Coverage Analysis In Wireless Sensor Network

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***Abstract*—A WSN can be composed of homogeneous or heterogeneous sensor nodes also termed as motes, which adapts the same or different coordination, sensing and computation abilities, respectively. Node deployment is a fundamental issue to be solved in WSNs. A proper node deployment scheme can reduce the complexity of problems in WSNs as, for example, routing, data fusion, communication,etc. Furthermore, it can extend the lifetime of WSNs by minimizing energy consumption. In this paper, we investigate random and deterministic node deployments for large-scale WSNs under the performance metrics.Thus, we have taken four different deterministic deployment patterns for Wireless Sensor Network (WSNs) namely a square grid ,a regular hexagon based, a octagon-square based and a decagon-star pattern for sensor nodes deployment and analysed each of them on the basis of their average coverage provided in the application field. Using basic geometry we propose a novel strategy for calculating the relative frequency of exactly k-covered points, by using k-coverage maps, for all the deployment methods .**

Keywords- *WSN(Wireless senser network);WSNs(Wireless senser networks)*

I. INTRODUCTION

In [1]A WSN can be defined as a wireless communication consisting of countless distributed devices using sensors to monitor physical or environmental conditions and also tracking objects It is capable to provide the information logged by the sensors to remote locations and it can do so without the use of a big and composite wired networks. The whole setup of data being sent from the sensors distributed across a wide area by means of the WSN is performed . Wireless network of sensors spread over an area. Such kind of networks is usually used for monitoring applications include indoor or outdoor and the tracking applications include tracking objects.

The WSN is built of “nodes” from a little to several hundreds or even thousands where each node is connected to one (or sometimes several) sensors. The data is forwarded probably via multiple hops to a sink (occasionally denoted as controller or monitor) that can use it locally or it is connected to new networks (e.g., the Internet) through a gateway. The nodes can be stationary or moving. They can be responsive of their position or not. They can be homogeneous or not .

In [2] a traditional single-sink WSN , the single-sink system suffers from the lack of scalability by increasing the number of nodes, the quantity of data gathered by the sink increases and once its ability is reached, the network size cannot be augmented. In addition, for reasons related to MAC and routing aspects, network performance cannot be measured independent from the network size .

A more general scenario includes multiple sinks in the network , given a level of node solidity, a larger number of sinks will decrease the possibility of isolated groups of nodes that cannot send their data due to unfortunate signal propagation conditions. In standard, a multiple sink WSN can be scalable while this is evidently not true for a single sink network. Still, a multi sink WSN does not represent a insignificant extension of a single sink container for the network trick. In numerous cases nodes send the data composed to one of the sinks, chosen among many, which forward the data to the gateway headed for the final user. From the protocol point of view means that a choice can be done based on a suitable criterion that could be least delay, greatest throughput, least number of hops, etc. Thus, the existence of multiple sinks ensures better network performance with respect to the single sink case, but the contact protocols must be more complex and should be designed according to appropriate criteria .

A WSN can be composed of homogeneous or heterogeneous sensors, which possess the same or different communication and computation capabilities, respectively. Although some works consider heterogeneous sensors, many existing works investigate node placement in the context of homogeneous WSNs. Less complexity and a better manageability are the most beneficial effects of homogeneity. Therefore, we consider homogeneous nodes in WSNs. These nodes can be deployed over a network in random or deterministic fashion. While the random node deployment is preferable in many applications, if possible, other deployments should be investigated since an inappropriate node deployment can increase the complexity of other problems in WSNs.

II. PERFORMANCE METRICS

In [21] ,there are discussed the following performance metrics.

A. Coverage

In WSNs, the simple reason for checking coverage is to provide the high quality of information in the region of interest. This is also known as the area coverage which is important for most WSN applications. A full coverage and a partial coverage are both considered for WSN applications. To satisfy the full coverage of a given region of interest, every point in it must be covered by at least one sensor without allowing any uncovered points. However, there may be exceptions when the partial coverage can be assumed as the full coverage. For example, temperature or pressure sensing in environmental monitoring applications, where reading at one point is adequate for a region since it may have the same readings in its surrounding area. In any case, the overall coverage pretty much depends on both the sensing ranges and the deployment scheme of the nodes. To fulfil the desired coverage of a region, adjusting the sensing range has its limitations due to the expensive energy consumption and restricted node capabilities. There- fore, node deployment becomes very important. K-coverage is the usual way of specifying conditions on coverage.

B. K-coverage

In literature , k-coverage refers to the minimum k- coverage. A network is said to have k-coverage if every point in it is covered by at least k sensors. Although minimum k-coverage is worthwhile for surveillance kind of applications, other kinds of coverage, such as an average k-coverage or the maximum k-coverage, may be more meaningful for other WSN applications. Moreover, it seems inappropriate to measure k-coverage for performance comparison due to its sole interest in the minimum coverage area of the network. For this purpose we investigate the relative frequency of the exactly k-covered points in node deployment strategies.

C. K-coverage Map

We introduce a k-coverage map, which is used to check all possible coverage areas and to analyze the relative frequency of exactly k-covered points. Using the idea of the k-coverage map we measure the quality of coverage performance of node deployment strategies. To avoid confusion with k-coverage, in the following, we also use the term “exact k-coverage” for the k-coverage map, which defines the total area of the field covered by k sensor nodes.

A disc-based sensing model is used for homogeneous nodes where each sensor has a maximum sensing range of rsense. The sensing range, rsense, is the same as the length of a unit cell. Therefore rsense is different deployment methods . A point is covered by a node if it lies either within a disc of sensing range, rsense, or exactly at circumference of a disc. No boundary conditions are considered for any deployment method which seems reasonable for large-scale WSN scenarios.

III. K-COVERAGE MAP FOR DIFFERENT DEPLOYMENT METHODS

For a uniform random deployment, it can be achieved by applying systematic sampling over a given field . Here we model the k-coverage map for a square grid , Tri-Hexagon Tiling (THT), .Octagon-square Tiling and Decagon-star Tiling deployments .

A. Square Grid Cell

We can easily model the k-coverage map by using basic geometry. Figure 1 shows the k-coverage map of all possible exactly k-covered points of a square grid cell. In the square grid cell, nodes are placed at the corners and their sensing ranges intersections form a tessellation of the region. As it is assumed that the sensing range is equal to the length of a cell, a square grid cell has exact 2-coverage, 3-coverage and 4-coverage regions. For instance, the middle region yellow-region has exact 4-coverage because it forms the intersection region of all nodes. Since the radii of circles are the same, some tessellations are symmetric. Therefore a grid cell has four symmetric red-regions near the border lines and four symmetric blue-regions covered by exactly 2 and 3 sensor nodes, respectively.

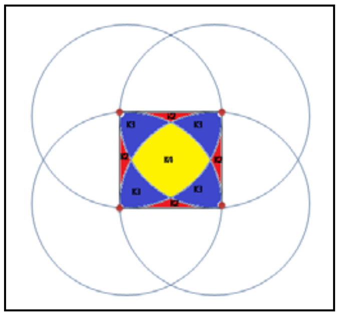

Figure 1. *The overall view of Square grid k-coverage map*

B. Trihexagon Trilling

The same approach is considered for the k-coverage map of a THT cell. The THT cell is illustrated in Figure 21.2, which is the combination of six equilateral triangles and one regular hexagon, where each of the tiling point hosts a node. The area of each equilateral triangle is fully covered by three nodes, thus having exact 3-coverage. Inside a regular hexagon, there are 3 possible exact k-coverages: 2-, 3-, and 6-coverage. In the following Figure , white regions are covered by three sensor nodes while red regions are covered by exactly two sensor nodes. The centre of a regular hexagon has exact 6-coverage because it can be reached by six sensor nodes ,which is shown in figure 2.

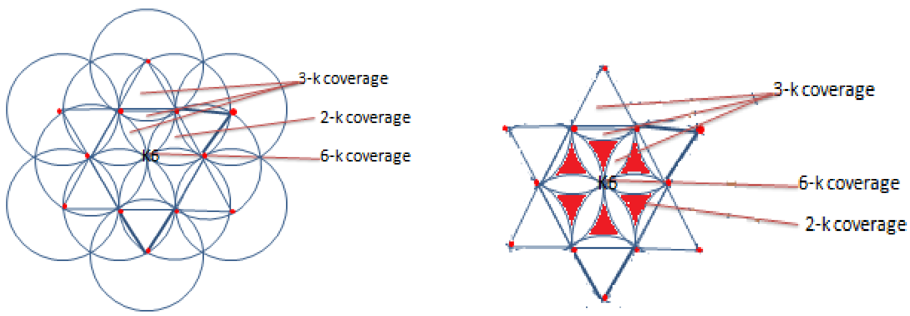

Figure 2. The overall view of Trihexagon tiling k-coverage map*)*

C. Octagon Square Tiling

Figure 3 shows the k-coverage map of all possible exactly k-covered points of a octagon-square tiling cell. In the square grid cell, nodes are placed at the corners and their sensing ranges intersections form a tessellation of the region. As it is assumed that the sensing range is equal to the length of a cell, a octagon-square trilling cell has exact 0-coverage,1-coverage, 2-coverage and 3-coverage regions. For instance, the middle region i.e red-region has exact 0-coverage ,white-regions are exact 1-coverage ,yellow-region has exact 2-coverage ,blue-regions are exact 3-coverage respectively.

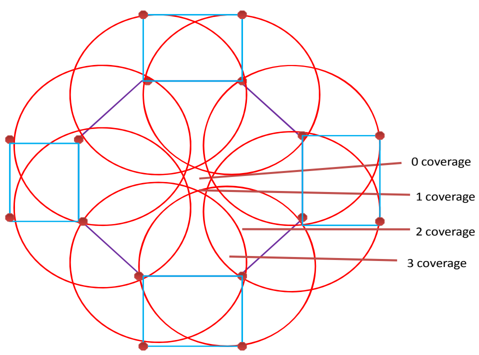

Figure 3. *The overall view of Octagon-Square tiling k-coverage map*

D. Decagon Star Tiling

Figure 4 shows the k-coverage map of all possible exactly k-covered points of a decagon-star tiling cell. In the square grid cell, nodes are placed at the corners and their sensing ranges intersections form a tessellation of the region. As it is assumed that the sensing range is equal to the length of a cell, a octagon-square trilling cell has exact 0-coverage,1-coverage, 2-coverage and 3-coverage regions. For instance, the middle region i.e red-region has exact 0-coverage ,white-regions are exact 1-coverage ,yellow-region has exact 2-coverage ,blue-regions are exact 3-coverage respectively.

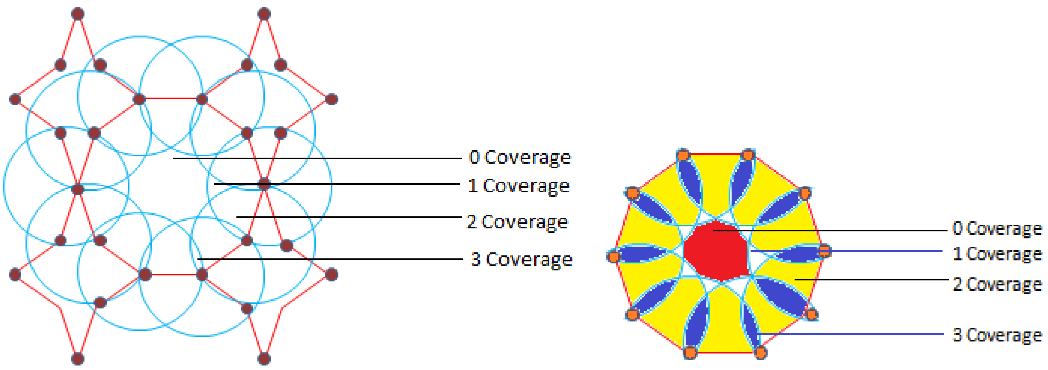

Figure 4. *The overall view of Decagon-Star tiling k-coverage map*

IV. K-COVERAGE MAP FOR DIFFERENT DEPLOYMENT METHODS

To find out total area coverage by different exact k-coverage , we have to first find out area of intersection between two circles in the following two situations .

A. To find area of intersection between two circles if circumference of one circle passes through the origin of the other circle and vice versa .

Suppose we have 2 circles that intersect each other in such a way that each circle passes through the other's centre. What is the area between the circles(or common area) i.e. area between the centers of the circles ,which is shown in figure 5 .

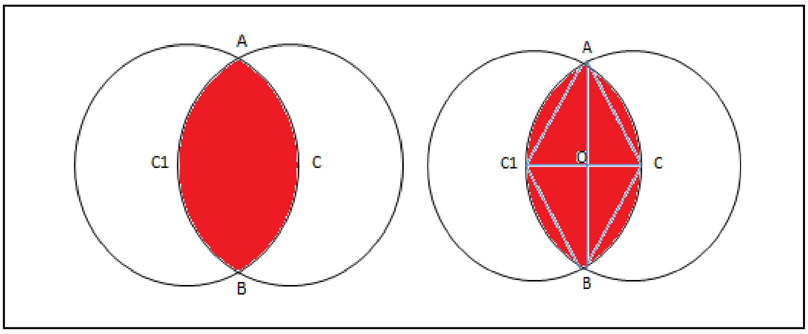

Figure 5. *The overall view of Area of intersection between two circles*

In figure radius of the circle is r . So C_1A ,C_1B , CA, CB ,CC_1 all having length r . So the area of the entire intersection

$$\boxed{A_1 = \frac{r^2(4\pi-3\sqrt{3})}{6}}$$

B. To find out the area of intersection between two circles having equations

$$x^2 + (y - r)^2 = r^2$$

$(x - r)^2 + y^2 = r^2$, which is shown in figure 6

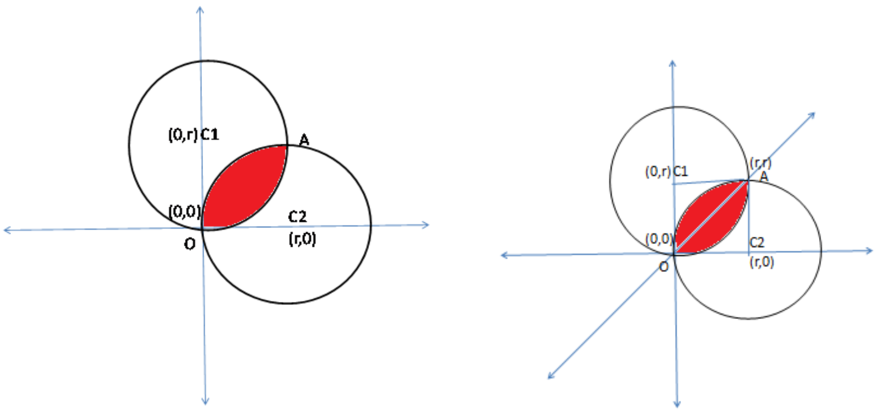

Figure 6. *The overall view of Area of intersection between two circles*

Area of intersecting area $\boxed{A_2 = r^2\left(\frac{\pi-2}{2}\right)}$

V. TOTAL AREA COVERAGE BY DIFFERENT EXACT K-COVERAGE

A. For a square-grid

Let the intersecting area between two circles ,where circumference of one circle passes through the centre of other is A_1 . So half of A_1 is $\frac{A_1}{2}$

One fourth of area of the circle is $\frac{\pi r^2}{4}$

So , $A_3 = \frac{\pi r^2}{4} - \frac{A_1}{2}$ is one 2-k coverage and one 3-k coverage which is shown in the figure 7 .

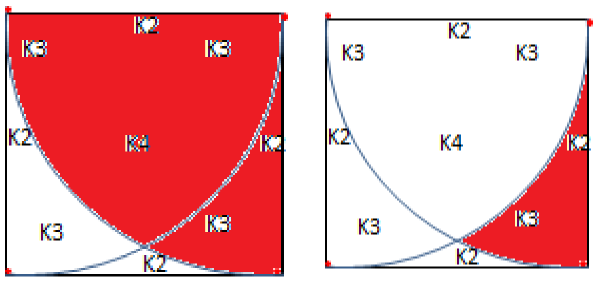

Figure 7. *The overall view of One fourth of the circle and one 2-k with one 3-k*

Area of the square is r^2 and one fourth of area of the circle is $\frac{\pi r^2}{4}$.

So $r^2 - \frac{\pi r^2}{4}$ shows one 2-k coverage , one 3-k coverage and another 2-k coverage which can be shown in figure 8 .

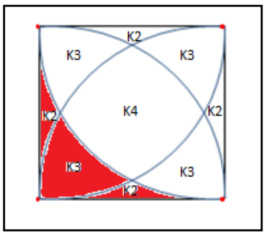

Figure 8. *The overall view of Two 2-k andOne 3-k coverage*

Area covered by one 2-k coverage $A_4 = [r^2 - \frac{\pi r^2}{4}] - A_3$

Area covered by one 3-k coverage $A_5 = A_3 - A_4$

A_2 is the combination of two 3-k coverage one 4-k coverage which can be shown in figure 9 as follows

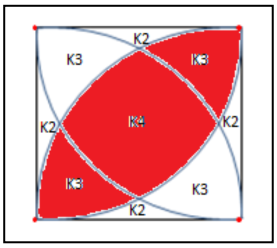

Figure 9. *The overall view of Two 3-k andOne 4-k coverage*

So area covered by one 4-k coverage $A_6 = A_2 - 2(A_5)$

B. For a tri-hexagonal tiling

Area of one sixth of circle is equal to $\frac{\pi r^2}{6}$, Area of equilateral triangle is $A_T = \frac{\sqrt{3}}{4} r^2$,So Area of exact 3-k coverage at the border of hexagon is $A_{3B} = \frac{\pi r^2}{6} - A_T$, which is shown in figure 10 .

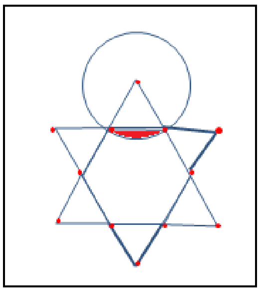

Figure 10. *The overall view of One exact 3-k coverage at the border of hexagon coverage*

Area of exact 3-k coverage inside the hexagon is twice the area of 3-k coverage at the border of hexagon i.e $A_{3I} = 2A_{3B}$, which is shown in figure 11 .

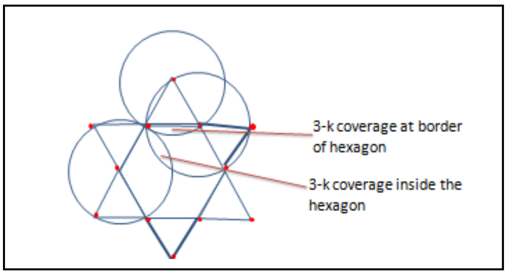

Figure 11. *The overall view of exact 3-k coverage inside the hexagon*

Here there are six 3-k coverage inside the hexagon and also six 3-k coverage at the border of the hexagon . so total area covered by 3-k coverage is $A_{3T} = 9A_{3I}$, which is shown in figure 12 .

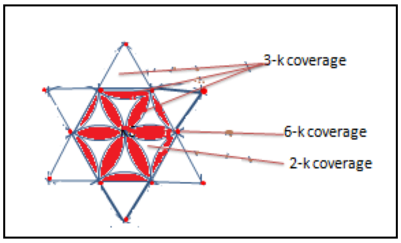

Figure 12. *The overall view of Total exact 3-k coverage of the hexagon*

Total area of 2-k coverage is equal to area of hexagon minus area covered by 3-k coverage plus € .Where € is the area covered by exact 6-k coverage . For perfect THT , €→ 0 . So we can write the equation for 2-k coverage as follows :[21] . $A_{2T} = A_H - [\, A_{3T} + €]$, which is shown in figure 13 .

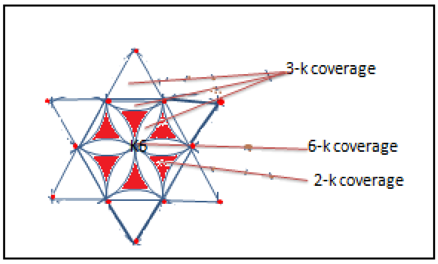

Figure 13. *The overall view of Total exact 2-k coverage of the hexagon*

C. For a octagon-square tiling

In [22]the octagon square based pattern can be shown as in figure 14 .

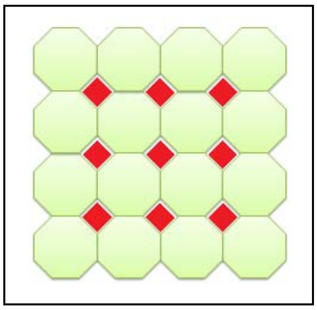

Figure 14. *The overall view of Octagon-square based pattern*

Area of sector with angle 45^0 is one eighth part of the whole area of circle i.e S= $\frac{\pi r^2}{8}$. Which is shown in the figure 15 .

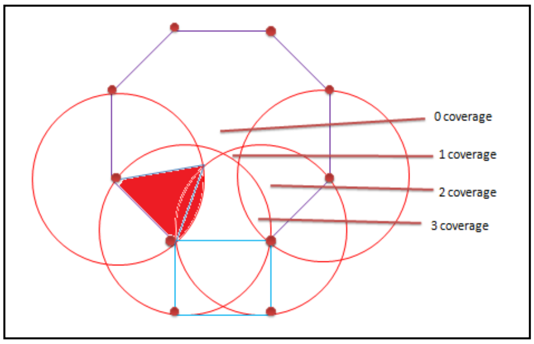

Figure 15. *The overall view of one eighth part of the of circle*

Area of half of one 3-k coverage = Area of one eighth of circle - Area of the given triangle .

Now area of triangle ABC i.e T $= \frac{1}{2} \times base(b) \times height(h)$, which is shown in figure 16

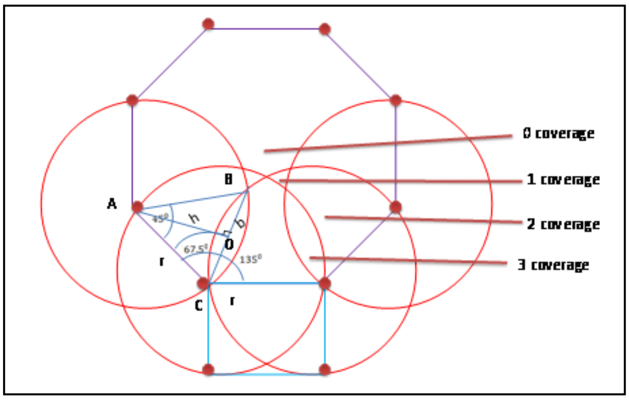

Figure 16. *The overall view of one eighth part of the of circle*

Since ABC is an isosceles triangle and $\angle A=45^0$ .So , $\angle B = \angle C=67.5^0$

$$\text{Here , } \cos 67.5^0 = \frac{b/2}{r}$$

$$\Rightarrow b = 2 \times \cos 67.5^0 \times r$$

In right angle triangle AOC , $h = \sqrt{r^2 - (b/2)^2}$

By using the value of b, h we can calculate the value of T i .e

$T = \frac{1}{2} \times b \times h$

Area of half of one 3-k coverage = S-T , which is shown in figure 17

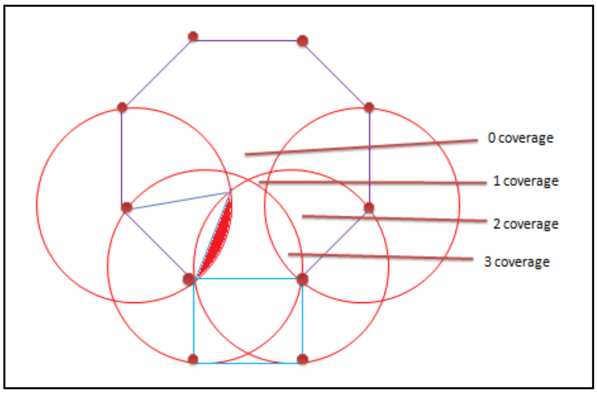

Figure 17. *The overall view of half of one 3-k coverage*

Area of one 3-k coverage i.e $A_3 = 2 \times$ (S-T)

The intersecting area between two circles ,where circumference of one circle passes through the centre of other i.e $A = \frac{r^2(4\pi - 3\sqrt{3})}{6}$. Here half of A is shown in the figure 18 . There are present two 3-k coverage area with one 2-k coverage area . So area of one exact 2-k coverage i.e $A_2 = \frac{A}{2} - (2 \times A_3)$.

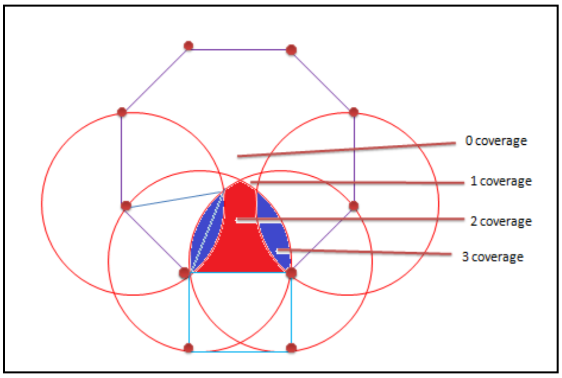

Figure 18. *The overall view of half of intersecting area between two circles*

The circular segment having angle 135^0 is shown in the figure 19 . Whose area i.e S_1 can be found out as follows : $S_1 = (\frac{135}{360}) \times \pi r^2$. The circular segment is having three exact 3-k coverage area and one 2-k coverage area one 1-k coverage area . So getting one exact 1-k coverage area we have to remove the 3-k coverage area and 2-k coverage area from the circular segment . So one exact 1-k coverage area i.e$A_1 = S_1 - [(2 \times A_2) + (3 \times A_3)]$

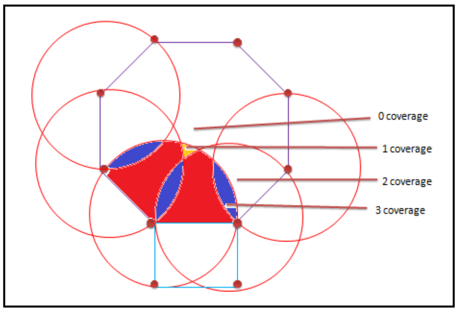

Figure 19. *The overall view of Circular segment having angle* 135^0

In a octagon there are present 8 exact 1-k coverage , so total area of 1-k coverage i.e $A_{T1} = 8 \times A_1$

In a octagon there are present 8 exact 2-k coverage , so total area of 2-k coverage i.e $A_{T2} = 8 \times A_2$

In a octagon there are present 8 exact 3-k coverage , so total area of 3-k coverage i.e $A_{T3} = 8 \times A_3$

In a octagon there are present 1 exact 0-k coverage , so area of 0-k coverage i.e $A_{T0} = A_{oct} - (A_{T1} + A_{T2} + A_{T3})$, which is shown in figure 20.

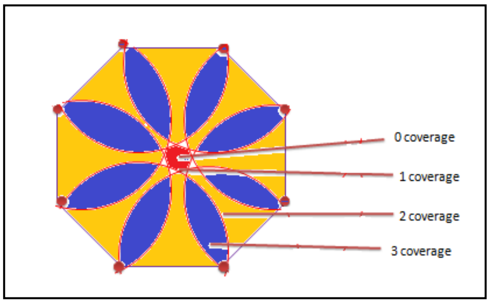

Figure 20. *The overall view of one 0-k coverage*

D. For a decagon star tiling

The decagon-star based pattern can be shown as in figure 21 .

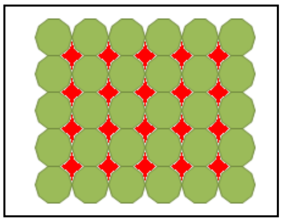

Figure 21. *The overall view of Decagon-star based pattern*

Area of sector with angle 36^0 i.e S is one tenth part of the whole area of circle . Which is shown in the figure 22 . Area of one tenth of circle i.e S= $\frac{\pi r^2}{10}$.

Area of half of one 3-k coverage = Area of one tenth of circle - Area of the given triangle

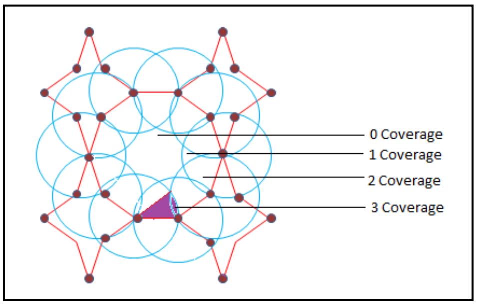

Figure 22. *The overall view of one tenth part of the of circle*

Now area of triangle ABC i.e T $= \frac{1}{2} \times base(b) \times height(h)$, which is shown in figure23 .

Since ABC is an isosceles triangle and $\angle$A= 36^0 .So , $\angle$B =$\angle$C=72^0

Here $cos\ 72^0 = \frac{b/2}{r}$ $\Rightarrow b = 2 \times cos\ 72^0 \times r$

In right angle triangle AOC , $h = \sqrt{r^2 - (b/2)^2}$, By using the value of b, h we can calculate the value of T i.e T$= \frac{1}{2} \times b \times h$

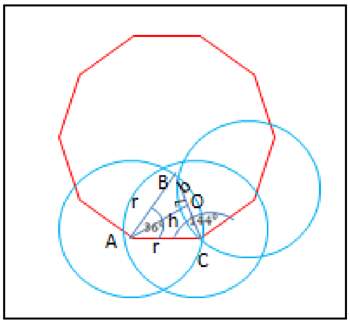

Figure 23. *The overall view of the triangle AOC*

Area of half of one 3-k coverage = Area of one tenth of circle - Area of the given triangle =S-T

Area of one 3-k coverage i.e $A_3 = 2 \times$ (S-T) , which is shown in figure 24 .

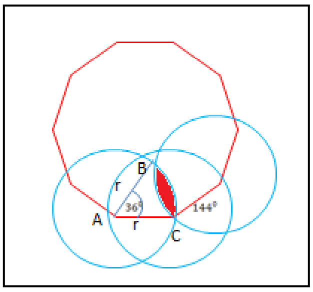

Figure 24. *The overall view of of one 3-k coverage*

The intersecting area between two circles ,where circumference of one circle passes through the centre of other i.e A = $\frac{r^2(4\pi-3\sqrt{3})}{6}$. Here half of A is shown in the figure 25 as follows . There are present two 3-k coverage area with one 2-k coverage area . Two get one exact 2-k coverage area we have to remove those 3-k coverage area from half of A . So area of one exact 2-k coverage i.e $A_2 = \frac{A}{2} - (2 \times A_3)$

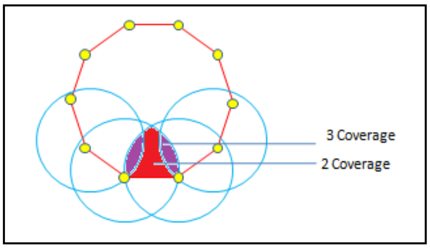

Figure 25. *The overall view of Half of intersecting area between two circles*

The circular segment having angle 144^0 is shown in the figure . Whose area i.e S_1 can be found out as follows : $S_1 = (\frac{144}{360}) \times \pi r^2$,which is shown in figure 26 . The circular segment is having three exact 3-k coverage area and one 2-k coverage area one 1-k coverage area . So getting one exact 1-k coverage area we have to remove the 3-k coverage area and 2-k coverage area from the circular segment .

So one exact 1-k coverage area i.e $A_1 = S_1 - [(2 \times A_2) + (3 \times A_3)]$

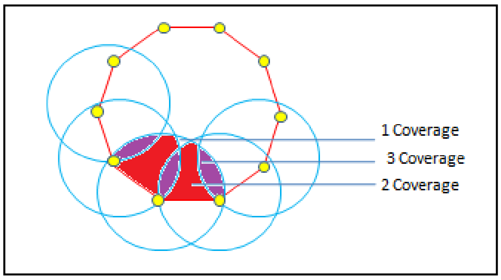

Figure 26. *The overall view of Circular segment having angle*

In a decagon there are present 10 exact 1-k coverage , so total area of 1-k coverage i.e $A_{T1} = 10 \times A_1$

In a decagon there are present 10 exact 2-k coverage , so total area of 2-k coverage i.e $A_{T2} = 10 \times A_2$

In a decagon there are present 10 exact 3-k coverage , so total area of 3-k coverage i.e $A_{T3} = 10 \times A_3$

In a decagon there are present 1 exact 0-k coverage , so area of 0-k coverage i.e $A_{T0} = A_{dec} - (A_{T1} + A_{T2} + A_{T3})$, which is shown in figure 27 .

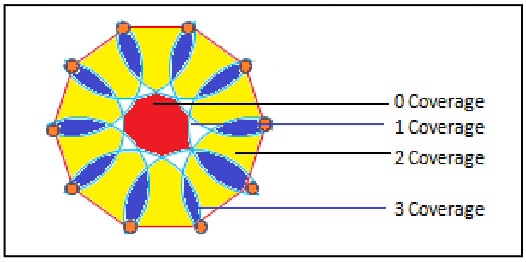

Figure 27. *The overall view of one 0-k coverage*

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