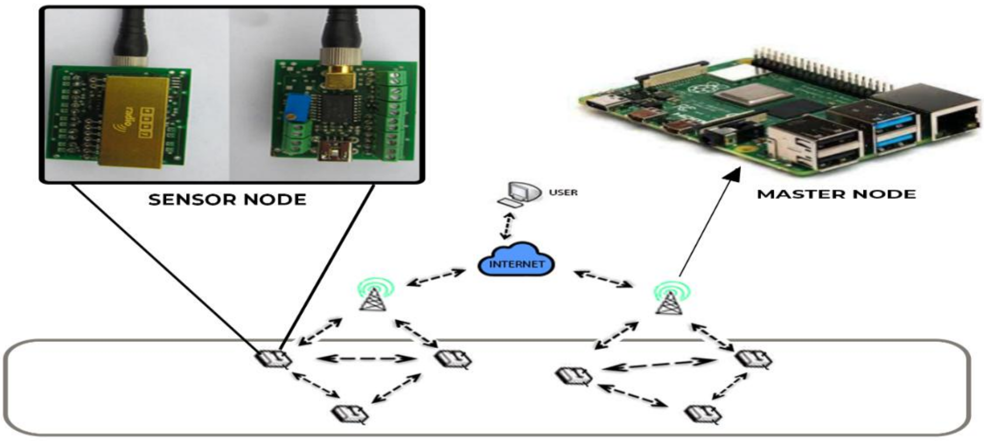

Figure 1: Circuit diagram of water pipeline sensor network[13].

The microcontroller of the sensor node was 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.

The algorithm being developed in this work aims at detecting coverage holes in the WSN which may result from improper sensor deployment, obstacles, or energy depleted nodes. From figure 2., coverage holes are a set of points in the WSN that are surrounded by a minimal cycle. These points are not covered by any sensor forming this cycle. This is illustrated in figure 2.

In this scheme, to identify coverage holes, the network architecture is analyzed to identify minimal cycles. It is important to note that all angles of a minimal cycle are referred to as Virtual

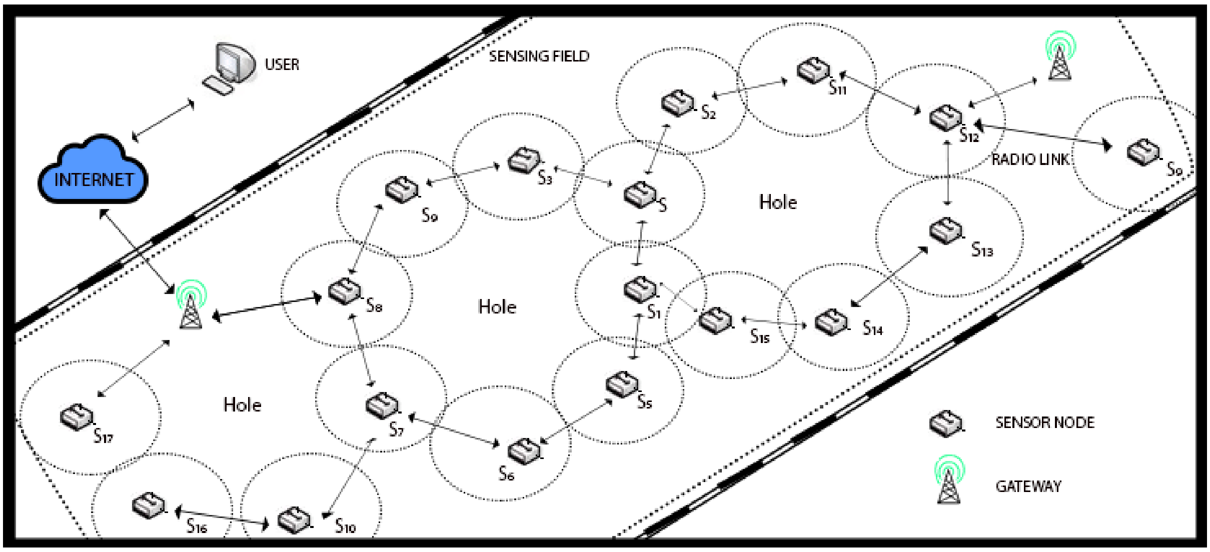

Figure 2: Coverage Holes illustration

Figure 3: Devices that made up the precision agriculture farmland used in this work.

The image above shows all the sensors used for the WSN deployed in the farmland for precision agriculture. The GSM module enables the wireless communications of sensor data (i.e. from Humidity sensor, temperature sensor, soil moisture, and PH sensor) from the Arduino to the sink (Raspberry pi).

3.4 MODEL TO EVALUATE THE MAXIMUM NUMBER OF ANTS TO LAUNCH

For the purpose of research and discovery of holes in a wireless sensor network, it is important to assess the highest number of ants that should be introduced into the network. According to poison distribution, we assume that holes show up in a surface S at a rate A within the network. Another assumption is that S can disjointly divided into sectors $L(\theta i), i \epsilon\{1 \dots p\}$ which defines the fixed surface of the angle θ_i and the distance of the longest route taken by each ant in that direction. The probability density of getting K_i number of holes in the surface $L(\theta_i)$ is given as [1]:

$$P(K_i, \theta_i) = \frac{exp^{-\lambda L(\theta_i)} * (\lambda L(\theta_i))^{K_i}}{K_i!} \quad (1)$$

Also, probability of having K_i holes in a particular sector i delimited by θ_i and θ_{i+1} is shown in equation 2 below:

$$P(K_i) = \int_{\theta_i}^{\theta_{i+1}} P(K_i, \theta_i) d\theta \quad (2)$$

Assuming that the surface $L(\theta_i)$ contains n_i sensor nodes, the estimated number of ants needed to find K_i holes in $L(\theta_i)$ is represented by equation 3.

$$n_{ants}^{i} = n_i \times P(K_i) \quad (3)$$

Suppose, $\theta_{i+1} - \theta_i < \theta_{max}$, the upper limit of the number of ants is expressed by the following inequality:

$$N_{ants} \le \sum P(K_i).n_i.\theta_{max} \quad (4)$$

$\forall i, P(K_i) \le 1, thus$

$$N_{ants} \le \sum n_i.\theta_{max} = \theta_{max} \sum n_i (5)$$

If we take $N = \sum n_i$as the total number of sensor nodes used in the network, then:

$$N_{ants} \le N.\theta_{max} (6)$$

(maximum number of ants used in the network)

Having established pseudo code for ACO based detection algorithm and model to evaluate the needed number of ants to be launched, test beds were set up for simulation.

IV. SIMULATION RESULT ANALYSIS

The algorithm was simulated in the two different WSN architectures as afunction of hole length. To validate the result, comparism was drawn with existing work in [1]. The network covers a surface area of 500m^2 and accommodates about 50 sensor nodes in the pipeline WSNs architecture, while the WSN architecture deployed over a farm land for precision agriculture covers a surface area of about 1500m^2 containing about 130 sensor nodes.The communication range (r_c) chosen for each node for WSN architecture is 15m. To evaluate the performance of the proposed algorithm, holes are artificially created in the considered network field using uniform distribution on the sensing area. Boundaries of each created hole are noted down. The pheromone addition rate (ε) and pheromone evaporation rate (ρ) are set to 0.2 respectively. Parameters ∝, β and θ are all set to 0.1 respectively, so that the pheromone quantities in addition with heuristic values equitably affect sensor decision in choosing the next hop node.

TABLE 1: SIMULATION PARAMETERS

SIMULATION PARAMETERS	WATER PIPELINE	AGRICULTURAL FARMLAND
Surface area	$500m^2$	$1500m^2$
Number of sensor Nodes	50	130
Communication range (r_c)	15m	15m
Pheromone addition/pheromone evaporation rate (ε,ρ)	0.2	0.2
Adjustable weights (α,β,θ)	0.1	0.1

Consideration was done to analyze the impact of hole length on the accuracy ratio. Note, the number of nodes are referred to as the hole length.

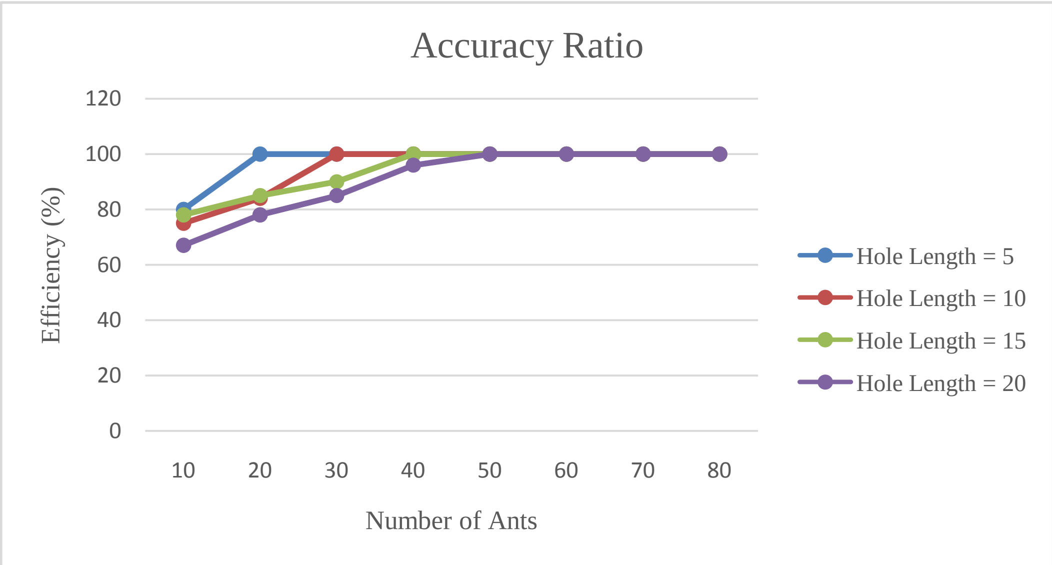

Figure 4: Accuracy ratio for developed algorithm as a function of hole length for first WSN architecture

The plot of figure 4 shows the variation in hole detection efficiency ratio as a function of the number of ants for a set of hole lengths ranging from five (5) to twenty (20). The simulation was conducted underten (10) iterations. From figure 4, it can also deduct that an increase in the number of ants increases the efficiency ratio. On observation, a hole length of 5 require about 20 ants to detect it. Moreover, when the hole length goes up to 10, about 30 ants were needed to detect the hole. This as result helps in establishing a relationship between the hole length and number of ants. An assertion that the longer the hole, the more ants are required to detect its entire links is drawn. Similar simulation was also carried out in the second WSN, and the result is as shown in figure 5 below.

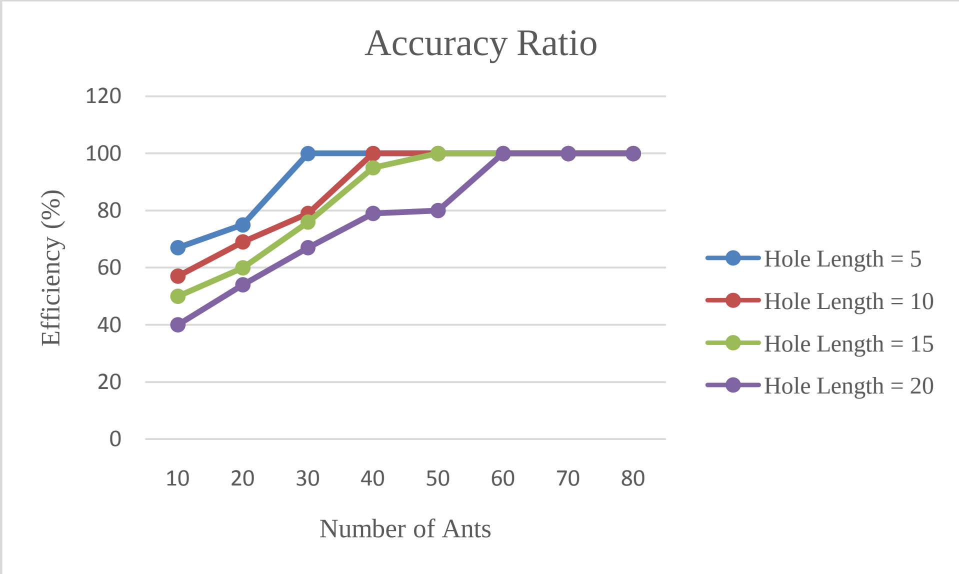

Figure 5: Accuracy ratio for developed algorithm as a function of hole length for second WSN architecture

The simulation was also carried out in the second WSN architecture so as to analyze the impact of the hole length in a more complex environment. The plot of figure 5 was also carried out using a number of iterations equal to 10. The results obtained showed that the efficiency ratio was an increasing function of the number of ants. For this architecture, about 38 ants were needed to detect a hole length of 5, while about 60 ants were required to detect a hole length of 20. To validate the performance of the developed algorithm, the simulation was also carried out using the algorithm by [1], and the simulation result is as shown in figure 6 and 7.

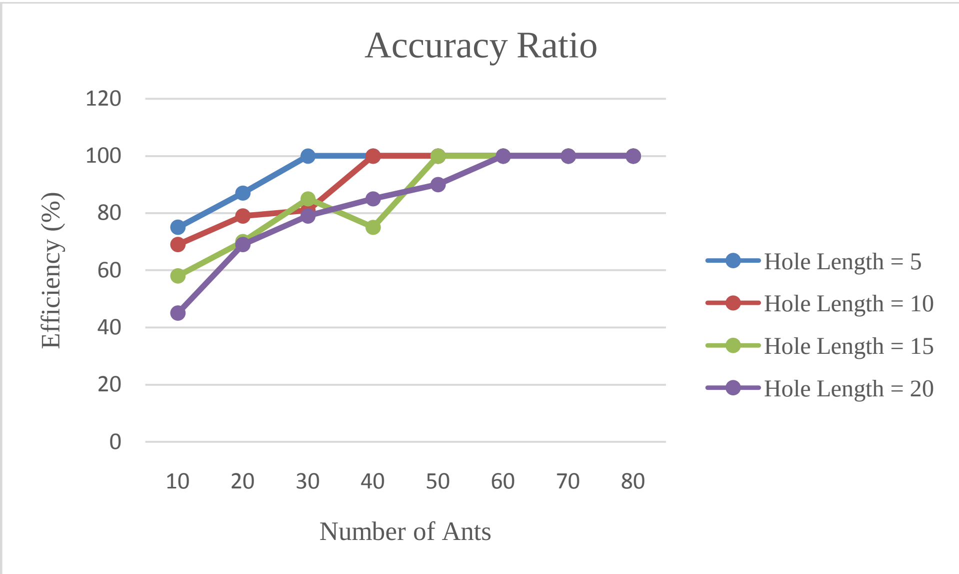

Figure 6: Accuracy ratio for compared algorithm as a function of hole length for first WSN architecture

The plot of figure 6 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 for the algorithm by [1]. The number of iterations for the simulation was equal to 10. From figure 6, 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 30 ants were required to detect it. Moreover, when the hole length increased to 10, about 40 ants were required to detect the hole. As can be seen, the number of ants needed to achieve 100% accuracy when the number of holes is 20 for the algorithm by [1] is 59, while that required by the developed algorithm in this work is 50. This shows a 15.3% reduction in the number of ants required to detect a hole in the network. As the numbers of holes were increased, it was also observed that the accuracy level of the developed algorithm also exceeded that of [1]. The analysis was also done on the second WSN architecture and the results are as presented in figure 7.

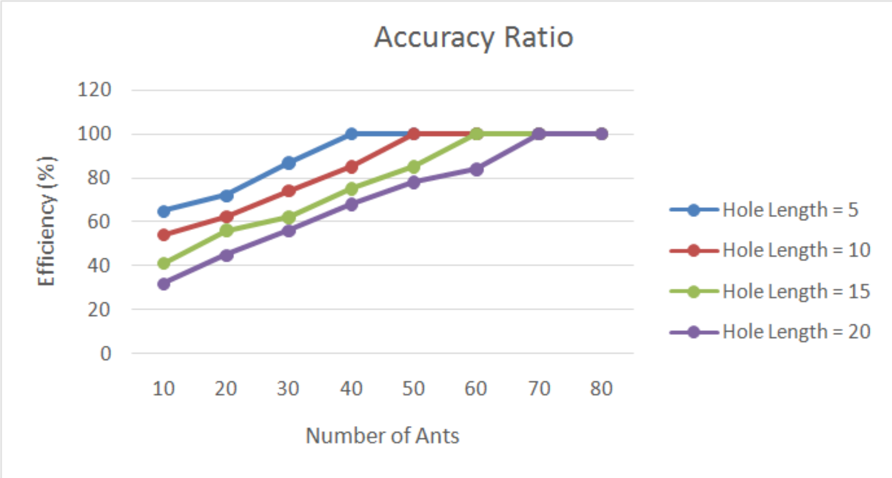

Figure 7: Accuracy ratio for compared algorithm as a function of hole length for second WSN architecture

From figure 7, for a hole length of 10, about 50 ants were required to detect the hole. As can be seen, the number of ants needed to achieve 100% accuracy when the number of holes is 20 for the algorithm by [1] is 59, while that required by the developed algorithm in this work is 50. This shows a 15.3% reduction in the number of ants required to detect a hole in the network.

Table 1: Accuracy ratio for compared algorithm as a function of hole length for first WSN architecture

	Hole Length = 5	Hole Length = 10	Hole Length = 15	Hole Length = 20
10	75	69	58	45
20	87	79	70	69
30	100	81	85	79
40	100	100	75	85
50	100	100	100	90
60	100	100	100	100
70	100	100	100	100
80	100	100	100	100

Table 2: Accuracy ratio for compared algorithm as a function of hole length for second WSN architecture

	Hole Length = 5	Hole Length = 10	Hole Length = 15	Hole Length = 20
10	65	54	41	32
20	72	62	56	45
30	87	74	62	56
40	100	85	75	68
50	100	100	85	78
60	100	100	100	84
70	100	100	100	100
80	100	100	100	100

V. PERFORMANCE EVALUATION

Experimental results showed that as the complexity and irregularity of the WSN increased, the more the algorithm required more ants to be deployed to increase the accuracy ratio. When the developed algorithm was deployed on the first WSN architecture, it showed a 25% reduction in the number of ants required to detect 2 holes in the network when compared to the algorithm by [1]. Also, as the numbers of holes were increased, it was observed that the accuracy level of the developed algorithm exceeded that of [1]. Results also showed that the detection ratio for each algorithm was enhanced for a smaller number of holes, with the developed algorithm outperforming the algorithm [1] for each hole number being compared.

Consideration was also done to analyze the impact of hole length on the accuracy ratio under a complex WSN architecture (second architecture). From the results obtained, it was observed that for a hole length of 10, about 50 ants were required by the algorithm to fully map the coverage hole. When compared with 59 ants needed in [1], there was a 15.3% reduction of the amount of ants needed to map the coverage hole. These results help to account for a reduction in resource demand, system complexity and promptness in mapping a minimal cycle by the developed algorithm, which would help to improve system performance and prolong the life span of the WSN.

VI. CONCLUSION

The proposed algorithm provided all the qualities of actuation, leakage detection, localization and parameter sensing with low energy consumption, reduction in resource demand, system complexity and quick mapping of minimal cycles. The validated result showed the effect of the variable wireless sensor network architectures on the coverage hole detection.Conclusively, comparative results with [1] ascertained 25% and 15.3% reduction in the number of ants required to detect holes in the two developed networkarchitectures respectively.

REFERENCES

[1]. Dhouha, KrichenCherif (2017), "Embedded and Cooperating Wireless Sensor Networks: Engineering Models and Protection Schemes" Communication Networks and Security Research LAB (CN &S), School of Communication Engineering of Tunis (SUP'Com), University of Carthage, Tunisia.

[2]. Kandris, D., Nakas, C., Vomvas, D. and Koulouras, G. (2020), "Applications of Wireless Sensor Networks: An Up-to-Date Survey" Applied System Innovation, vol.3 Issue 14. DOI: 10.3390/asi3010014. www.mdpi.com/journal/asi2020.

[3]. Vandana, J., (2018), "History and Architecture of Wireless Sensor Networks for Ubiquitous Computing". International Journal of Advanced Research in Computer Engineering and Technology (IJARCET), Volume 7, Issue 2, 2018. ISSN: 2278-1323.

[4]. Senouci, M. R. and Mellou, A., (2016), "Deploying Wireless Sensors Networks: Theory and Practice", DOI: https://doi.org/10.1016/C2015-0-01311-9.

[5]. Yang, J. and Fei, Z. (2010), "HDAR: Hole Detection and Adaptive Geographic Routing for Ad hoc Networks", In Proceedings of the 19th International Conference on Computer Communications and Networks (ICCCN),Zurich Switzerland.

[6]. Kanno, J., Selmic, R.R. and Phoha, V.(2009) "Detecting Coverage Holes in Wireless Sensor Networks". In Proceeding of the 17th Mediterranean Conference on Control and Automation, Thessaloniki Greece. June 2009.

[7]. Yan, F, Ma, W. and Shen, F. (2020). "Connectivity Based K-Coverage Hole Detection in Wireless Sensor Networks". Mobile Network Application 25, pp.783-793 (2020). https://doi.org/10.1007/s11036-019-0301-1.

[8]. Khedr, A. and Attia, A.(2018). "New Holes and Boundary Detection Algorithm for Heterogeneous Wireless Sensor Networks" International Journal of Communication Networks and Information Security (IJCNIS).ISSN: 2076-0930(print), ISSN: 2073-607X (online).

[9]. Das, S. and Debbarma, M. K. (2020), "A Comparative Study on Coverage Hole Detection Improvement with Inner Empty Circle over Delaunay Triangulation Method in Wireless Sensor Networks". In book: Communication Software and Networks, Proceedings of India 2019. DOI:10.1007/978-981-15-5397-4 56.

[10]. Chakchai So-In, Tri Gia Nguyen and NhuGiaNgyyen (2019), "An Efficient Coverage Hole Healing Algorithm for Area Coverage Improvement in Mobile Sensor Networks". Peer-to-Peer Networking and Applications 12, 541-552 (2019).

[11]. Zhang, G., Qi, C., Zhang, W., Ren, J. and Wang, L. (2017). "Estimation and Healing of Coverage Holes in Hybrid Sensor Networks: A Simulation Approach". MDPI Open Access Journal, vol.9 (10), pages 1-15. September (2017).

[12]. Aljuaid K., Alahmadi E.A., Albuoderman M. and Iqbal J. (2020), "Comparative Review of Pipelines Monitoring and Leakage Detection Techniques". 2020 2ndInternational Conference on Computer and Information Sciences (ICCIS) 2020, pp.1-6. Doi:10.1109/ICCIS49240.2020.9257602.

[13]. Onuzulike, V. C., Nwabueze, C. A., Akaneme, S.A. and Iloh, J.P. (2022), "Enhanced ACO Based Algorithm For Detection Of Coverage Holes In Embedded Wireless Sensor Network" International Journal of Engineering and Management (IJAEM) ISSN: 2395-5252, Volume 4, Issue9, pp:1257-1266, September, 2022.