An Efficient Coverage for Sensor Deployments in Wireless Sensor Network

Rajeeb Sankar Bal,

Senior Lecturer
Department of Computer Science and Engineering
ABIT, Cuttack, Odisha, India
rajiv.s.bal@gmail.com

Sanata Kumar Swain,

Senior Lecturer
Department of MCA
ABIT, Cuttack, Odisha, India
sanu.sanata@gmail.com

Abstract

The Wireless sensor networks constitute the environment of a broad range of applications related to national security, surveillance, military, health care, and environmental monitoring. The coverage of Wireless Sensor Network has answered the questions about quality of service (or surveillance) which can be provided by Wireless Sensor Network. The sensor node deployment is an important and fundamental issue to be solved in Wireless Sensor Networks. By the mathematical computation and analysis, the sensor node deployments in the circular region or disk, as a rule, are better than those in the form of circle overlapping with calculation of the efficient coverage areas and its ratios decrease with increasing number of sensor nodes. But the efficient coverage area ratios decrease with increasing number of sensor nodes. Sometime information is incompletely monitored or undetected. This is coverage problem with connectivity problems. The coverage problem is also one of basic problem in wireless sensor networks. The paper analyses sensor node deployments and computes their efficient coverage areas and their efficient coverage area ratios. In addition, the relation between the number of sensors in circular region or disk and efficient coverage area ratio is discussed.

Keywords- Wireless Sensor Network (WSN); Wireless Sensor (WS); Sensor Node (SN).

I. INTRODUCTION

A WSN or WSs are provided a bridge between the real physical and virtual worlds. In WSN, the sensor nodes or devices are capable of detecting change temperature, pressure, humidity, sound and many more.

A. *WSN Communication*

Further, WSN is a collection of some (sometimes even hundreds & thousands) smart SNs which collaborate among themselves to form a sensing network. The smart SNs are wireless computing devices that sense information in much variety of environments to provide a multidimensional view of the environment. For example, some sensors can sense light, some can sense temperature simultaneously. There are the three main task of a WSN can be divided into three categories:

1. Sensing,
2. Processing and
3. Acting.

After sensing the environment based on the query provided by the user, a SN can process the sensed data, may even sometimes aggregate it with other SNs data and send it to the base station. According to the results provided by individual SNs, the WSN can act by providing the results to the user or to a sink node connected to the satellite or internet.

In WSN, the SNs deployed in the areas where transmission through wires are not reliable and possible. A WSN consist of large number of sensor nodes with sensors for sensing, processor for data processing and transceiver for communication range capabilities. The SNs in the network monitors the surrounding areas and gathers application specific parameters like pressure, humidity, chemical activity, mechanical stress level, temperature, light and other parameters.

In WSN, the SNs periodically sense the data and process it to the adjacent or neighbour nodes to form a communication network. The collected data send to the sink node in hop. By hop transmission utilizing the minimum possible power. When data reach the sink node, it is then routed to the task manager node or user via satellite or internet where users can have access to the data as shown in Figure 1.

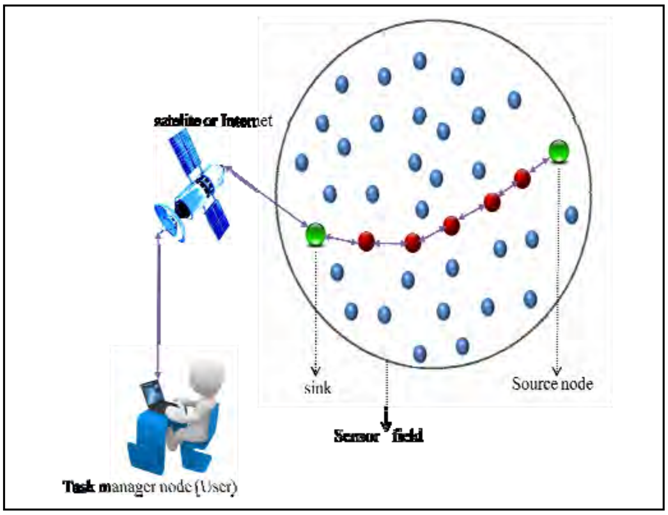

Figure 1. The communication architecture of WS or WSN.

The rest of the paper is organized as follows: Section II introduces coverage in WSN explained. Section III introduces coverage problems in WSN explained. Section IV introduces related work on efficient coverage area and its ratio based on different Sensor deployments. Section V introduces problem descriptions and coverage rang with definitions. Sensor deployment has been explained in Section VI. The Simulation and discussions have been described in Section VII. This paper concludes with Section VIII.

B. The SNs Architecture

In Figure.2, it shows WS with SN architecture. Each SN consists of following four units:

1. Sensing unit:
2. Processing unit:
3. Communication unit:
4. Power generator unit:

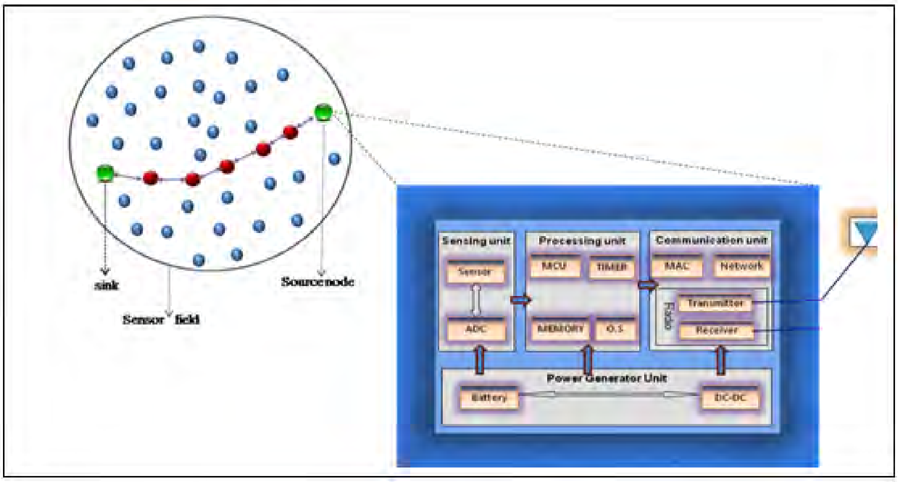

Figure 2. The SNs architecture.

II. THE COVERAGE IN WSN

WSNs are a rapidly growing area for research, government organization and industrial development. WSNs are used to capable of tracking and monitoring the activities of an interest area for changes in the environment. They are very useful for health, military, home, environmental, and scientific applications to name a few. One of the important active areas of research in WSNs is that of coverage. The coverage in WSNs is usually defined as a measure of quality of service and maintains connectivity.

Coverage: Generally, the coverage can be classified into three groups; area coverage, point coverage and barrier coverage.

1. *Area or Blanket coverage*: The main goal of the WSN in area or blanket coverage is to monitor (cover) a area (the collection of all space points within the sensor field), and each point of the area need to be monitored shown in Figure 3.

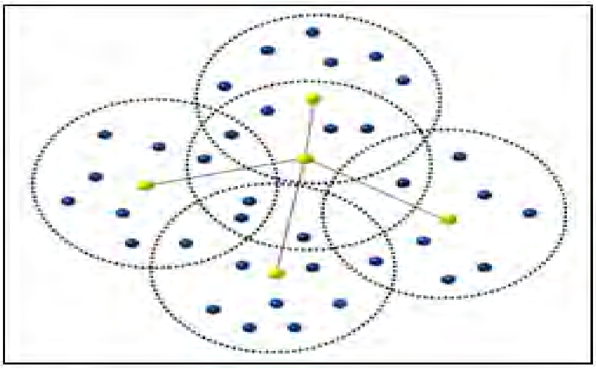

Figure 3. The area coverage in WSN

2. *Point Coverage*: The main goal is to cover a set of target (point) with known position that need to be monitored. The point coverage scheme focuses on determining SNs exact positions which guarantee efficient coverage application for a limited number of immobile points (targets). Generally, it can be solved as a special case of the area coverage problem when SNs number may leave out of account shown in Figure 4.

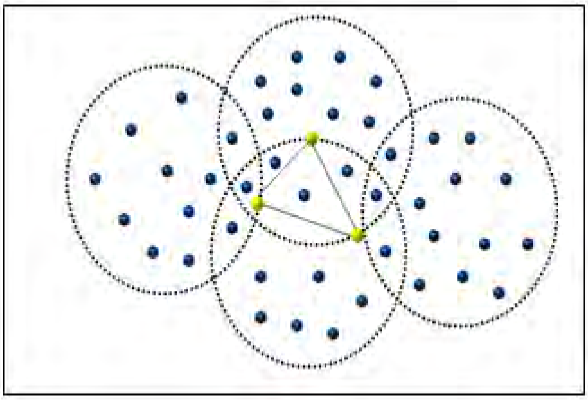

Figure 4: The point coverage in WSN.

3. *Target coverage:* It is considered as number of targets with known position that needs to be continuously observed (covered) and a large number of sensors closely deployed to the target.

4. *Barrier coverage:* It refers to the detection of movement across a barrier of sensors. This is useful in applications where the major objective is to detect intruders as they cross a border or as they penetrate to a protected area shown in Figure 5.

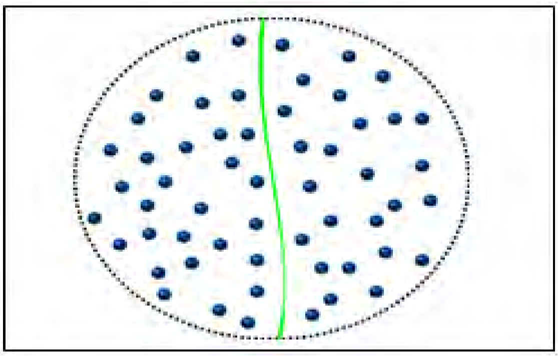

Figure 5. The barrier coverage in WSN.

III. THE COVERAGE PROBLEMS IN WSN

In [1], the coverage of WSN considers either area (point) coverage or path coverage some strategy focus on evaluating the coverage performance and others improving the coverage performance. Some strategy consider about stationary network and others mobile network. However, the existing strategies for the coverage of WSN have some primary conditions. Firstly, we assume that the boundary of sensing and communication of SN is a proper circle which is a known and static radius (or fixed sensing range) in considering the coverage problem. In figure.6 shows the effect of barriers on the sensing area of SN. Therefore, the sensing areas are very irregular and dynamic in real situation for WSN, which usually employ low quality radio modules to reduce the cost.

Additionally, there are some sensors having a sector sensing range, such as the directional antenna. Hence, the irregularity is the common issue in wireless sensor networks and to continue to ignore it. There is a need to evaluate the effect of location in-accuracies on the performance of various coverage protocols. Secondly, by leveraging mobile nodes, many network wide performance metrics inclusive coverage can be greatly improved than the traditional approach by deploying a great amount of stationary SNs and then apply coverage control algorithms to schedule sensors' activity in an efficient way. However, the movement of sensors might be caused by the environment and resources such as more battery supply, advanced computing and more storage.

Thirdly, there are many important problems in sensor network design where the physical dimensionality of the network plays a very significant role and the optimal solution of such a problem in a 3D network is quite different from the optimal solution in a 2D network. Since the density of SNs to completely cover a 3D region is problematic higher than the corresponding two-dimensional case, SNs deployed in a 3D setting like in underwater or in the atmosphere, should collaborate with each other to regulate their depths according to their sensing ranges in order to achieve complete three-dimensional coverage.

Fourthly, as per the application requirements the existing coverage schemes for WSN adjust the state of SNs. In practice, the coverage scheme can induce the changes of SNs states to bring the change of other properties.

Lastly, evaluating and improving coverage performance of area (point) and path coverage, while maintaining connectivity and maximizing the network lifetime.

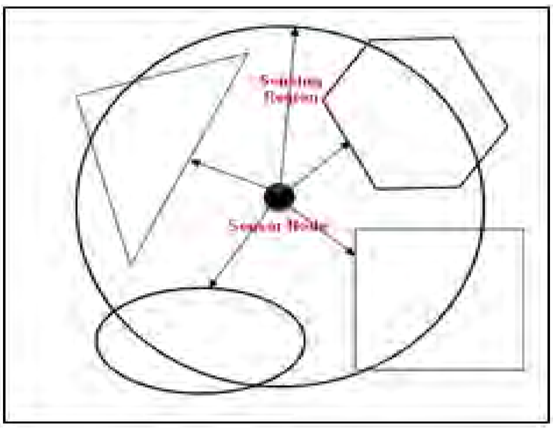

Figure 6. The SN surround by non-penetrate obstacle.

IV. THE COVERAGE PROBLEMS IN WSN

The analysis formula of the minimum number of SNs, the maximum efficient coverage area and its ratio, the maximum of total efficient coverage area of SNs and the maximum of total efficient coverage area ratio of SNs under the condition of seamless coverage. By analyzing both the deployments and considering different coverage redundancy requirement for different applications.

The paper analyses several SN deployments and computes their efficient coverage areas and their efficient coverage area ratios. In addition, the relation between the number of sensors and efficient coverage area ratio is discussed.

V. THE PROBLEM DESCRIPTION

A. The Assumption of Coverage Range

1. A SN is detecting ability is omnidirectional, that is, its coverage range is a disk or circle whose radius r and whose area is D ($D = \pi r^2$).

2. In a sensor field, all sensor nodes have radio power is uniform, that is, the radio radius of all SNs are either equal radius (r) or unequal radius (R).

3. In a WS field, all sensors are in the same plane.

B. Definitions

In the sensor field of WSNs, a piece of zone A_Z is possibly covered by several SNs shown in Figure 7. In this case, the coverage resulted from SN A_1 among these SNs is redundant for area zone A_Z. Because the information of area zone A_Z can be sensed and acquired by other SNs. Therefore, the definitions can be followed:

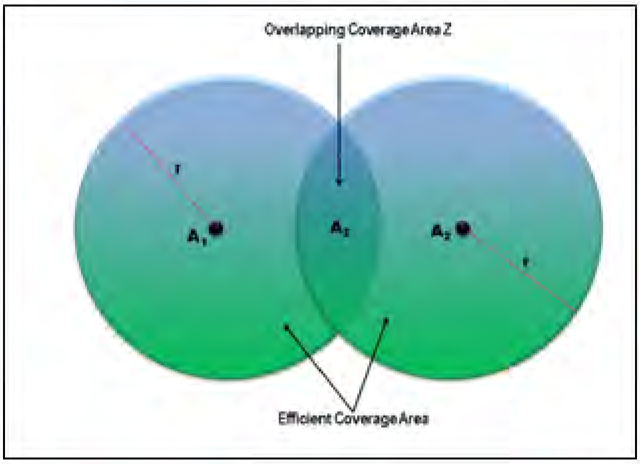

Figure 7. The efficient coverage area.

1) Definition of efficient coverage area : To change the default, adjust the template as follows.

In [2][3], it is the coverage area that is overlapping coverage area zone Z's area A_z subtracted from sensor node A_1's coverage range $(D = \pi r^2)$.

$$A_{\text{Efficient Coverage Area}} = D - A_z$$

$$A_{\text{Efficient Coverage Area}} = \pi r^2 - A_z$$

2) Definition of efficient coverage area ratios:

$$E_{\text{fficient Coverage Area Ratio}} = A_{\text{Efficient Coverage Area}} (A_z) / \text{Coverage range} (D = \pi r^2)$$

$$= \frac{D - A_z}{D}$$

$$= 1 - \frac{A_z}{D}$$

VI. THE SN DEPLOYMENTS

The SNs are to be placed exactly at the designated grid points. This method promises to provide certain percentage and degree of coverage and also the connectivity. Types of grids used in networking shown in figure.8.

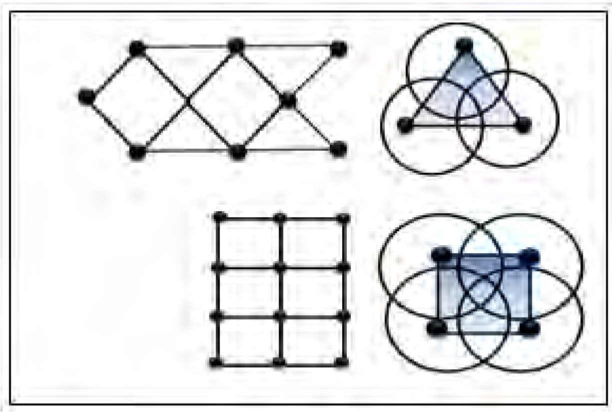

Figure 8. The Types of grids deployment.

A. The SN Deployments Based on Circle

1) Area of Overlapping at center of The Circles : The two sensor nodes at centre vertexes of the circle (its edge length is equal to r) as shown in Figure.9., two sensor nodes are respectively deployed at two vertexes of the circle the length of which edge is equal to the length of the radius r of circle.

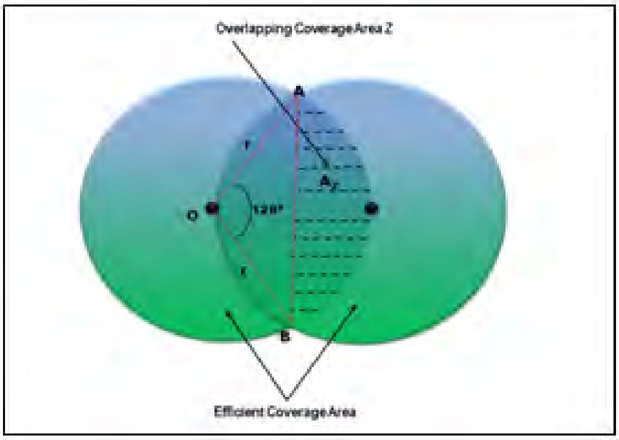

Figure 9: The SNs at vertexes of center of circle (edge length is r).

Area with shadow $= \frac{1}{3}\pi r^2$

Area $\Delta OAB = \frac{1}{2} r^2 \sin(120^0)$

Area with horizontal lies in overlapping area

$$= \frac{1}{3}\pi r^2 - \frac{1}{2} r^2 \sin(120^0)$$

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

Hence the net Area with shadow (A_Z)

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

The efficient coverage area of symmetric circle (A_{ECA}):

$$A_{ECA} = \pi r^2 - A_Z$$

$$A_{ECA} = r^2 (\pi - 2(\frac{\pi}{3} - \frac{\sqrt{3}}{4})) \qquad (1)$$

The efficient coverage area ratio of symmetric circle (R_{ECA}) :

$$R_{ECA} = 1 - \frac{A_Z}{\pi r^2}$$

$$R_{ECA} = 1 - \frac{2}{\pi} (\frac{\pi}{3} - \frac{\sqrt{3}}{4}) \qquad (2)$$

2) Area of Overlapping at Different section of The Circles (Symmetric Circles) :

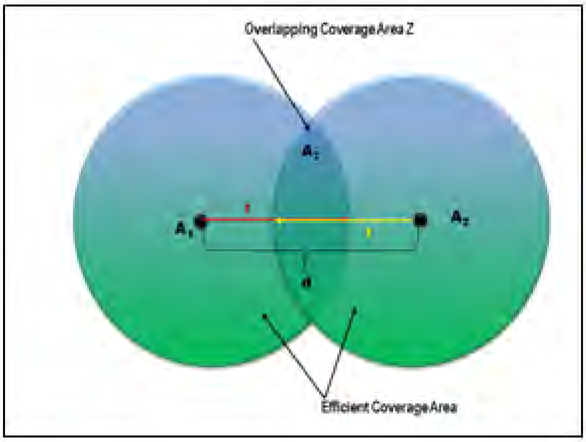

Figure 10. The sensor nodes at vertexes of center of circle (edge length is r) with various sections.

In the figur.10 can be shown the distance (d) between the centers of the circles affects the size of the overlapping area. Now, some conditions for the distance (d) between the centers of circles are as follows:

1. If d = 0 the area of the overlapping is πr^2 .
2. If d $\geq$ 2r the area of the overlapping is 0.

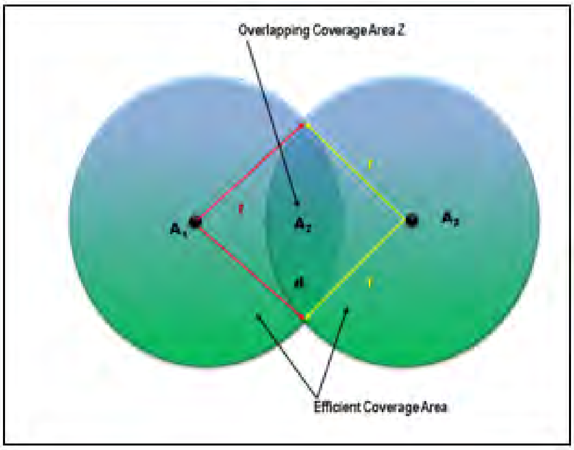

Figure 11: The area is formed by two overlapping sectors of the circles.

In the figure 11, the area is formed by two overlapping sectors of the circles. So the plan is to work with one of the circles in finding the area of its sector, then finds the area of the segment of sector by subtracting the area of its triangle, and finally multiplies this area by two to get the overlapping area that we want.

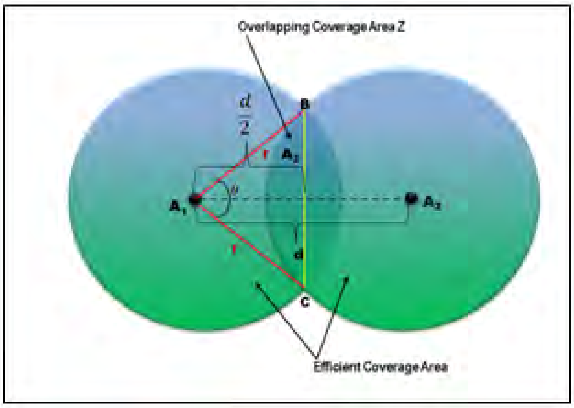

Figure 12. The Area of the Circle’s sector.

In figure.12, the area of a circle's sector is given by Area = $\frac{\theta}{2} r^2$, where θ is the central angle of the sector in radians

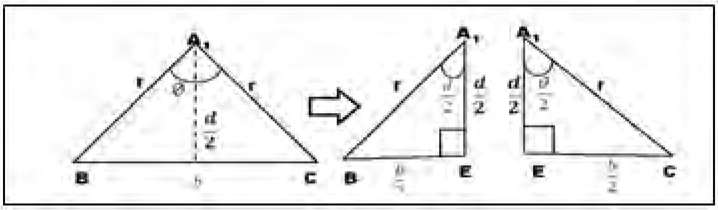

Figure 13: The Area of the Circle Sector's segment to form triangle.

In the figure 13, we need first the area of the triangle that forms it(that is triangle A_1BC). In this case, BC is base (b) and $\frac{d}{2}$ is height of the triangle. So using area of the triangle. We use two approaches to find the area of the triangle.

a) Pythegorean Theorem:

As per the Pythegorean theorem in one of the right triangles to find an expression for the base of the triangle in terms of radius (r) and distance between two circles (d). Let's call b the base of the triangle A_1BC, so the base of the right angles shown in figure 13 is $\frac{b}{2}$.

By the Pythegorean theorem we have,

$$(\frac{b}{2})^2 + (\frac{d}{2})^2 = r^2$$
$$\Rightarrow b = \sqrt{4r^2 - d^2}$$

So, the area of the triangle is going to be given by

$$Area = \frac{1}{2} xbase\ (b)\ xheight\ (h)$$

$$Area = \frac{d}{4}\sqrt{4r^2 - d^2}$$

Thus, we get the efficient area is

$$A_z = \frac{d}{4}\sqrt{4r^2 - d^2}$$

$$A_{Efficient\ Coverage\ Area} = \pi r^2 - A_z \qquad (3)$$

$R_{Efficient\ Coverage\ Area\ Ratio1}$ = $A_{Efficient\ Coverage\ Area}$ / Coverage range (D = πr^2)

= 1 – (D / A_z) (4)

b) Trigonometry Theorem:

As per trigonometry, one of the right triangles and the fact that we already know , find an expression for the area in terms of radius (r) and an angle θ. First we define the base and the height of the triangle in terms of r and θ.

$$\sin(\frac{\theta}{2}) = \frac{b/2}{r}$$

$$\Rightarrow b = 2r\sin(\frac{\theta}{2})$$

and

$$\cos\frac{\theta}{2} = \frac{h}{r}$$

$$\Rightarrow h = r\cos(\frac{\theta}{2})$$

So the area of the triangle is going to be given by

$$Area = \frac{1}{2} xbase \ (b) \ xheight \ (h)$$

$$\Rightarrow Area = \frac{1}{2}(2r\sin(\frac{\theta}{2}))(r\cos(\frac{\theta}{2}))$$

$$\Rightarrow Area = r^2 \sin(\frac{\theta}{2})\cos(\frac{\theta}{2})$$

Now, using the double angle formula,

$$\sin(2\theta) = 2\sin(\theta)\cos(\theta)$$

$$\Rightarrow Area = \frac{1}{2} r^2 \sin(\theta)$$

Since we know the area of the triangle, the area of the segment can be determined by difference in area between the sector and triangle.

Area of the sector's segment in terms of r and θ is as follows:

$Area_{segment} = Area_{sector} - Area_{triangle}$

$$= (\frac{\theta}{2} r^2) - \frac{1}{2} r^2 \sin(\theta)$$

$$Area_{segment} = \frac{r^2}{2}(\theta - \sin(\theta))$$

Area of the sector's segment in terms of r and θ is as follows:

$Area_{segment} = Area_{sector} - Area_{triangle}$

$$= r^2 \cos^{-1}(d/2r) - d/4 \sqrt{4r^2 - d^2}$$

Thus, we get the efficient area is

$$A_z = r^2 \cos^{-1}(d/2r) - d/4 \sqrt{4r^2 - d^2}$$

$$A_{Efficient\ Coverage\ Area} = \pi r^2 - A_z \qquad (5)$$

$R_{Efficient\ Coverage\ Area\ Ratio1} = A_{Efficient\ Coverage\ Area}$ / Coverage range ($D = \pi r^2$)

$$= 1 - (Az / D) \qquad (6)$$

c) Area of Overlapping at Different section of The Circles (Asymmetric Circles):

The two sensor nodes at centre vertexes of the circle (its edge lengths are R and r) as shown in Figure.14, two sensor nodes are respectively deployed at two vertexes of the circle the length of which edges are equal to the length of the radius R and radius r of two circle.

Let two circles of radii R and r and centered at (0, 0) and (d, 0) intersect in a region shaped like an asymmetric lens.

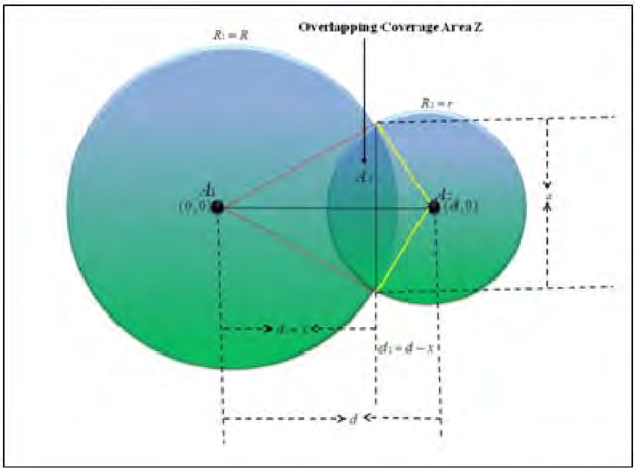

Figure 14: The overlapping asymmetric circles

The area of asymmetric overlapping circle is Area(A_z) =Area of Circle with radius R and center (0, 0) +Area of Circle with radius r and center (d, 0).

$$A_z = A(R, d_1) + A(r, d_2)$$

$$A_z = r^2 \cos^{-1}\left(\frac{d^2 + r^2 - R^2}{2d * r}\right) +$$

$$R^2 \cos^{-1}\left(\frac{d^2 + R^2 - r^2}{2d * R}\right) -$$

$$\frac{1}{2}\sqrt{(R + r - d)(r + d - R)(d - r + R)(d + r + R)}$$

$A_{\text{Efficient Coverage Area}} = \pi R^2 - A_z$ (At circle A_1 with radius R)

$R_{\text{Efficient Coverage Area Ratio1}} = A_{\text{Efficient Coverage Area}}$/Coverage range ($D_1 = \pi R^2$ at circle A_1)

$= 1 - (A_z/D_1)$ (7)

$A_{\text{Efficient Coverage Area}} = \pi r^2 - A_z$ (At circle A_2 with radius r)

$R_{\text{Efficient Coverage Area Ratio2}} = A_{\text{Efficient Coverage Area}}$ /Coverage range ($D_2 = \pi r^2$ at circle A_2)

$= 1 - (A_z/D_2)$ (8)

VII. SIMULATIONS

Mathematically, this paper computed and simplifies coverage problem. In seamless WSN, it is theoretically proved SN's maximum efficient coverage area is shown in figure.15. But the maximum efficient coverage area ratio is 0.6089620423672094 in (1) and (2).

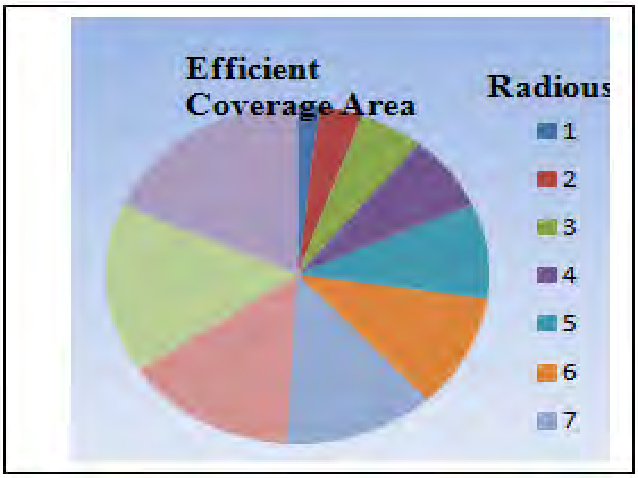

Figure 15. The maximum efficient coverage area at center of overlapping of circle.

The area is formed by two overlapping sectors of the circles in (3) and (4). Hence, the result of maximum efficient coverage area using Pythegorean theorem for symmetric circle is shown in figure.16.

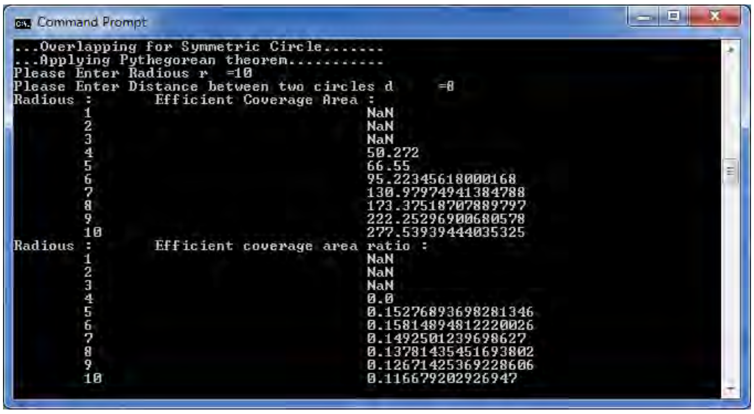

Figure 16. The maximum efficient coverage area and its ratio using Pythegorean theorem for symmetric circle.

The area is formed by two overlapping sectors of the circles in (5) and (6). Hence, the result of maximum efficient coverage area using Trigonometry theorem for symmetric circle is shown in figure.17.

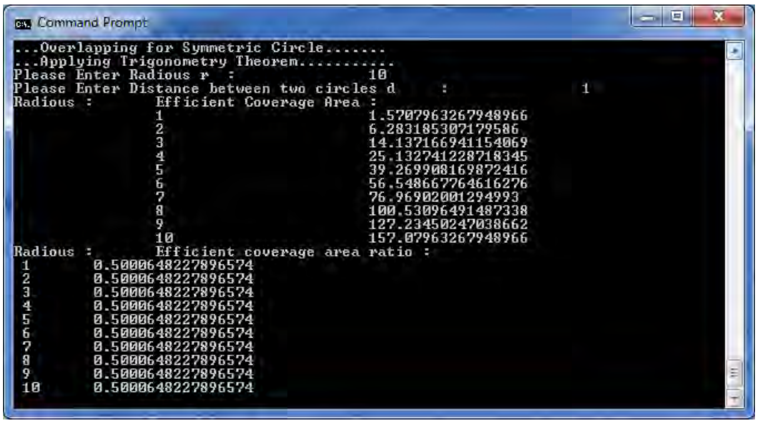

Figure 17. The maximum efficient coverage area and its ratio using Trigonometry theorem for symmetric circle.

The area is formed by two overlapping sectors of the circles in (7) and (8). Hence, the result of maximum efficient coverage area for asymmetric circle is shown in figure.18.

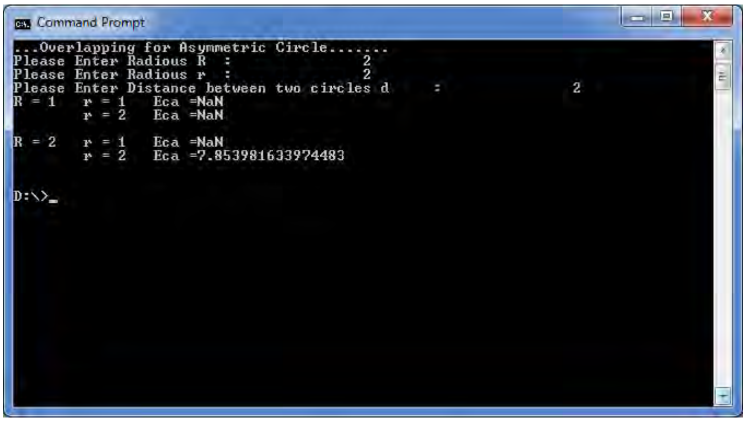

Figure 18. The maximum efficient coverage area and its ratio for asymmetric circle.

VIII. CONCLUSION

According to simulation above, the overlapping of circle has the efficient coverage area and its ratio and uses two SNs compared to symmetric and asymmetric overlapping area. But, it can be concluded that by means of mathematical modelling, theoretical analysis and formula deduction, the effective coverage area ratio decreases with increase of radious of symmetric and asymmetric overlapping circles.

REFERENCES

[1] GaoJun Fan and ShiYao Jin (2010). Coverage Problem in Wireless Sensor Network: A Survey. ACADEMY PUBLISHER, VOL.5, NO. 9.

[2] Naregalkar Akshay, M.Praveen Kumar, B.Harish and Sujata Dhanorkar (2010). An Efficient Approach for Sensor Deployments in Wireless Sensor Network, IEEE, 978-1-4244-9005-9/10.

[3] Sudeep Shakya, Nirajan Koirala and Narayan Nepal (2014). Numerical Analysis of Sensor Deployment in Wireless Sensor Network. International Journal of Computer Applications Volume 90, No 6.

[4] www.mathworld.wolfram.com.

AUTHORS PROFILE

Mr. Rajeeb Sankar Bal: Obtained MCA degree from Fakir Mohan University, Balasore, Odisha in the year 2002, and MTech in Computer Science & Engg from BPUT, Odisha , in the year 2002. Served in guest faculty in different premier institutes namely Institue of Management & Information Technology, Cuttack, Ravenshaw University, Cuttack and IGNOU study center, Cuttack, Odisha Currently working as Senior Lecturer in the Department of Computer Science & Engineering Ajay Binay institute of Technology at Cuttack, Odisha, India. Having research interests include Sensor Network, Soft Computing.

Mr. Sanata Kumar: Obtained MCA degree from BPUT, Odisha in the year 2005. Served in faculty in different premier institutes namely KIIMS, Cuttack, Cuttack, Odisha. Currently working as Senior Lecturer in the Department of MCA Ajay Binay institute of Technology at Cuttack, Odisha, India. Having teaching experiences include C,C++,DS,JAVAand research interests include Sensor Network, Soft Computing.