An Approach to Calculate Exact Coverage Area for Connected Wireless Sensor Network

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Abstract

One of the advanced technologies used in the communicating systems of the intelligent grid is Wireless Sensor Network (WSN). WSN has a wide range of applications covers many fields like catastrophe management, hostilities field recognition, border insurance, patient health monitoring, and others. The sensor connectivity and coverage problems recently have a great attention. In this paper, we presented the connectivity and coverage of nodes in WSN, a new algorithm is prepared to extract exact coverage area of plain uniform depletion of node samples according to simple disk model. This algorithm considers the connection of nodes within maximum range of transmission communications, therefore no disconnected graph occurs. While uncovered area within region of interest (RoI) inside coverage area is calculated, although many uncovered regions occurred. So the coverage percentage area is calculated in an exact solution. This algorithm will be one of keystone study to better control of sensor depletion.

Keywords: Wireless network sensor, Connectivity, Coverage, Intelligent grid.

1. Introduction

Wireless Sensor Network (WSN) in some cases called remote sensor and actuator systems (WSAN) are spatially conveyed self-sufficient sensors to monitor physical or natural conditions, for example, humidity, temperature, pressure, weight, and so on [1]. Its helpfully pass data and information remotely through the network system to other places. Most of the current network systems are bi-directional, likewise empowering control of sensor action. The improvement of WSN was inspired by military applications, for example, hostilities field recognition systems; Nowadays these systems are utilized as a part of numerous mechanical and purchaser applications, for example, modern process observing and control, machine wellbeing checking, etc. [2]. WSN consists of "nodes" range from a couple to many hundreds or even thousands, where every node is connected with other node or nodes sensors. The sensor network node has regularly a few parts: A radio transceiver with a built-in antenna or association with an outside antenna. A microcontroller, work as an interface with the sensors and a vitality source, normally a battery or an inserted type of vitality reaping [3].

The size and the cost of a sensor node may differ and variable, its measure from that of a shoebox down to the extent of a grain of tidy, the cost of it goes from a couple to several dollars, contingent upon the many-sided quality of the individual sensor nodes [4]. This paper is organized as follows: Section 3, covers the fundamentals problems of WSN. Section 3, presents the proposed algorithm to estimate uncovered area. Section 4, shows the experimental results. Finally, section 5, contains the conclusions and future work.

2. Fundamental problems of WSN

The performance and design of WSN affected by several factors and constraints like, energy, efficiency, deployment, data management, connectivity and coverage [5]. In this paper, we focus on the most two of them, connectivity and coverage [6].

2.1. Connectivity of WSNs

The topology of communication in WSN represented as a graph, signified by G = (V, E), where V is vertices set of sensor, E is wireless communication links set, i.e., the line fragments associated neighboring sensors. According to the disk communication model, if Euclidean distance (straight-line distance between two points in Euclidean space) of the two sensors is in the communication range r_c, the couple of sensors can be neighbors. As indicated by Fig. 1, both sensors A and B are neighbors and there is a bi-directional connection between them as they are inside each other's communication range, while sensor C is disengaged [7], [8].

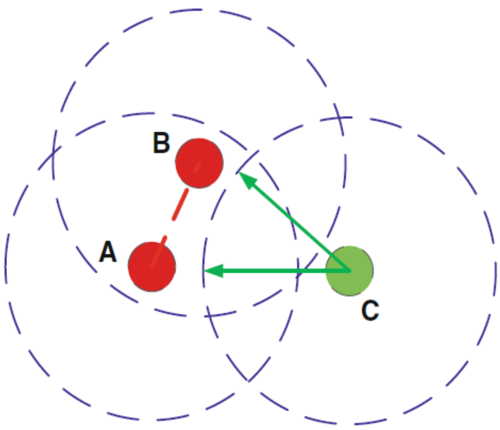

Figure (1) Node sensors Connection [7].

WSN is said to be connected if, there is a single-hop or multi-hop communication path between any two sensors consisting of consecutive wireless communication links. Connectivity of WSN is principally dictated by the sensors' communication ranges and deployment areas. Figure 2, for instance, outlines an associated graph of a WSN, where 100 sensors are arbitrarily deployed at a square district with territory $100 \times 100\ m^2$ and the communication range of each sensor is set at 30 m [9].

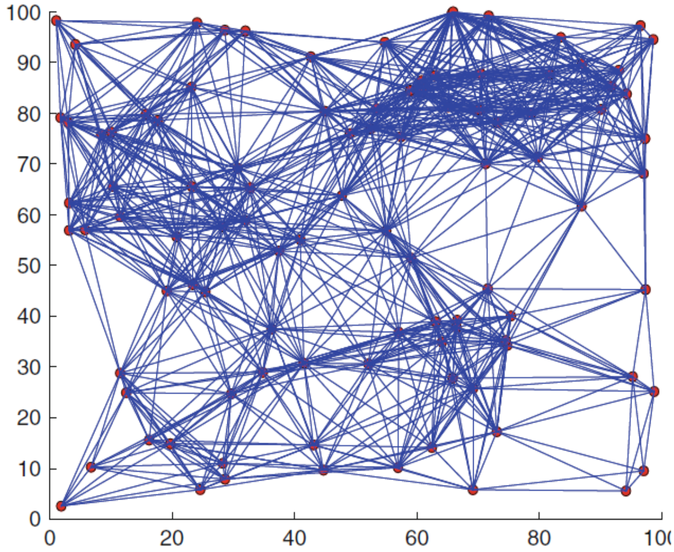

Figure (2) WSN connected graph, 100 sensors are randomly and uniformly deployed in a square region with area 100 × 100 m^2, the communication range is set as 30 m [9].

One of the essential standards of network configuration is the greatest survivability of the network system. The system must keep on working if there should be an occurrence of edge or disappointments. Diverse ideas of adaptation to internal failure exist, the least difficult one compared to the connectivity of the graph, that is, the minimum number of vertices which must be erased keeping in mind the end goal to annihilate all paths between a couple of vertices [10]. The most extreme connectivity is alluring since it relates to not just the greatest adaptation to the non-critical failure of the network yet additionally the most maximum number of inside disjoint paths between any two particular vertices [11]. A major issue in network configuration is to build a minimum cost network that fulfills some predefined connectivity necessities between the couple of nodes [12].

2.2. Coverage of WSNs

Wireless Network Sensor nodes are deployed in an important area to monitor specific conditions or observe some changes in its used application. If the Euclidean distance between the sensor and the point is less or equal to the sensing range (r_s) according to the disk/Boolean sensing model this point is covered [12], [13]. The model of Disk sensing is generally utilized because it is simple and it is empowering hypothetical abstraction and analysis.

Any point p is covered by a sensor s_i, iff: $d(s_i, p) \le r_s$ (1)

Where $d(s_i, p)$ is the Euclidean distance between the sensor s_i and the point p.

For the coverage in full sense, the whole region of the used application field is covered by at minimum one sensor and in the network there is no sensing coverage gap, see figure 3.

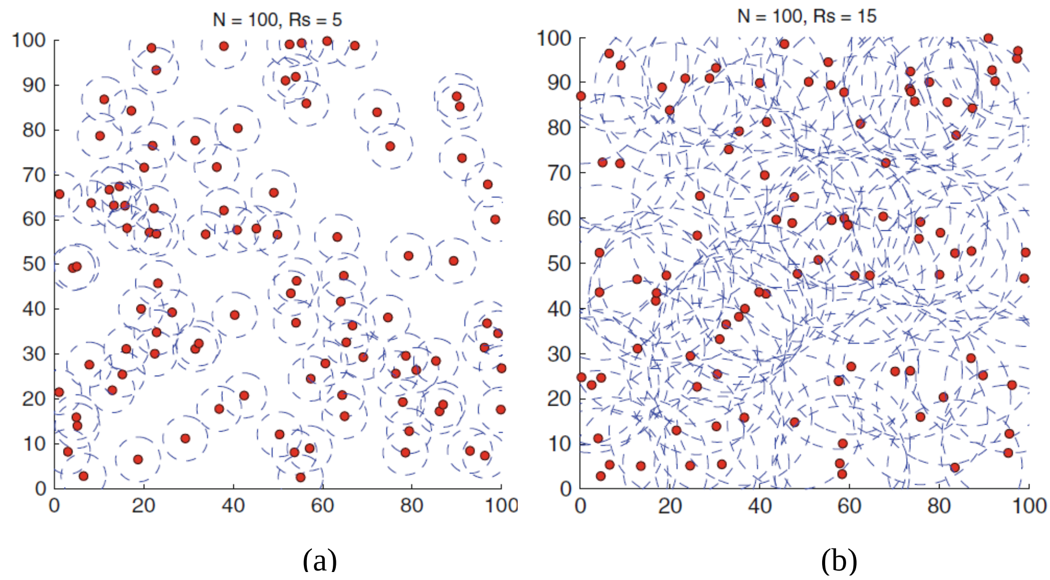

Figure (3) Sensing coverage of a random WSN with 100 sensors and sensing range (a) Rs = 5 m. The field of interest is not fully covered, (b) Rs = 15 m. The field of interest is nearly fully covered [9].

The significant goal of coverage issue is to proficiently cover a region or set of points or target under different constraints. The uses of a coverage algorithm depend on the mechanism of sensor deployment, which subjects to cover, and on other properties of WSN.

3. The proposed algorithm to estimate uncovered area of sensor connected node in WSN

Estimating the uncovered areas in WSN includes too many factors like, fading of transmitted signals, node disable, power source depletion, natural and mandatory obstacles. Although clear and deterministic algorithm with many overlapping circles is not actually found. An exact solution is prepared and implemented to be a keystone to more precision calculations for the coverage area of sensor-connected nodes that is important to study the behavior of WSN in uncontrolled environments especially random depleted nodes like battlefields and wide forest and so on.

Algorithm Steps:

Step1: Find a simple connected graph for WSN ($r_{ij} < R_0$)

Where r_{ij} distance between two nodes and $R_0$is the maximum transmission distance of node.

Step2: Calculate two intersected points between any two node circles of radius R_0. If only one or no intersected point, the two circles are not intersected.

Step3: Estimating central angle of each intersected point in radius from x- axis counterclockwise.

Step4: Find the direction of arc covered by another circle. If central angle greater than π then intersected points will be interchanged. Since intersection arcs are less than two pies (180 degree) because the two circles have equal radii, then the first and second angles are sorted to draw arc always counter clockwise, and put these angles in a way the first is less than the second, if the second is less than the first angle (arc cross the x-axis in this case) two pies are added to the second angle to maintain situation.

Step5: For each node, creates many records, each record keeps information about each node and circle intersections, then sorted records according to node number as a primary key and starting angle of the intersection as a secondary key, these records are saved in two databases, abstract and master detailed databases.

Step6: Joins covered arcs with each other and keeps the number of disconnected arcs for next processes.

Step7: Find uncovered arcs of each circle of node using the following:

a- Number of disjoins uncovered arcs is the same as in covered arcs, although records of covered arcs are combined as:

Start angle of uncovered arc = end angle of the previous record.

End angle of uncovered arc = start angle of next record of the covered arc.

b- Since angles are rearranged then the last start and end angles must be checked, if they are in right order, then two pies are added or subtracted from them to keep situation.

Now, to join all uncovered arcs for all connected nodes and estimate slice area related to uncovered arc in that node, continue with the following steps:

Step8: Read first unused record in the abstract database, to find start and end record in the master database.

Step9: Keep current node number, and x, y coordinates of the second point of intersection in a sequence record.

Step10: Estimate circle slice area corresponding to uncovered arc by:

$$\text{Area of triangle related to uncovered arc} = \sqrt{p(p-a)(p-b)(p-c)} \qquad (2)$$

Where a, b, and c are triangle edges and $p = (a + b + c)/2$, Heron's formula [14].

Area of a sector according to uncovered arc = included angle in radian × ${R_0}^2$, and

Area of a slice = area of a sector – area of the triangle as shown in figure 4.

Step11: Keep counting number of records just treated in the master database, since the process of finding total covered area cannot end without covering all records in the master database, and all connected uncovered arcs sequences must be closed, or an error message will be occurred

Step12: Find node number connected to end angle of the current node, then search it in the abstract database.

Step13: Find match connected node record from many records of a connected node in the master database, if the first connection node number in new record matches the current node number a complete match occurs.

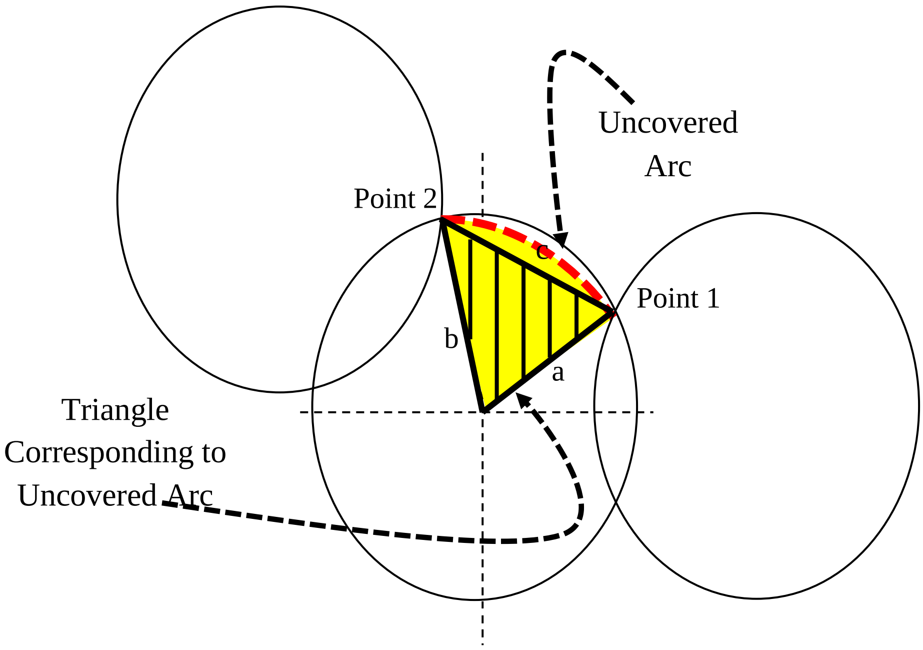

Figure (4) Triangle and the slice of a circle corresponding to the uncovered arc.

Step14: Check if the new second node is the same as start node number of the beginning node sequence, then the sequence of uncovered arcs is closed, otherwise the sequence is not closed, go to step (17).

Step 15: Check if number of total records in master database is not yet exhausted, a new sequence record is constructed for remaining uncovered curves, otherwise step (20).

Step16: Set new record as current record and go to step (8).

Step17: Set new field as a current field in a sequence record.

Step 18: Find second the connected node from the master database.

Step19: Check abstract database for next record, find another node number then go to step (8).

Step 20: Estimate all polygon areas constructed.

Step21: Find maximum polygon area as the overall area covered by connected sensor nodes.

Step22: Estimate total area:

a- Area of bigger enclosed by uncovered arcs = polygon area + ∑ all corresponding slices.
b- Area of smaller disclosed by uncovered arcs = polygon area - ∑ all corresponding slices.

As shown in figure 5, the total area enclosed = area of bigger uncovered arcs - ∑ all corresponding smaller areas, and the total area of uncovered sensing nodes = area of RoI – total area enclosed.

If many records are constructed, each record introduces a sequence of a closed loop of uncovered arcs circumfluent an area, points of intersected arcs can be used to make a polygon. Bigger polygon area is a total coverage. Other one or more loops of uncovered arcs if exist will make uncovered sensing areas inside the bigger one since WSN is totally connected nodes with uncovered sensing areas inside or outside RoI, End of the algorithm.

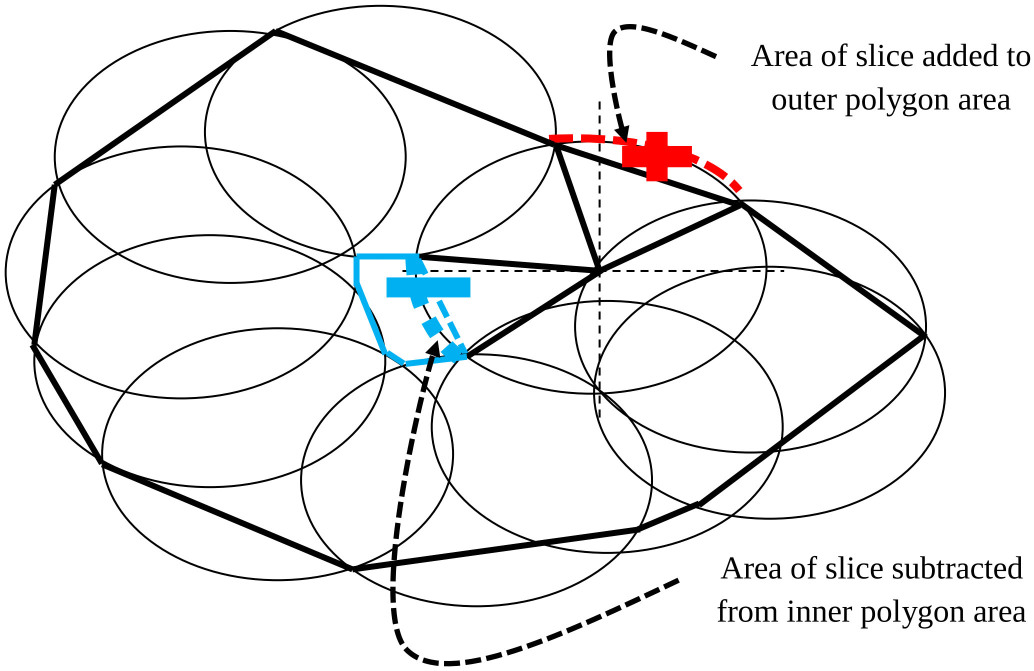

Figure (5) Area of a slice is added to outer polygon area while the area of a slice is subtracted from inner polygon area.

4. The Experimental Results

The implementation of the proposed algorithm to calculate the exact coverage area of the connected nodes of WSN is achieved using MATLAB engines. To emphasize validity and accuracy of the algorithm the results are presented as a graph including a set of nodes surrounded by a circle with maximum transmission radius, lines are added between intersection points of circle pairs, and between intersected points and nodes itself. While calculating total coverage area acts by allocating a polygon of covered or uncovered areas and a corresponding slice of uncovered arcs. All these areas are added or subtracted as explained in the proposed algorithm previously, therefore polygons generated from the algorithm is added to the graph as boundaries to the covered and the uncovered areas.

Many schematic examples are applied for a limited number of nodes to verify and purify the algorithm from bugs and semantic impurities as in the following cases:

Case 1: General case to a limited number of nodes (5) to follow up proceedings step by step and compare manual procedural calculations with that produced by the computer (slices and polygon areas to find total coverage area), table 1. It is notable to mention that the algorithm includes sophisticated comparisons between a variety of variables that make a bottle neck of checking, there are four levels of nested searches. Emphasis comparison accuracy, a set of key variables is added to support selected mechanism, figure 6, shows lines connect intersected points of circle pairs to each other and center nodes shows the boundary.

Table (1) Five nodes connected with no uncovered area

<table>
<tr><td>Chain Index</td><td>1</td><td>3</td><td>6</td><td>4</td><td>7</td><td>5</td><td>2</td><td>Total (mm^2)</td></tr>
<tr><td>Chain Node Number</td><td>1</td><td>2</td><td>4</td><td>3</td><td>5</td><td>3</td><td>2</td><td>Note: 7 Slices</td></tr>
<tr><td>Slice Area (mm^2)</td><td>8.383917298546 11</td><td>0.410631098834 979</td><td>4.885009983296 09</td><td>0.059672225853 0560</td><td>9.812914275615 41</td><td>0.022379922428 9949</td><td>0.263814752458 128</td><td>23.838339557032775</td></tr>
<tr><td colspan="7">Area of polygon (mm^2)</td><td colspan="2">15.359183090932701</td></tr>
<tr><td colspan="7">Total area (mm^2) = total slice areas + polygon area</td><td colspan="2">39.197522647965480</td></tr>
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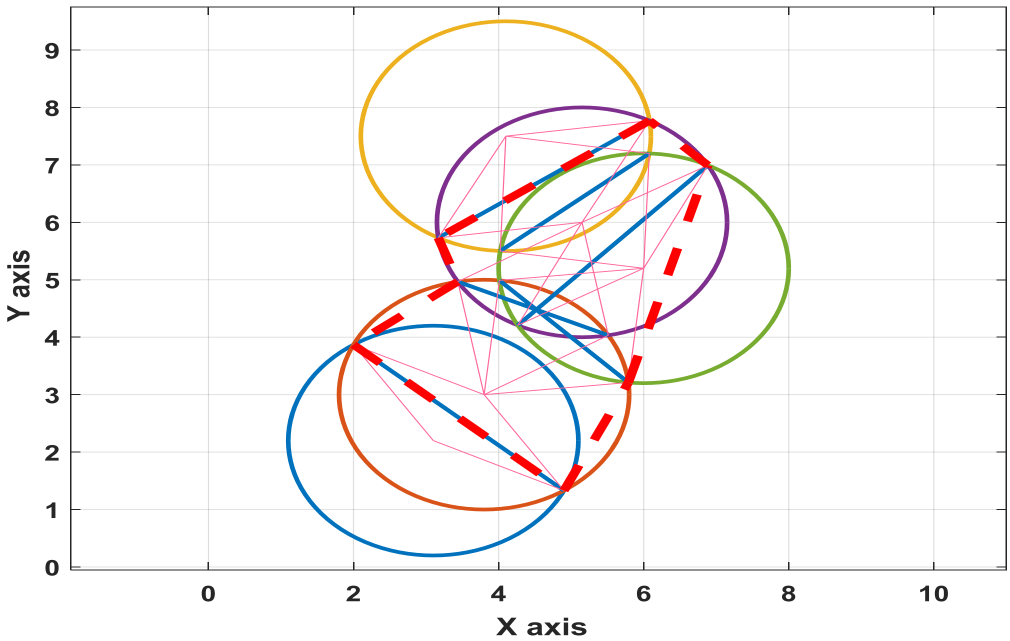

Figure (6) Normal limited number of nodes is used to verify the algorithm.

Case 2: Limited number of nodes (5) with node full covered by other nodes, table 2. The result shows there are no conflicts appear between eliminates node from calculations and overall calculation of coverage areas, figure 7 shows lines connect intersected points of circle pairs to each other and center nodes shows the boundary.

Table (2) Five nodes connected with hidden nodes.

Chain1 Index	1	5	4	3	Total (mm^2)
Chain1 Number	1	5	4	3	Note: Node 2 is hidden
Slice Area (mm^2)	7.541639875478592	7.541639875478592	7.541639875478592	7.541639875478592	30.166559501914390
Area of polygon (mm^2)					24.161903789690590
Total area (mm^2) = total slice areas + polygon area					54.328463291604976

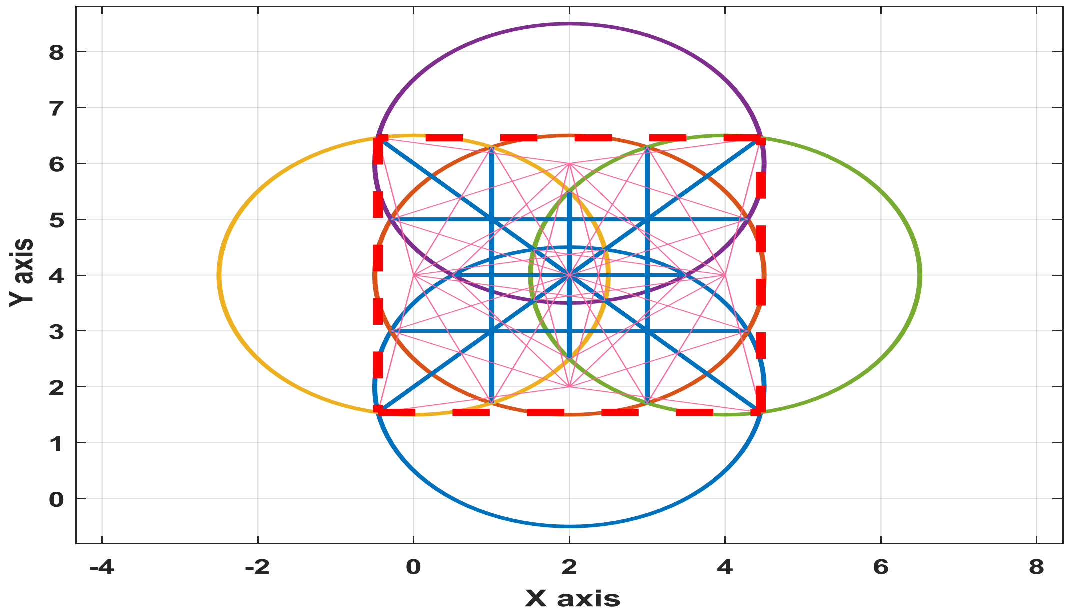

Figure (7) A limited number of nodes with node full covered by other nodes.

Case 3: Limited number of nodes (18) which construct an open cavity, table 3. The result obtained shows that calculating coverage area related to the exact area under sense, while convex hull, for example, will overcome open convex and considered it a part of the area as shown in figure 8, lines connect intersected points of circle pairs to each other and center nodes shows the boundary.

Table (3) Eighteen nodes connected with cavity

Chain Index	Number of slices	Total slice area (mm^2)	Total polygon area (mm^2)	Total area of chain (mm^2)
Chain 1	24	12.186512499750554	26.011724543228710	38.198237042979265
Total area (mm^2) = total slice areas + polygon area				38.198237042979265

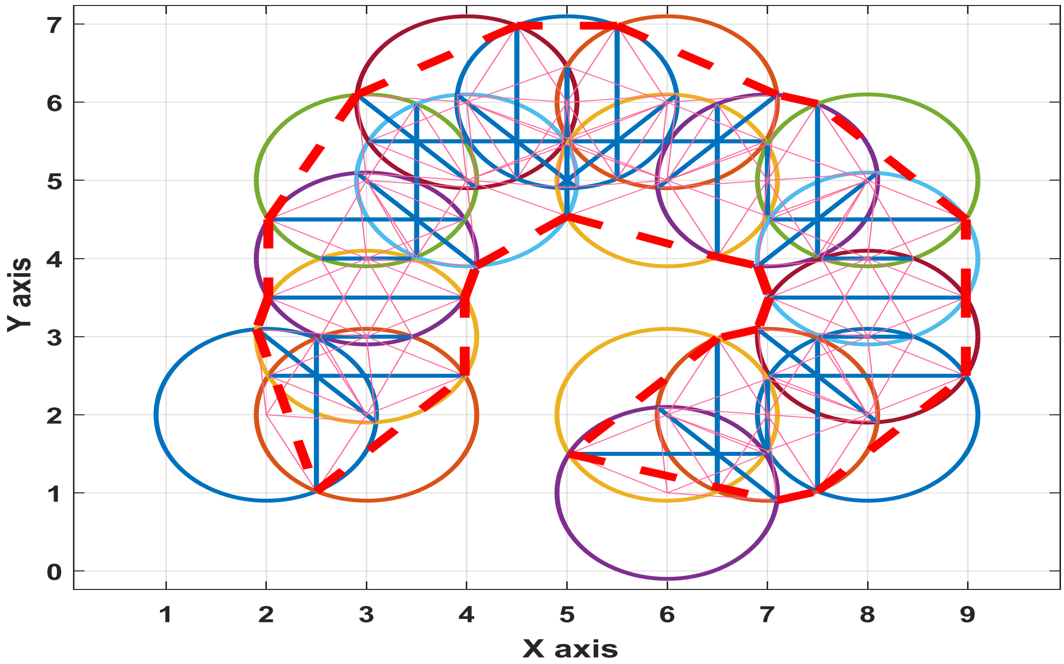

Figure (8) A limited number of nodes with open cavity area.

Case 4: Limited number of nodes (21) which include uncovered sensing area, table 4. The uncovered area and polygon generated with it and related slices are calculated and acted as predicates as shown in figure 9.

Table (4) Twenty-one nodes connected with the uncovered area inside

Chain Index	Number of slices	Total slice area (mm2)	Total polygon area (mm^2)	Total area of chain (mm^2)
Chain 1	17	7.637350125 799649	38.5972669997 53586	46.234617125553235
Chain 2	7	1.231888629 641724	5.12604582689 1606	3.894157197249882
Total area (mm^2) = area 1 (chain 1) – area 2 (chain 2)				42.340459928303350

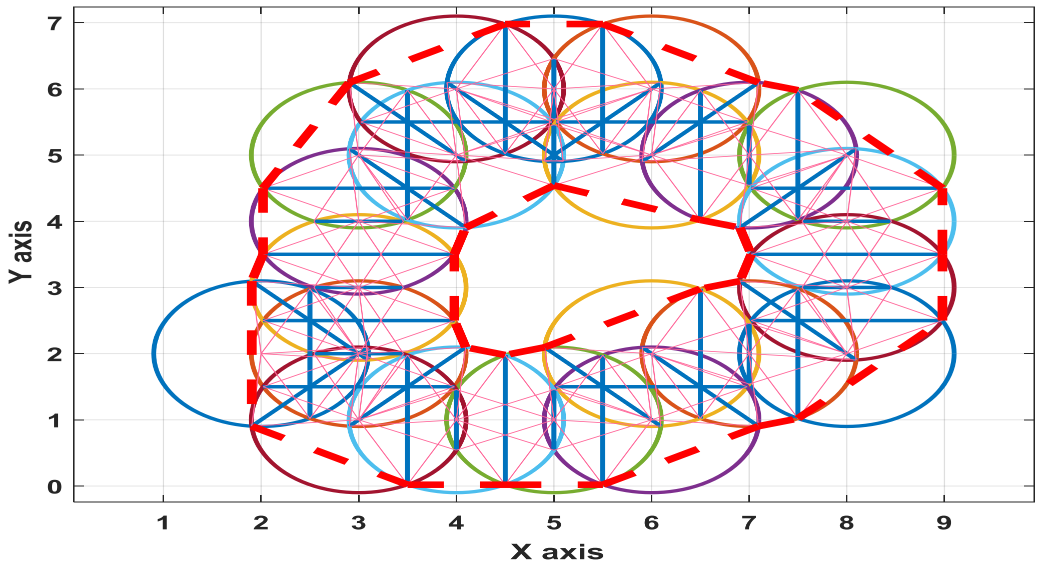

Figure (9) a limited number of nodes with uncovered sensing area.

5. Conclusions and future work

To deal with wireless sensor network (WSN) many limitations are applied to the proposed algorithm. Nodes in WSN must be connected to each other within the predefined radius of transmission.

Random depletion of nodes in region of interest (RoI) may be used in uncontrolled environments. An exact calculation for coverage and for showing the behavior of uncovered sensing areas can be a very good tool to study the behavior of network.

Random depletion of nodes shows many uncovered sensing areas (UnSAs) inside the total coverage especially when the radius of transmission is less than the magnitude of deviation in depletion. These UnSAs are explored and calculated one by one in the proposed algorithm.

In the proposed algorithm, we built a MATLAB functions depends on sort method to achieve number of comparisons, find number of intersection coordinates of circles, combined covered arcs, find uncovered arcs, and store chain of connected arcs. Since an abstract database is used that indicates fewer records in master database. Also, each record when used in the master database it will be marked ‘used’, so only one comparison is needed to transit to the next record. All these techniques will raise the efficiency of exact calculation of the coverage area.

The limited equal radius for all nodes according to simple disc model in WSN gives a property that is any intersected two circles can’t produce shared arcs more than pie radius which makes a direct prediction of the side of the intersected arc, and no need to other ways to predict.

For the future work, the proposed algorithm can be extended to consider different types of nodes as a cluster configuration. No cutting edges are considered in the outer area because of the edges of RoI that make a clip to circles expanded outside it. Add clip edges into consideration of area coverage calculation is adequate flexible of the algorithm, since when a straight edge is faced slice area will be zero and no need to add or subtract it from polygon area.

References

[1] Morteza M. Zanjireh, Hadi Larijani, “A Survey on Centralized and Distributed Clustering Routing Algorithms for WSNs”. IEEE 81st Vehicular Technology Conference. Glasgow, Scotland: IEEE. Spring, 2015.

[2] Soltani, R., Bash, B.; Goeckel, D., Guha, S., and Towsley, D.,"Covert single-hop communication in a wireless network with distributed artificial noise generation", 2nd Annual Allerton Conference on Communication, Control, and Computing (Allerton), pp. 1078–1085, 2014, doi: 10.1109 /ALLERTON. 7028575. 2014.

[3] Dargie, W. and Poellabauer, C., "Fundamentals of wireless sensor networks: theory and practice". John Wiley and Sons. Pp. 168–183, Pp.191–192, 2010.

[4] Sohraby, K., Minoli, D., and Znati, T., "Wireless sensor networks: technology, protocols, and applications". John Wiley and Sons. pp. 203–209, ISBN 978-0-471-74300-2, 2007.

[5] Hakima Chaouchi, Jean-Marie Bonnin, "Wireless sensor networks: A survey on recent developments and potential synergies", The Journal of Supercomputing vol. 68, Issue 1· April 2013.

[6] Al-Karaki J. N., Gawanmeh A., “The Optimal Deployment, Coverage, and Connectivity Problems in Wireless Sensor Networks: Revisited”, IEEE Access, vol. 5, pp. 18051-18065, September 2017.

[7] Patnaik S. et al., "Recent Development in Wireless Sensor and Ad-hoc Networks", Signals and Communication Technology, Springer India, DOI 10.1007/978-81-322-2129-62, 2015.

[8] Yick J., Mukherjee B., Ghosal D., "Wireless sensor network survey, Computer Networks", vol. 52 Issue 12, pp. 2292–2330, 2008.

[9] Yun Wang, Yanping Zhang, Jiangbo Liu and Rahul Bhandari, "Coverage, Connectivity, and Deployment in Wireless Sensor Networks", Chapter 2, Springer India, 2015.

[10] Chiara Buratti, Andrea Conti, Davide Dardari and Roberto Verdone, “An Overview on Wireless Sensor Networks Technology and Evolution”, Sensor Open Access, vol. 9, pp. 6869-6896, August 2009.

[11] Kamalesh V. N and S K Srivatsa, "Adjacency Matrix based method to compute the node connectivity of a Computer Communication Network, IJCSI International Journal of Computer Science Issues, vol. 7, Issue 1, no. 2, January 2010.

[12] Nidhi Chaudhary and Sahil Gupta, "A Survey on Coverage Problem in Wireless Sensor Network", International Journal of Engineering and Computer Science (IJECS). vol. 4, Issue 5, pp. 11952-11955, May 2015.

[13] Liu B., Brass P., Dousse O., Nain P. and Towsley D., "Mobility improves coverage of sensor networks", In: Proceedings of the 6th ACM International Symposium on Mobile Ad Hoc Networking and Computing, pp. 300–308. ACM, 2005.

[14] James Stewart, Lothar Redlin, and Saleem Watson, “PRECALCULUS: Mathematics for Calculus” Fifth Edition, Brooks/Cole Cengage Learning, Belmont, CA, USA, 2009.

الاتصال والتغطية في شبكة الاستشعار اللآسلكي

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الخلاصة

واحدة من التقنيات المتقدمة المستخدمة في أنظمة الاتصالات للشبكة الذكية هي شبكة الاستشعار اللاسلكية (WSN). WSN لديها مجموعة واسعة من التطبيقات تغطي العديد من المجالات مثل، إدارة الكوارث، اكتشاف حقل المعركة، التأمين على الحدود، مراقبة صحة المرضى، وغيرها. أن مشاكل الربط والتغطية للمستشعرات في الآونة الاخيرة لها أهمية عظيمة. في البحث، قمنا بعرض الاتصال وتغطية العقد في WSN، تم اعداد خوارزمية لحساب مساحة التغطية المضبوطة لمجموعة عقد شبكة الاستشعار بالتوزيع المتجانس المستوي لنموذج القرص البسيط. هذه الخوارزمية تعتمد ارتباطات العقد ضمن مدى الاتصالات الاقصى للعقدة لذلك لايوجد في المساحات مناطق منفصلة. في حين تم احتساب كل المساحات غير المغطاة بالاستشعار ضمن المنطقة قيد الاهتمام (RoI) ضمن المساحة المغطاة. لذا تم احتساب النسبة المئوية للمساحة المغطاة بالضبط. ان استخدام هذه الطريقة سيكون الحجر الاساس للدراسات التي تتطلب سيطرة أفضل لنشر عقد المتحسسات.

الكلمات المفتاحية: متحسسات الشبكة اللاسلكية، الربط، التغطية، الشبكة الذكية.