Achieving Connected *k*-coverage in Wireless Sensor Networks using Computational Geometry-based approaches

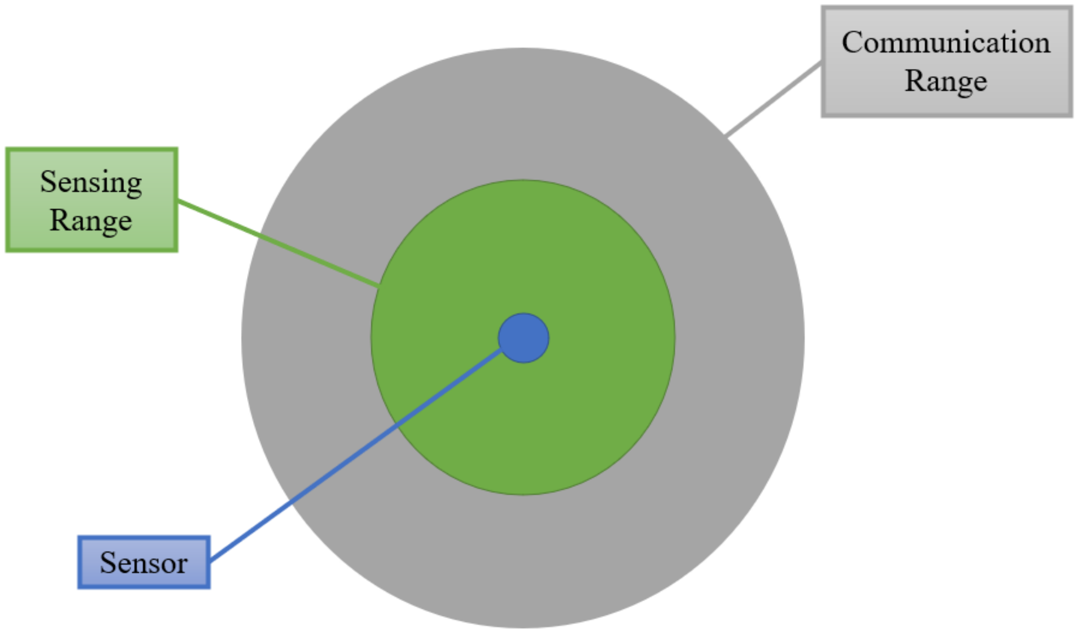
Venkata Swamy ***Kalyan*** *Nakka*

Outline

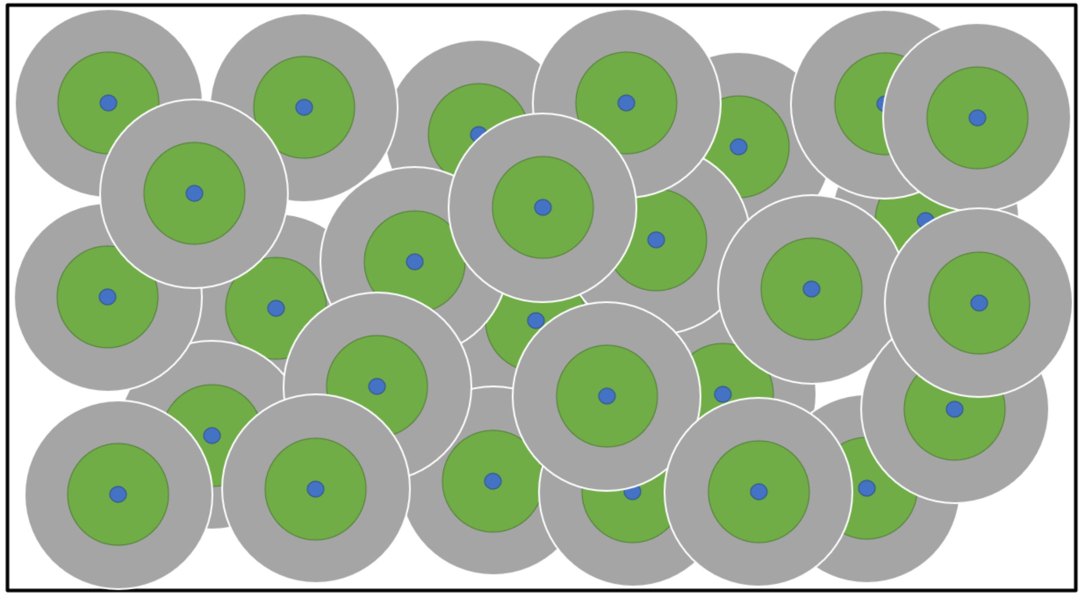
- **Introduction**
- Dr. Ammari’s Research
- Preliminaries
- Square Tessellation Approach
- Hexagonal Tessellation Approach
- Results
- Conclusion

Planar Wireless Sensor Networks

Sensor



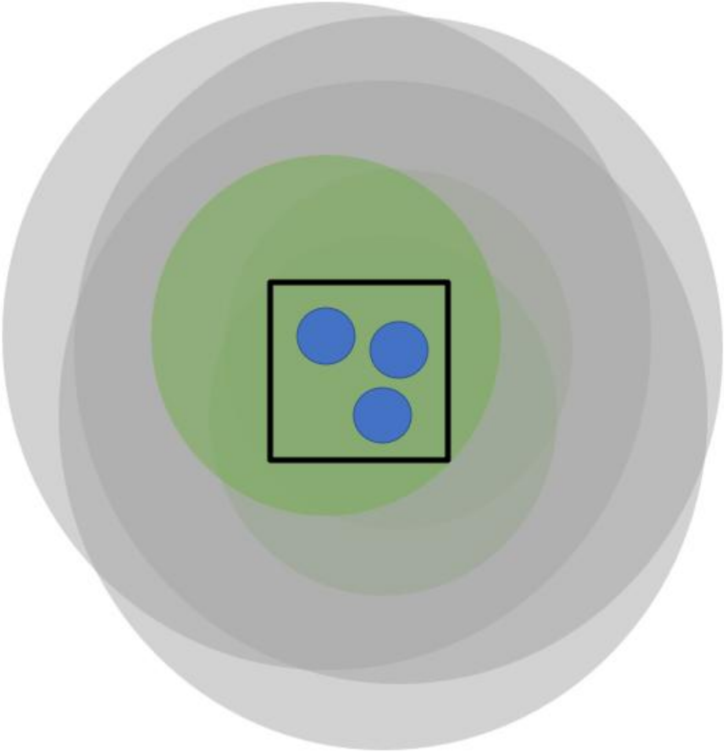
Sensors deployed in FoI



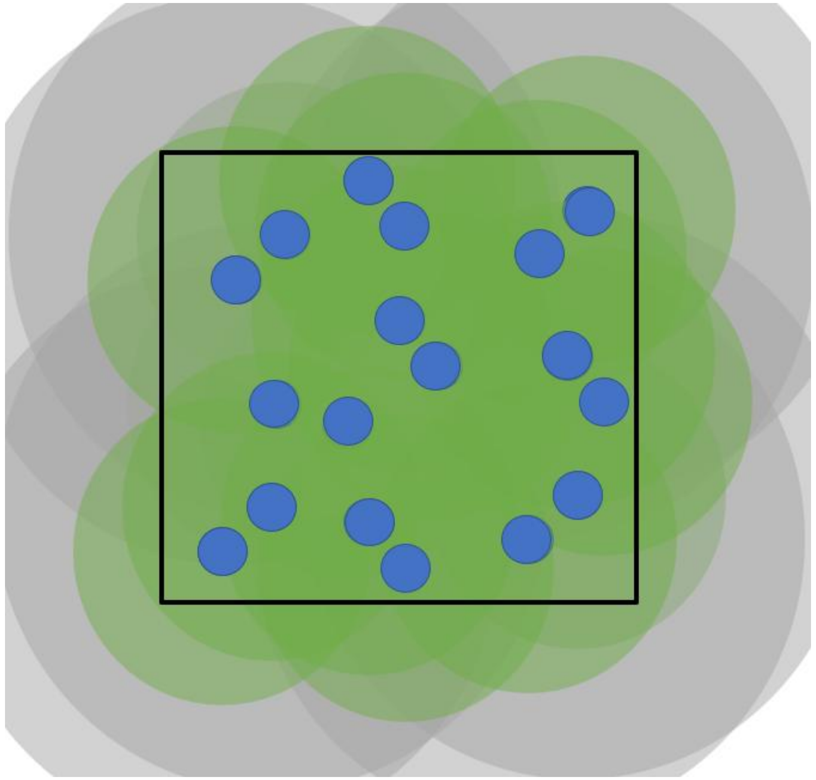
Field of Interest (FoI)

Problem of Connected *k*-coverage in Wireless Sensor Networks

k-coverage



Connected *k*-coverage



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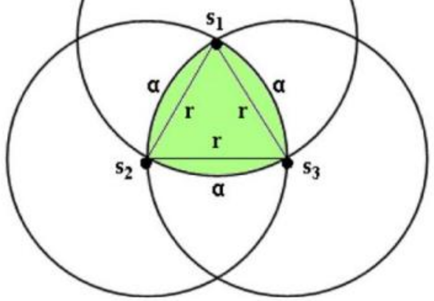
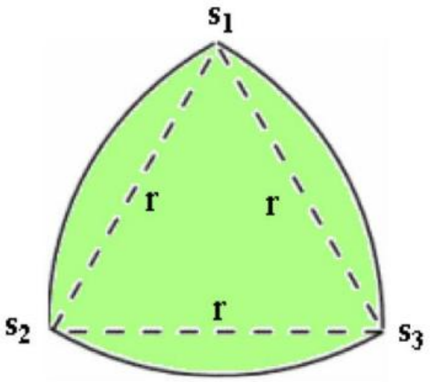
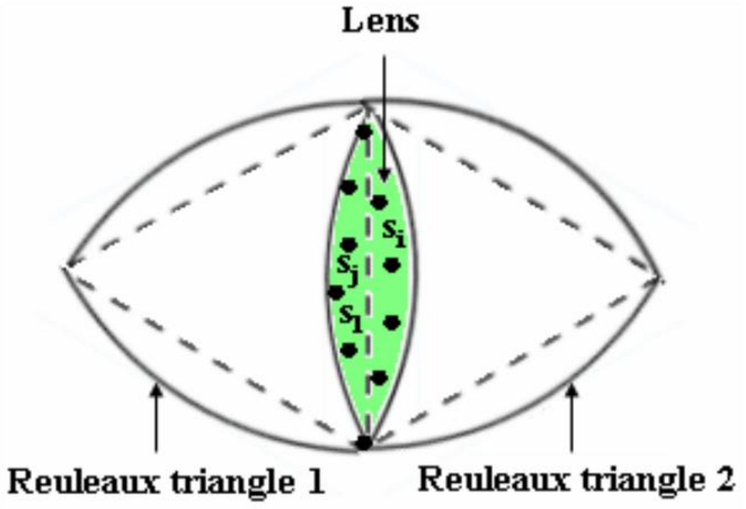
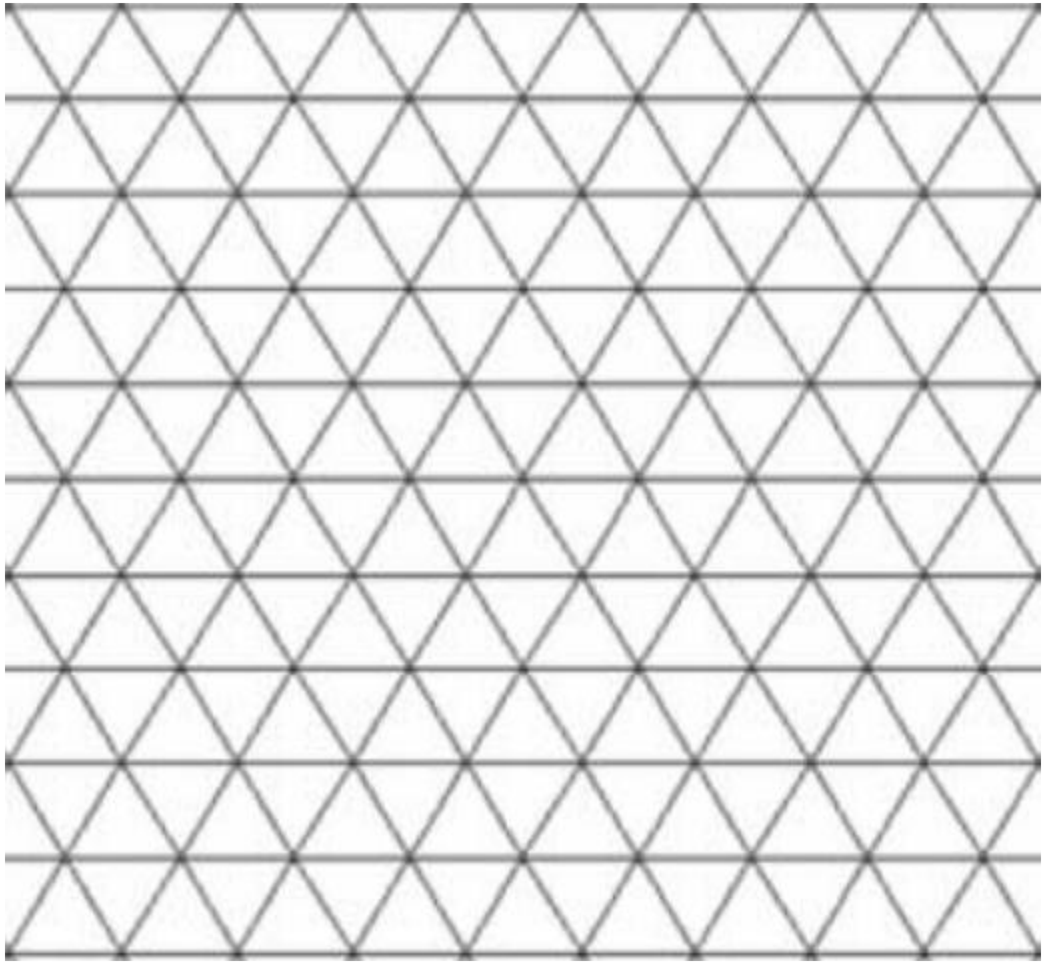
Reuleaux Triangle Tessellation

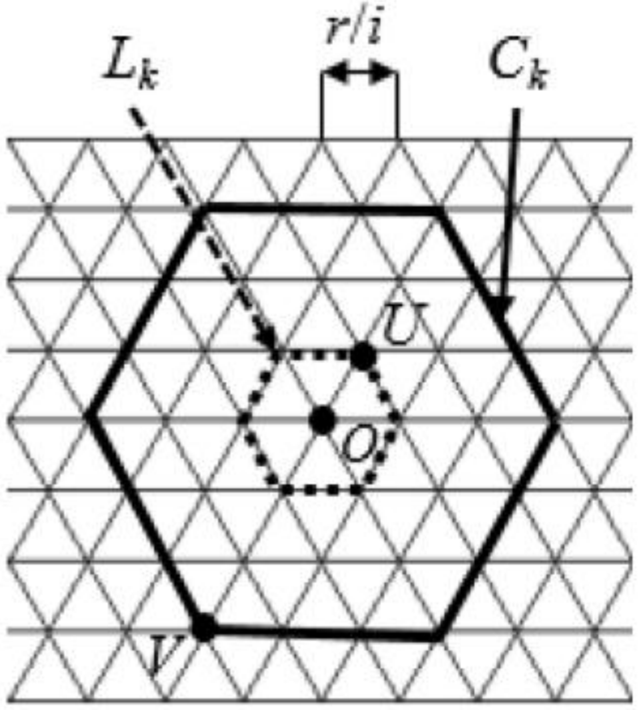


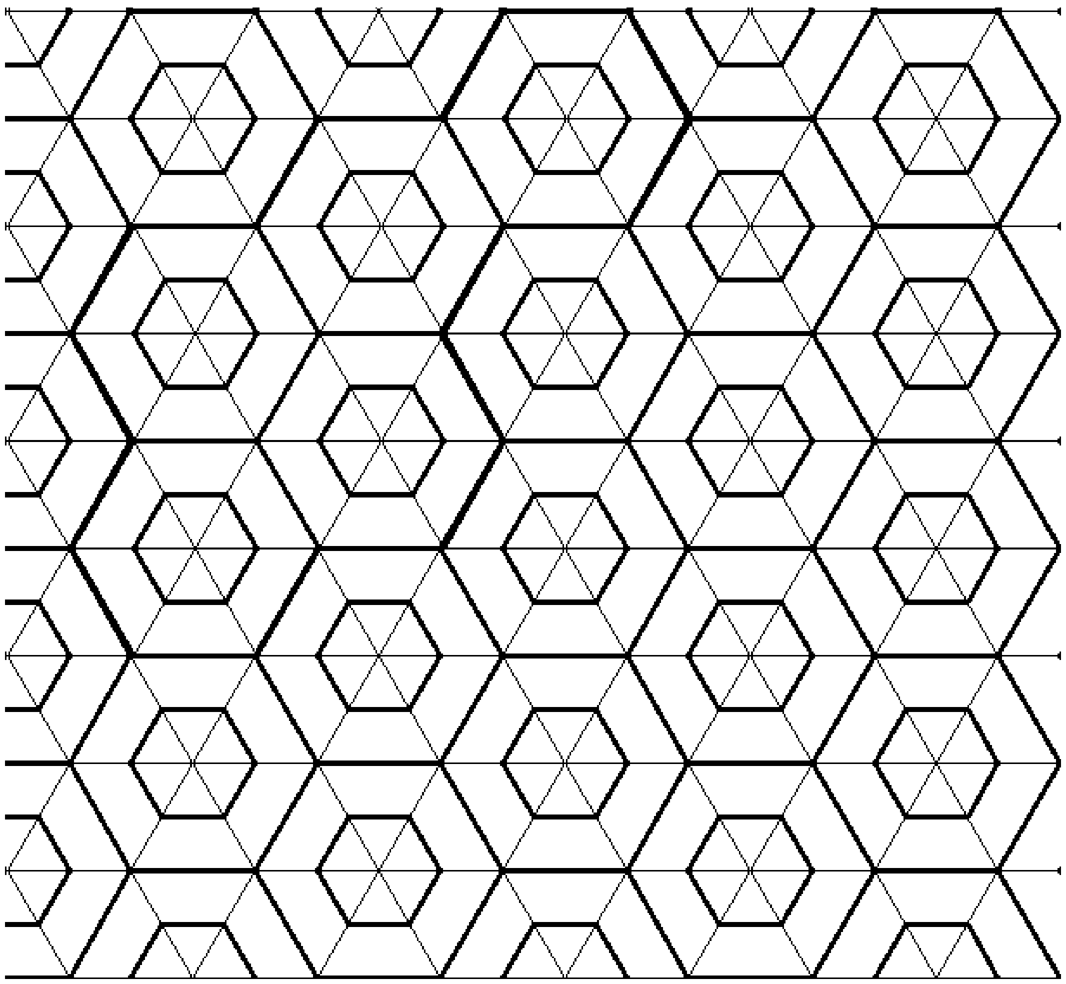




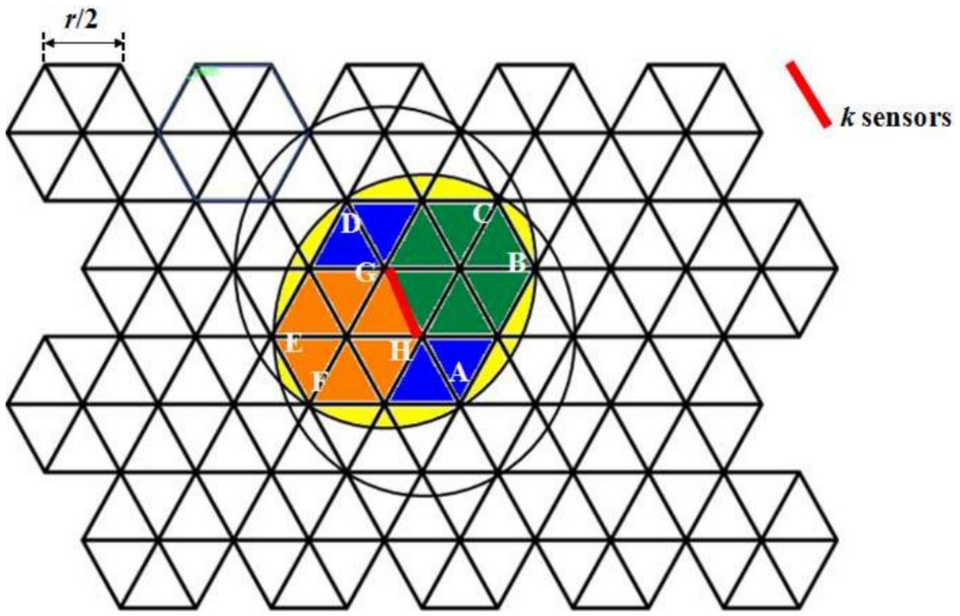


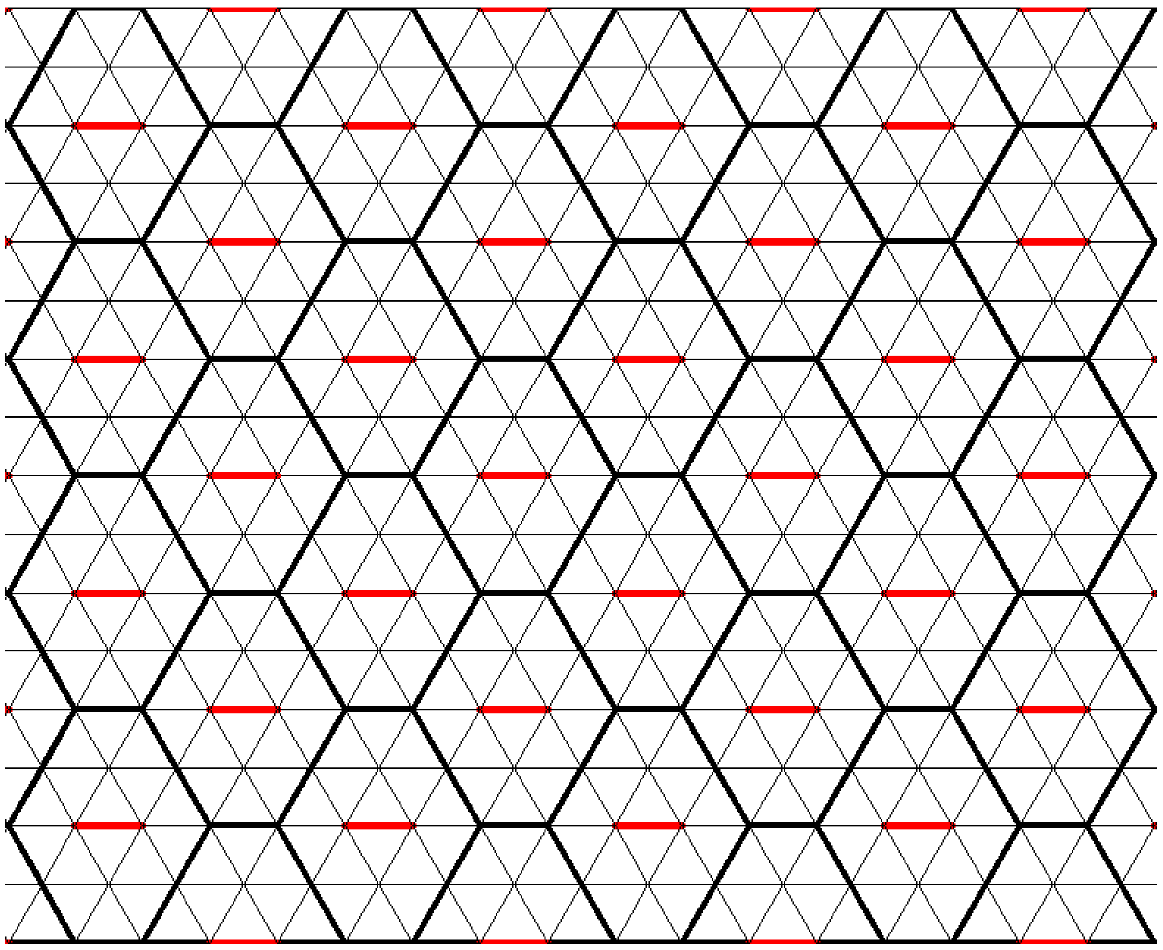
Regular Hexagonal Tessellation





Irregular Hexagonal Tessellation





How to achieve Connected *k*-coverage ?

1. Decide a ***Tile***.
2. Determine the Sensor Placement strategy for that Tile.
3. Compute the necessary relation for ensuring network connectivity in the proposed tessellation.

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Sensing Model

- Deterministic Sensing Model
- Every point *P* in the field may be sensed by a sensor *s* if and only if the Euclidean distance $\delta(P, s)$ is lower than or same as sensing range.
- The point *P* sensed by sensor *s* is denoted by *Cov(P, s)*, where,

$$\mathrm{Cov}(\mathrm{P},\mathrm{s}) = \begin{cases} 1, & if\ \ \delta(\mathrm{P},\mathrm{s}) \le r_s \\ 0, & otherwise \end{cases}$$

Network Model

- All sensors are randomly and densely dispersed in the FoI.
- All sensors are homogeneous.
- All sensors and sink are aware of their own locations.
- Both sensing and communication ranges of all sensors are modelled to be of disk-shaped.
- All sensors are mobile and can move to specified locations.
- All sensors drain their power supplies for tasks like sending and receiving data, detecting, moving about, and other activities.

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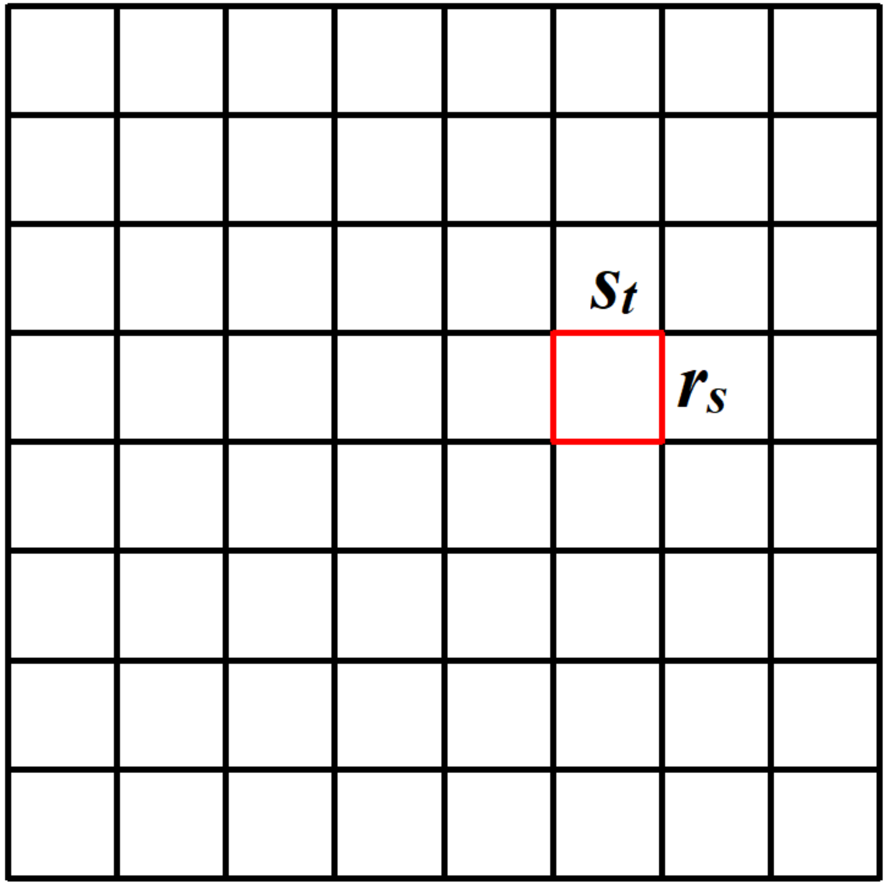
Connected *k*-coverage Theory

We solve this problem using Square tiles by following below steps,

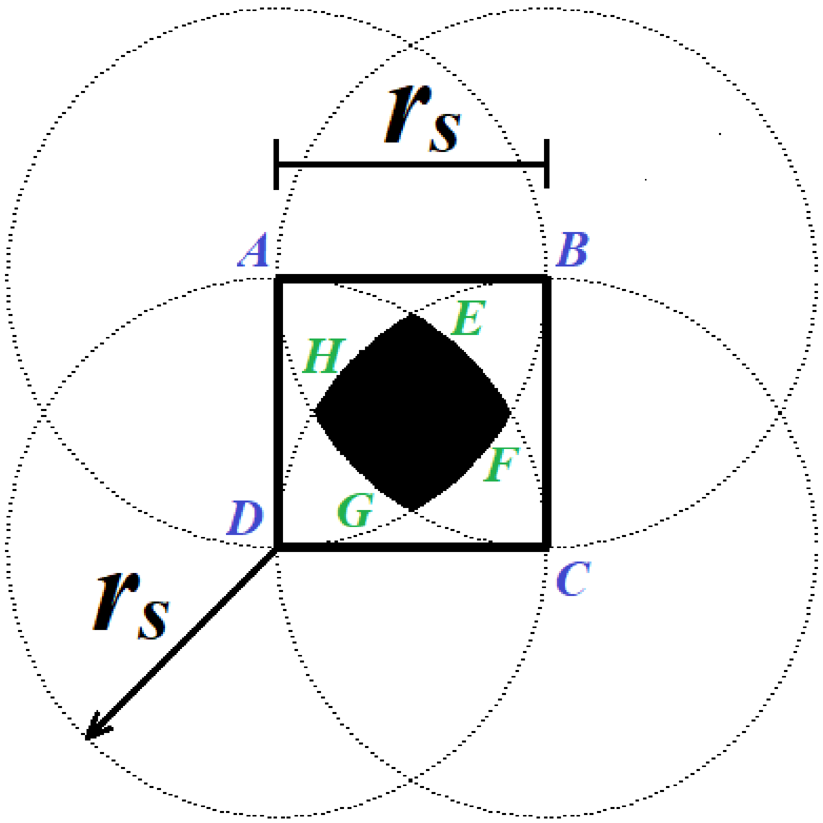
1. Generate a Square Tessellation.

2. Construct Cusp Square areas.



$s_t = r_s$

Cusp Square area of Square Tile

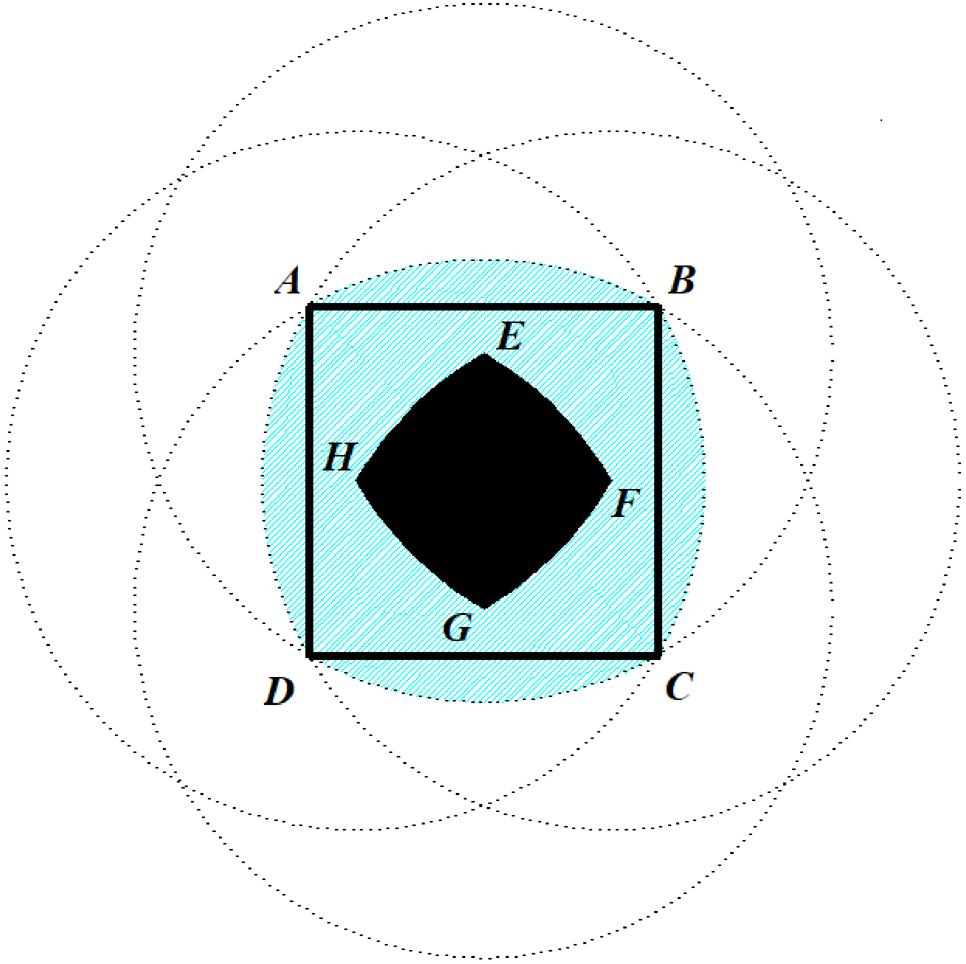


k-coverage Area of each Square Tile

k-covered area A_k :

$$A_k = \left(\frac{2\pi + 3 - 3\sqrt{3}}{3}\right) r_s^2$$

r_s: Sensing range of the sensors

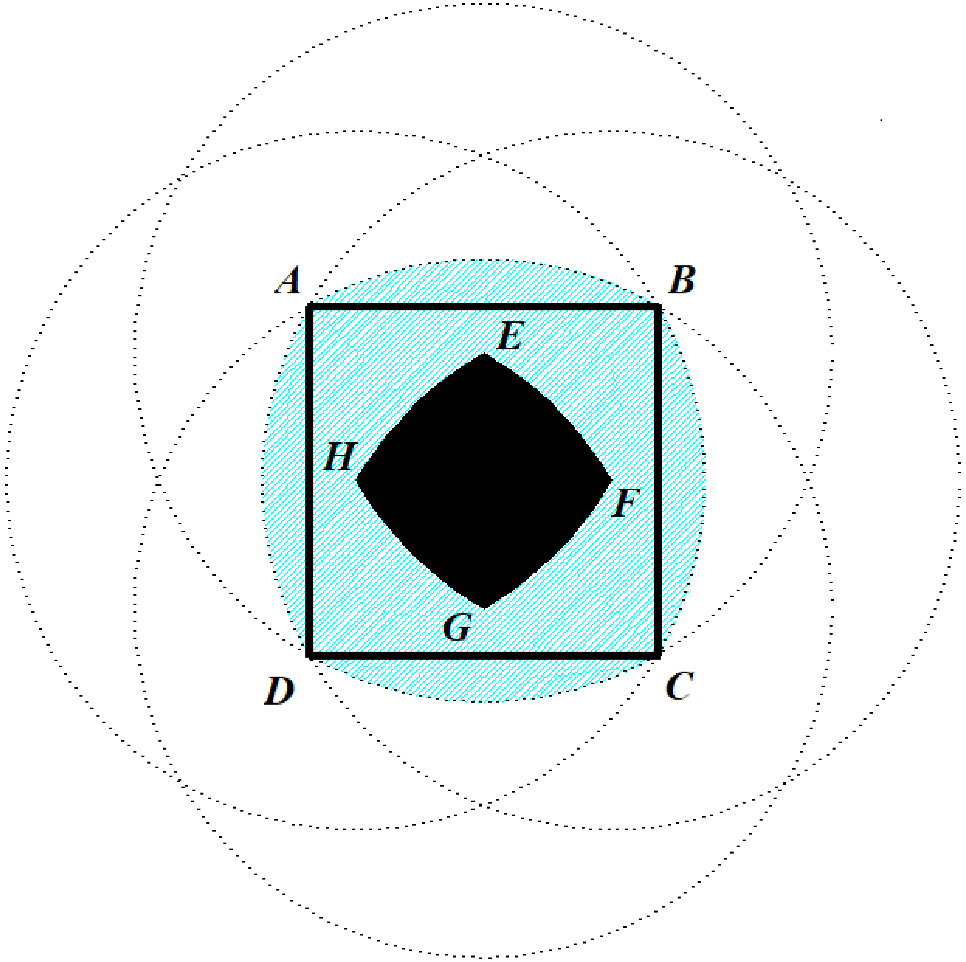


Planar Sensor Density

$$\lambda(k, r_s) = \frac{0.734k}{r_s^2}$$

r_s : Sensing range of the sensors

$k \geq 1$

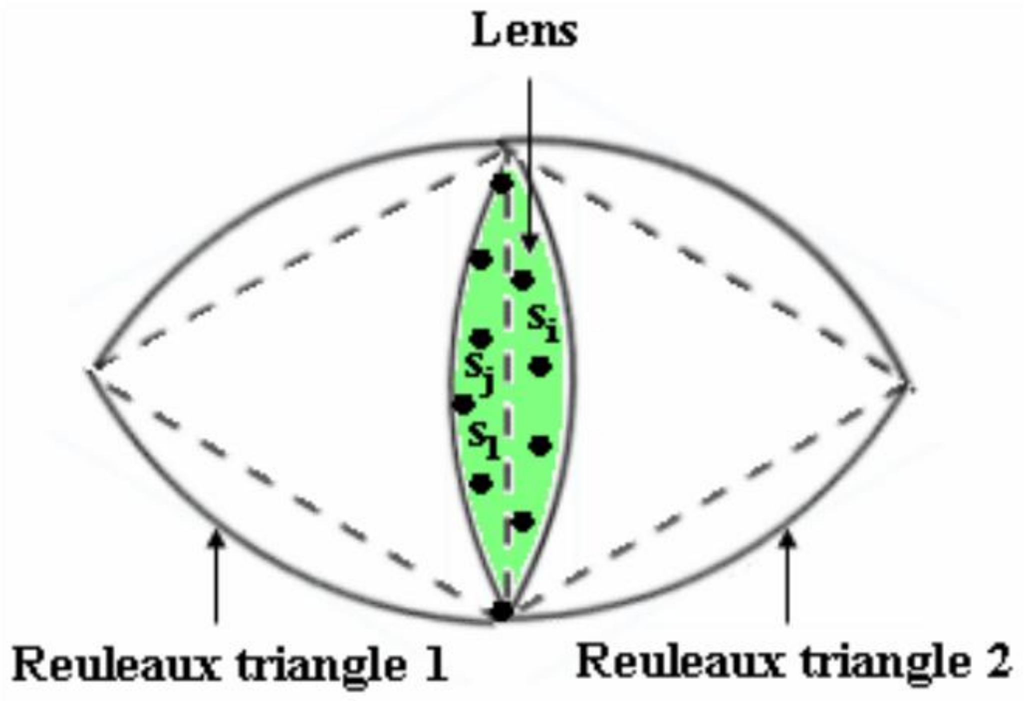


Planar Sensor Density

$$\lambda(k, r_s) = \frac{0.814k}{r_s^2}$$

r_s : Sensing range of the sensors

$k \geq 1$

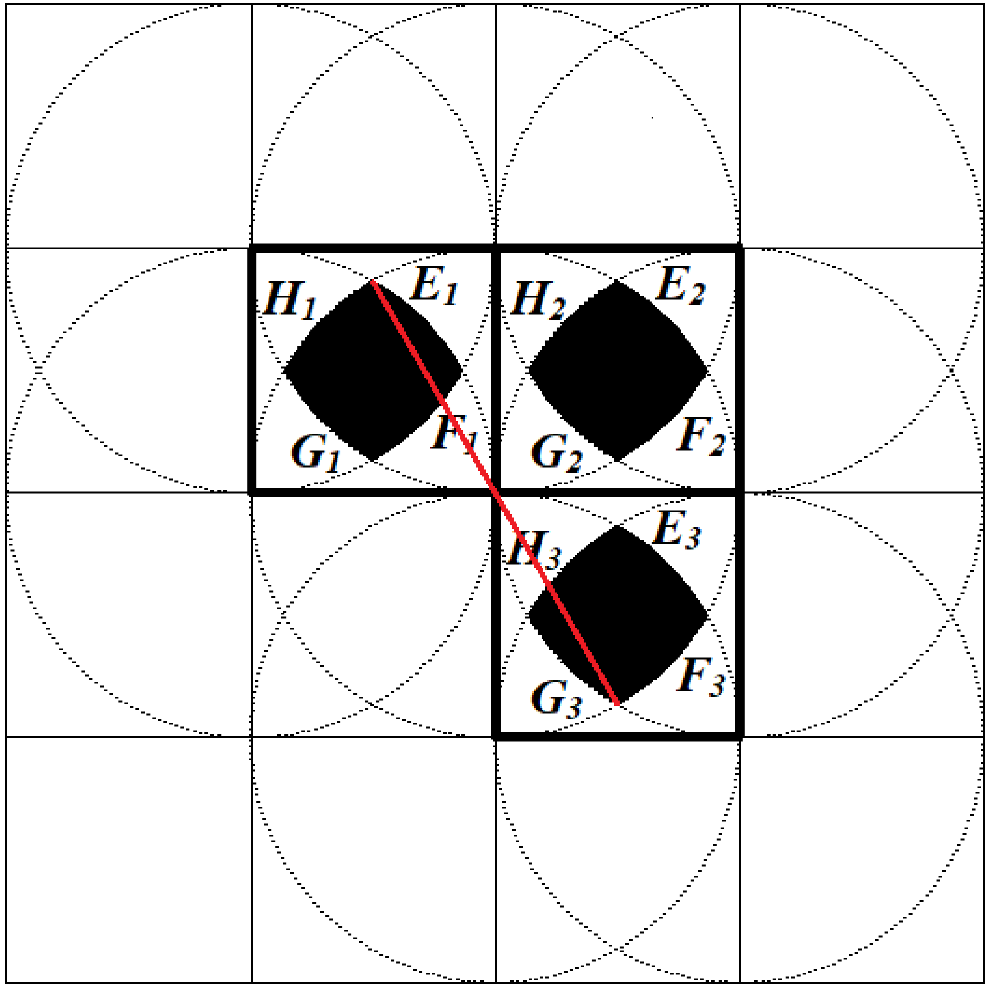


Network connectivity relationship

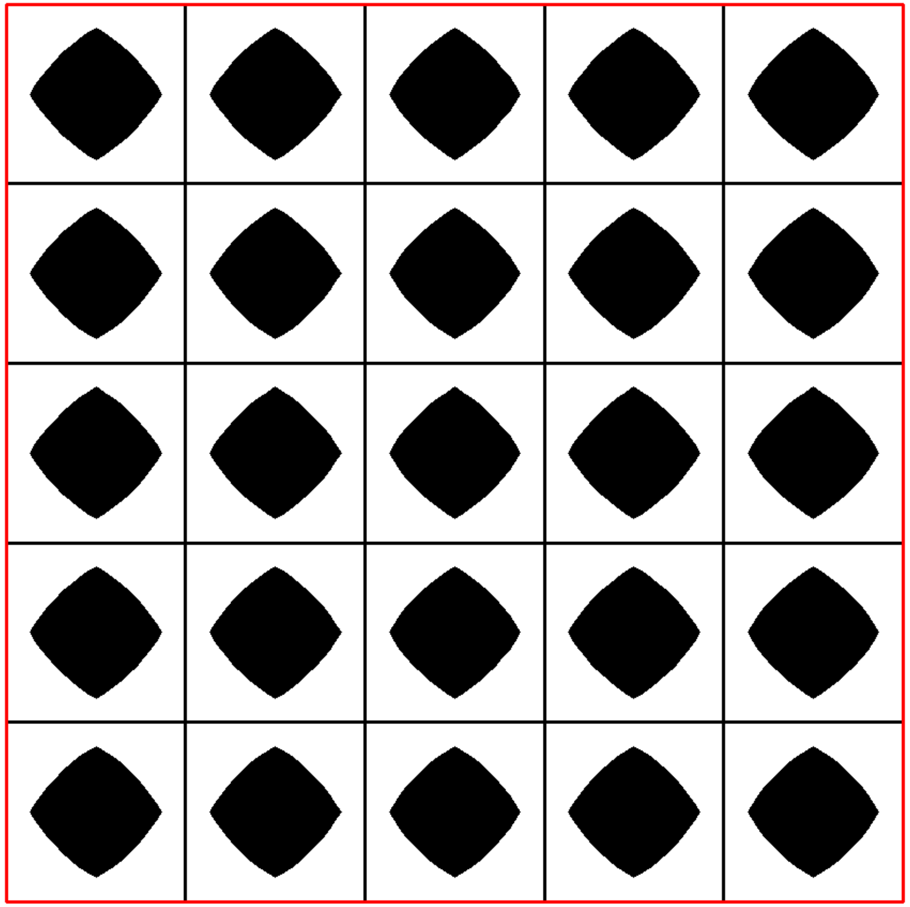
$$r_c \geq 2r_s$$

r_s : Sensing range of the sensors

r_c : Communication range of the sensors



k-coverage using Cusp Squares (*k*-CSqu) Protocol



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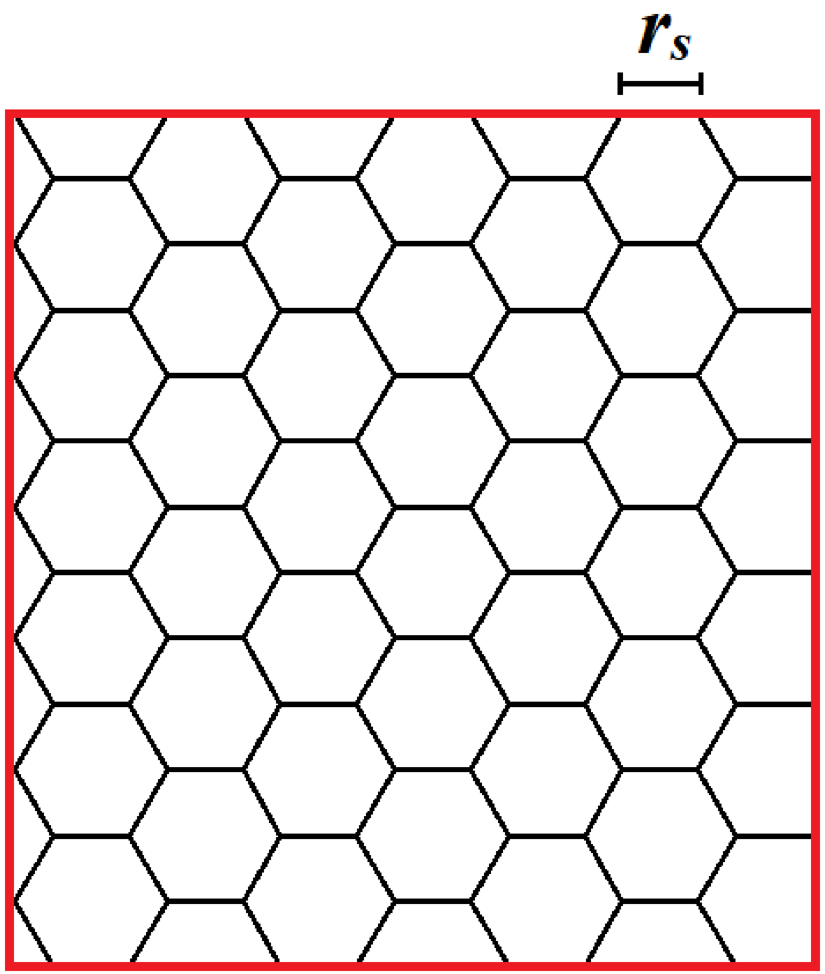
Connected *k*-coverage Theory

Achieve 1-coverage of PWSN

- Place sensors at centers of regular hexagonal tiles.

Planar sensor density for 1-coverage:

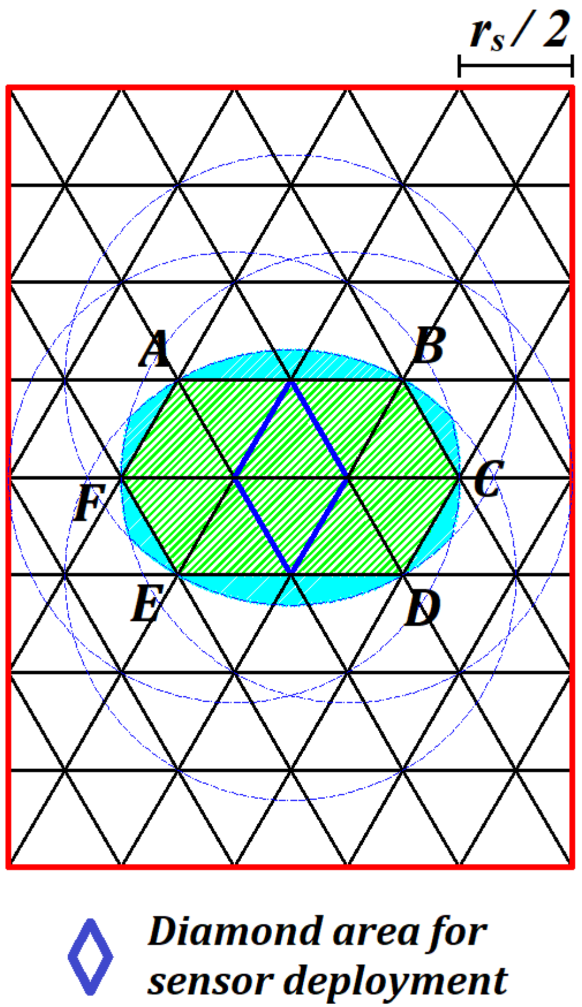
$$\lambda(r_s) = \frac{0.38}{{r_s}^2}$$



Construction of Irregular Hexagonal Tile

Modify regular hexagon tessellation side length to $r_s / 2$.

Consider diamond area formed by two equilateral triangles of same base in the tessellation.



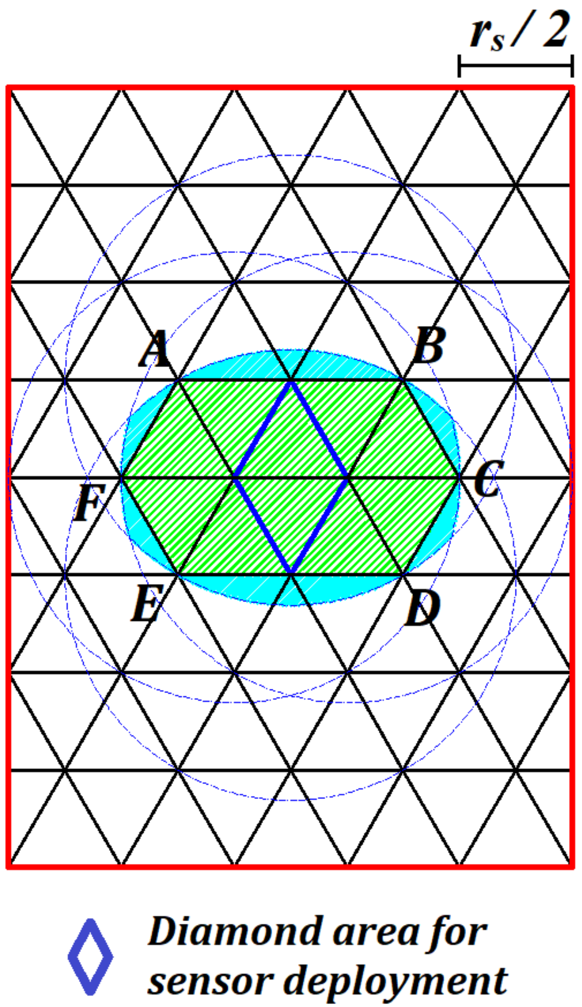
k-coverage area and Planar Sensor Density

k-coverage area for the configuration is:

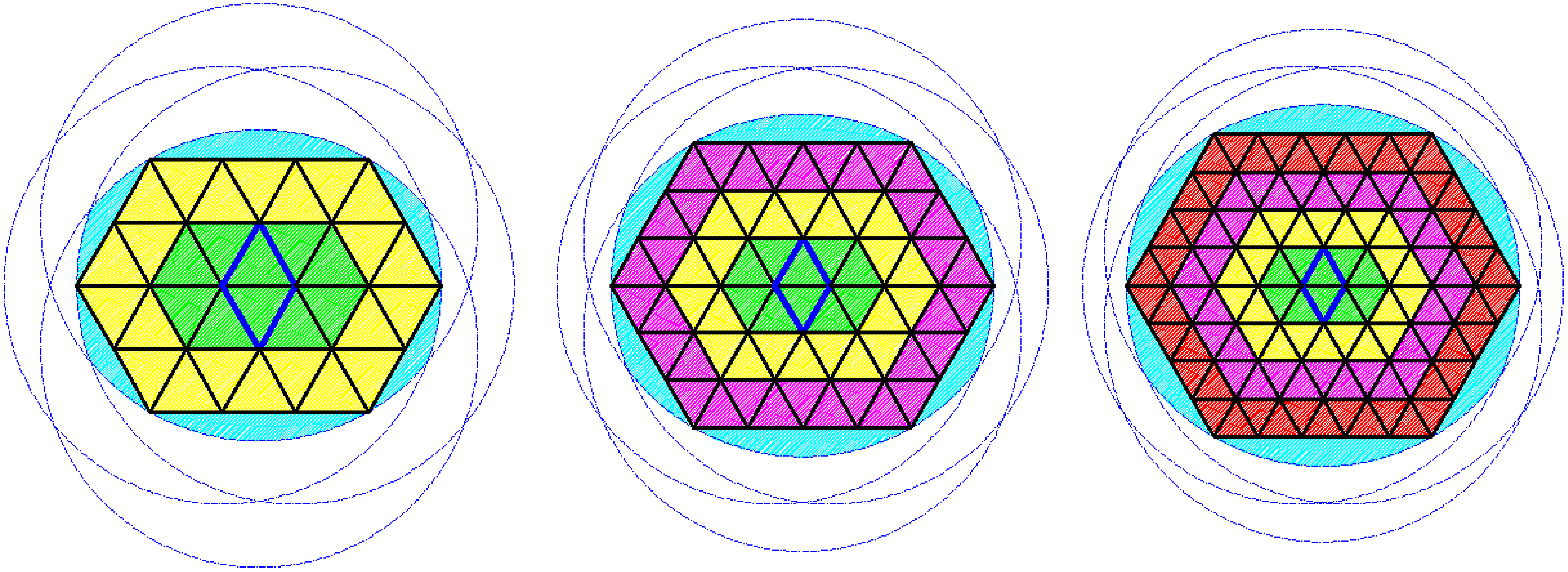
$$A_k = \left[\pi + \frac{\sqrt{3}}{8} - \frac{\sqrt{15}}{4} - 4\sin^{-1}\left(\frac{1}{4}\right)\right] {r_s}^2$$

Planar Sensor Density:

$$\lambda(k, r_s) = \frac{0.7251\, k}{{r_s}^2}$$



Irregular Hexagonal Tiles for different values of *n*



(a) $IrHx(r_s / 3)$ (b) $IrHx(r_s / 4)$ (c) $IrHx(r_s / 5)$

Generalized Irregular Hexagonal Tile

$IrHx(r_s/n)$

$\overline{AB}$	$\overline{BC}$	$\overline{CD}$	$\overline{DE}$	$\overline{EF}$	$\overline{FA}$	# Rings
r_s	$\frac{(n-1)r_s}{n}$	$\frac{(n-1)r_s}{n}$	r_s	$\frac{(n-1)r_s}{n}$	$\frac{(n-1)r_s}{n}$	$n-1$

Triangles in $IrHx(r_s/n)$

n	$\overline{AB}$	$\overline{BC}$	$\overline{CD}$	$\overline{DE}$	$\overline{EF}$	$\overline{FA}$	# Rings
2	r_s	$r_s/2$	$r_s/2$	r_s	$r_s/2$	$r_s/2$	1
3	r_s	$2r_s/3$	$2r_s/3$	r_s	$2r_s/3$	$2r_s/3$	2
4	r_s	$3r_s/4$	$3r_s/4$	r_s	$3r_s/4$	$3r_s/4$	3
5	r_s	$4r_s/5$	$4r_s/5$	r_s	$4r_s/5$	$4r_s/5$	4

n	Ring #1	Ring #2	Ring #3	Ring #4
2	10			
3	10	22		
4	10	22	34	
5	10	22	34	46

Total number of equilateral triangles N, $IrHx(r_s/n)$ is given by:

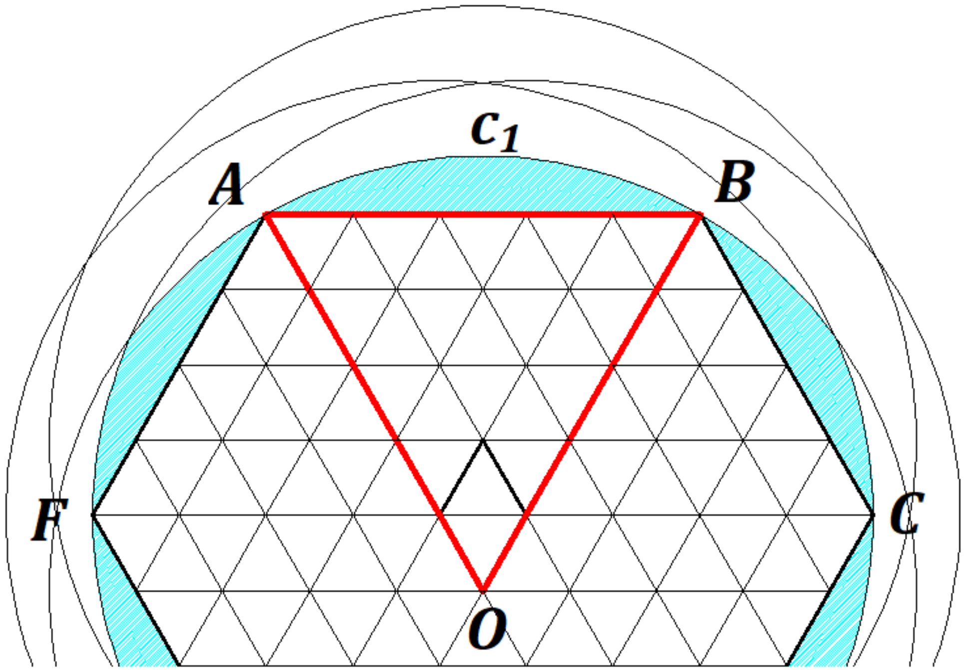
$$N = 2(n-1)(3n-1)$$

$n \geq 1$

k-coverage Area over the Longer side of $IrHx(r_s/n)$

$$A_{LS} = \left(\frac{\pi}{6} - \frac{\sqrt{3}}{4}\right) r_s{}^2$$

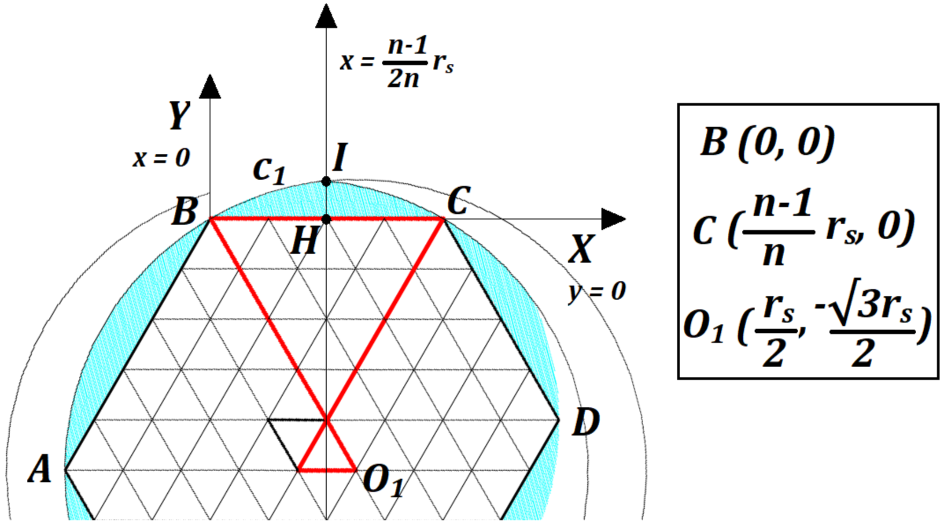
r_s: Sensing range of sensor



k-coverage Area over the Shorter side of *IrHx*(r_s/n)

$$A_{SS} = \left[\frac{\pi}{6} + \sin^{-1}\left(\frac{-1}{2n}\right) - \frac{\sqrt{4n^2-1}}{4n^2} - \frac{\sqrt{3}(n-2)}{4n}\right] r_s$$

r_s : Sensing range of sensor



k-coverage area of $IrHx(r_s/n)$ Tile

The k-covered area A_k:

$$A_k = \left[\pi + \frac{(3n^2 - 6n + 2)\sqrt{3}}{4n^2} - \frac{\sqrt{4n^2 - 1}}{n^2} - 4\sin^{-1}\left(\frac{1}{2n}\right)\right] {r_s}^2$$

r_s: Sensing range of sensor

$n \geq 1$

Planar Sensor Density of *IrHx(r_s/n)* Tile

The planar sensor density $\lambda(k, r_s, n)$:

$$\lambda(k, r_s, n) = \frac{k}{\left[\pi + \frac{(3n^2 - 6n + 2)\sqrt{3}}{4n^2} - \frac{\sqrt{4n^2 - 1}}{n^2} - 4\sin^{-1}\left(\frac{1}{2n}\right)\right] {r_s}^2}$$

r_s: Sensing range of sensor

$k \geq 1$ and $n \geq 1$

Planar Sensor Density of *IrHx*(r_s/n) for different values of *n*

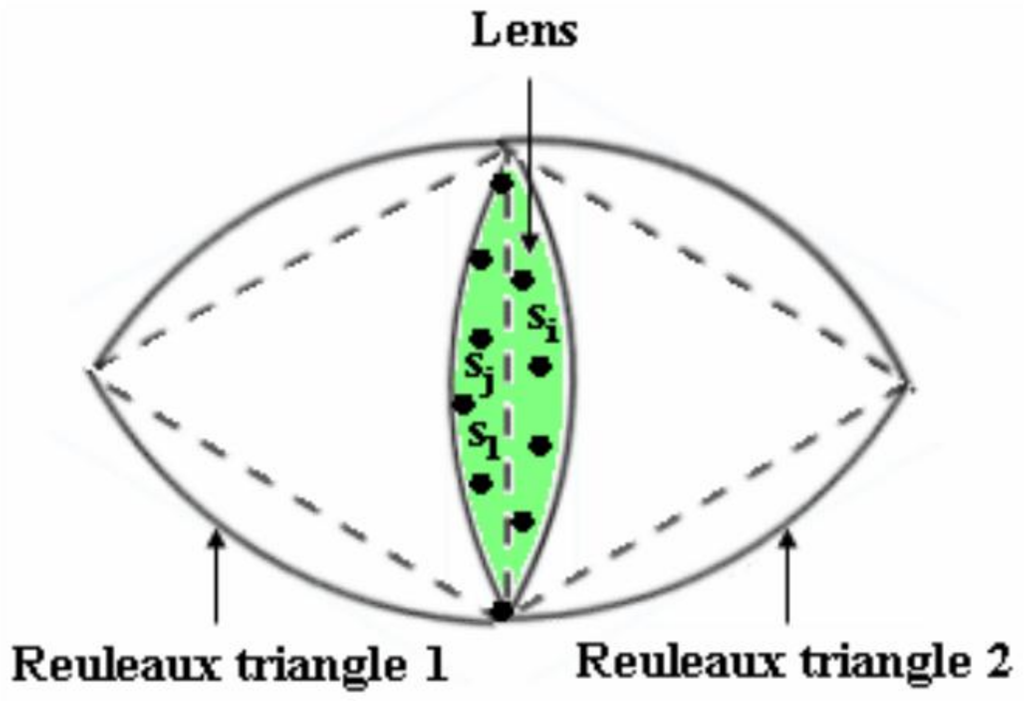
n	2	3	4	5	10	20	100	∞
$\lambda(k, r_s, n)$	$\frac{0.7251\,k}{{r_s}^2}$	$\frac{0.4267\,k}{{r_s}^2}$	$\frac{0.3511\,k}{{r_s}^2}$	$\frac{0.3168\,k}{{r_s}^2}$	$\frac{0.2639\,k}{{r_s}^2}$	$\frac{0.2431\,k}{{r_s}^2}$	$\frac{0.2252\,k}{{r_s}^2}$	$\frac{0.2252\,k}{{r_s}^2}$

Planar Sensor Density

$$\lambda(k, r_s) = \frac{0.814k}{r_s^2}$$

r_s : Sensing range of the sensors

$k \geq 1$

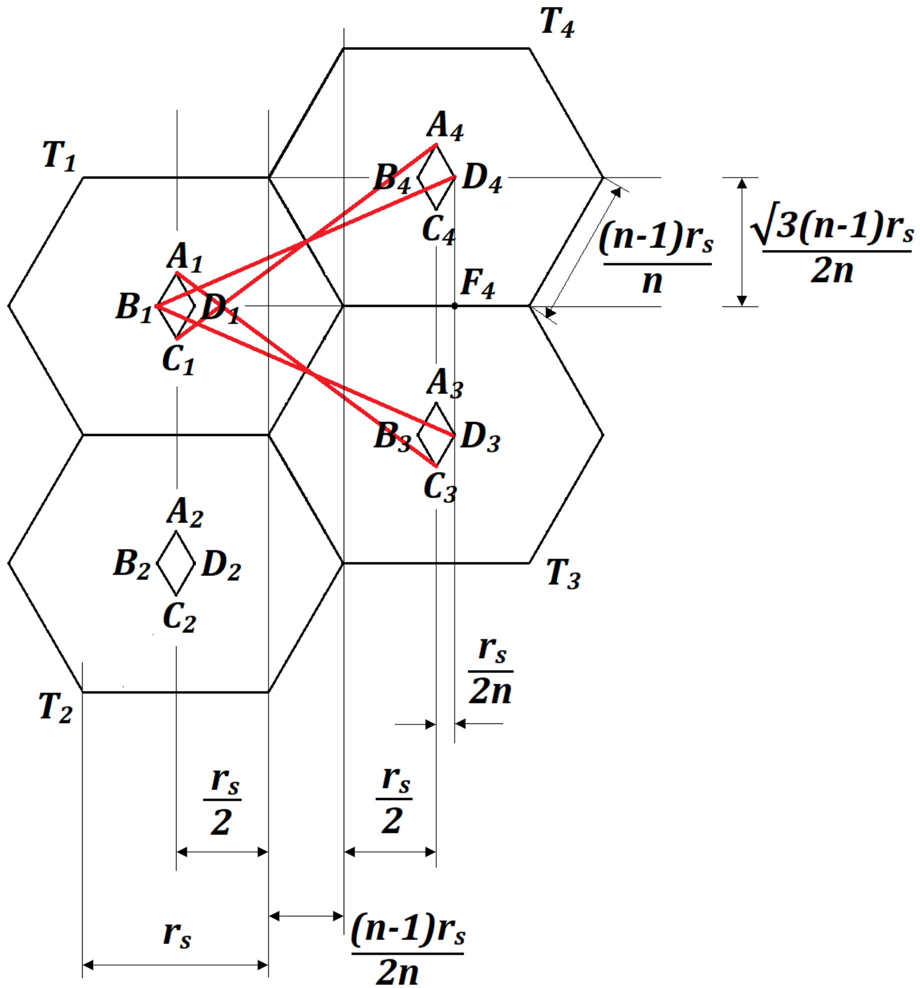


Network connectivity relation

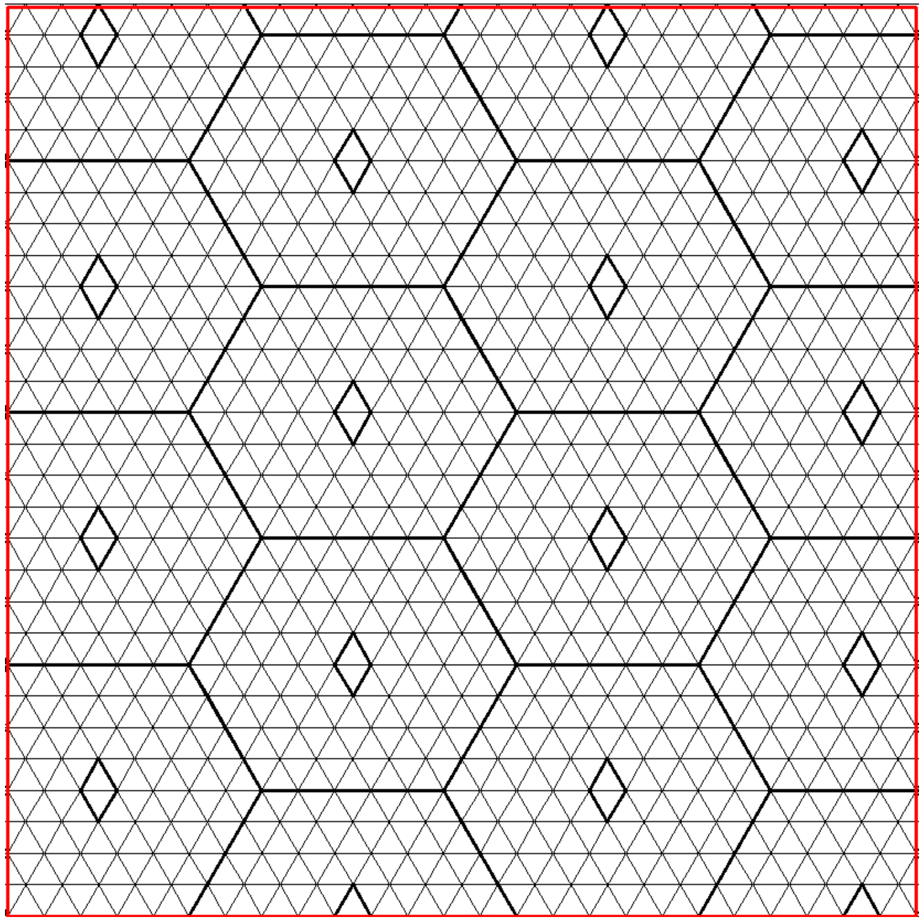
$$r_c \geq \frac{\sqrt{3n^2+1}}{n} r_s$$

r_s: Sensing range of the sensors

r_c: Communication range of the sensors



k-coverage using Inner Diamonds (*k*-InDi) Protocol



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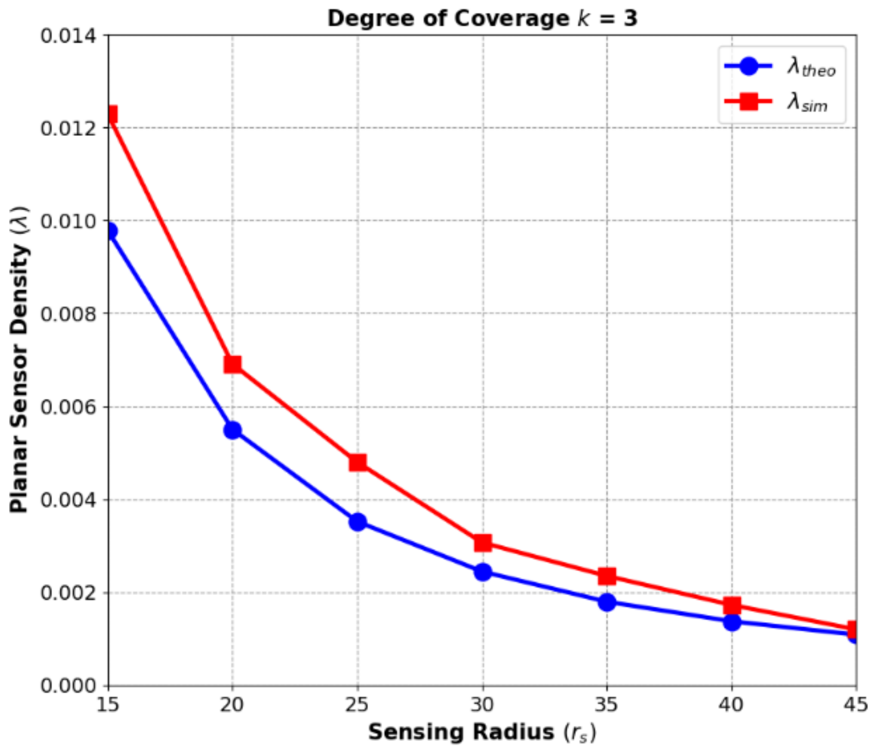
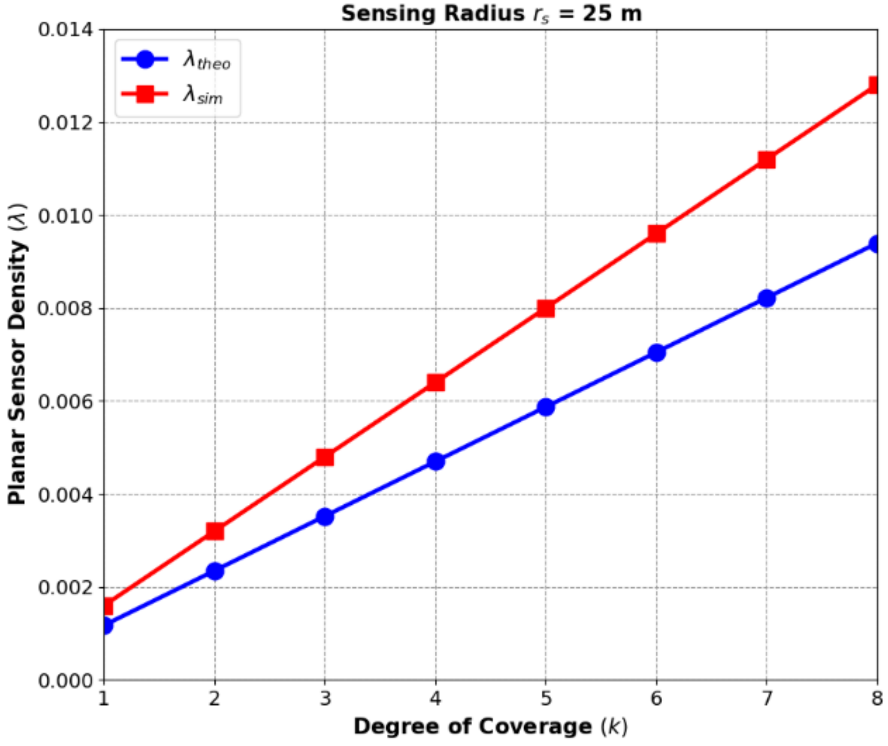
k-CSqu Results

Planar sensor density λ vs. Sensing radius r_s

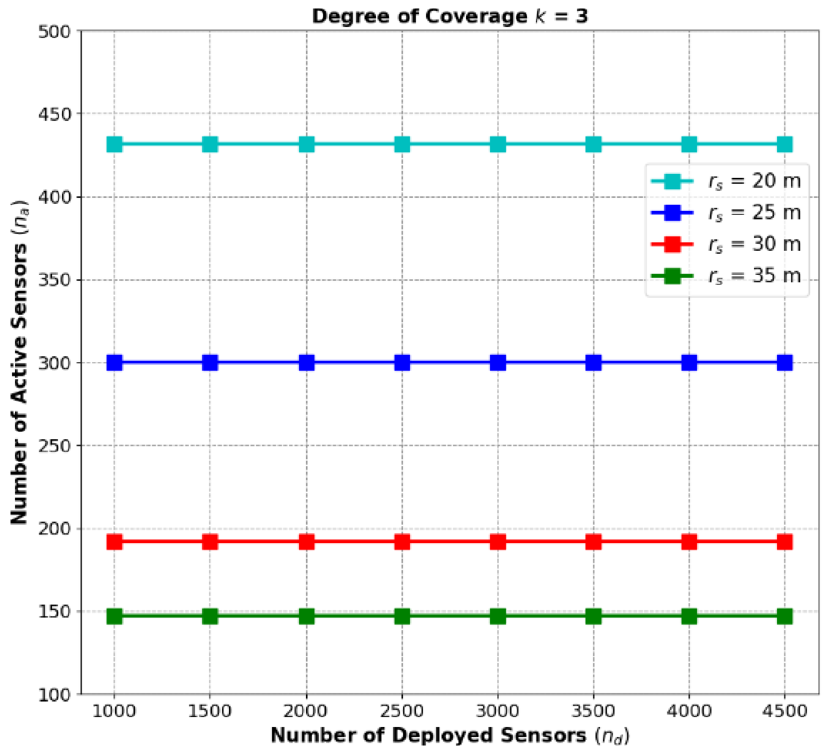


Planar sensor density λ vs. Degree of coverage k



k-CSqu Results

Number of active sensors n_a vs. Number of deployed sensors n_d for different Sensing radius r_s



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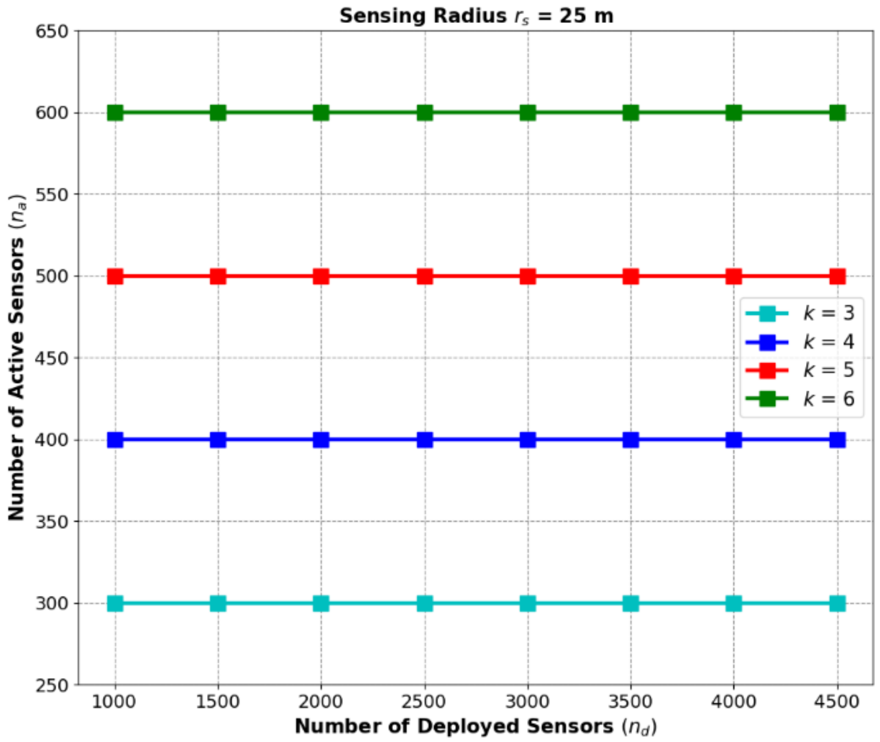
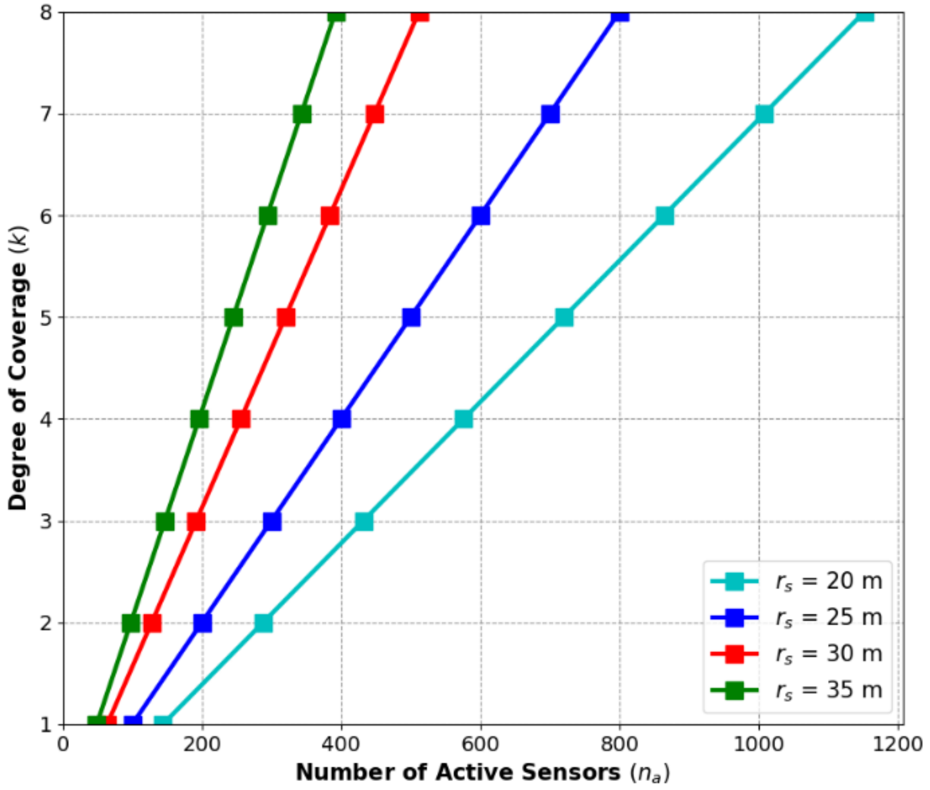


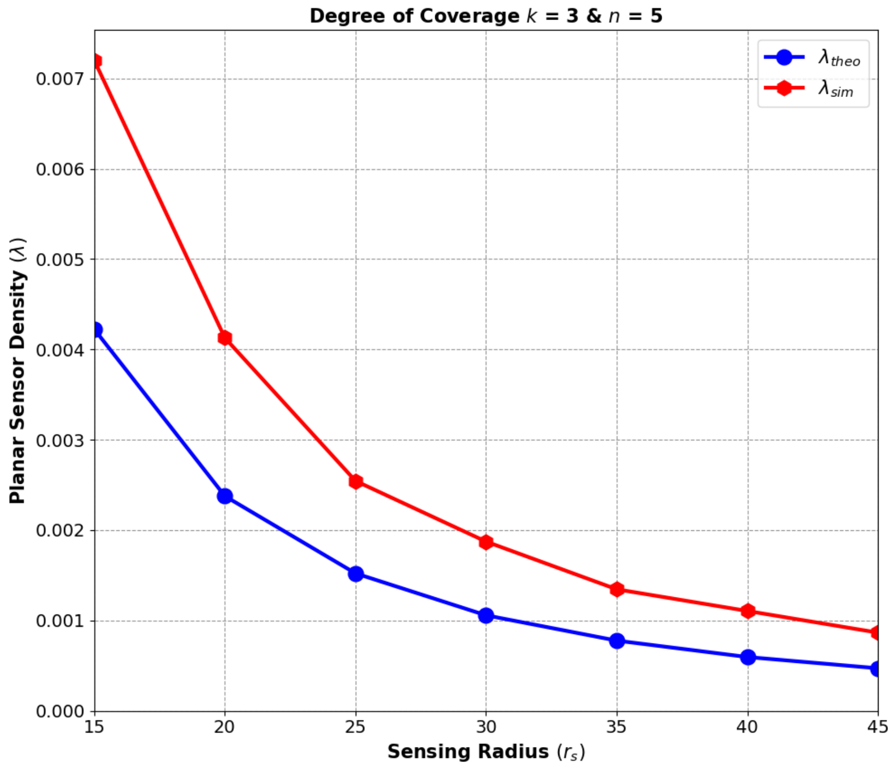
k-CSqu Results

Degree of coverage *k* versus Number of active sensor n_a

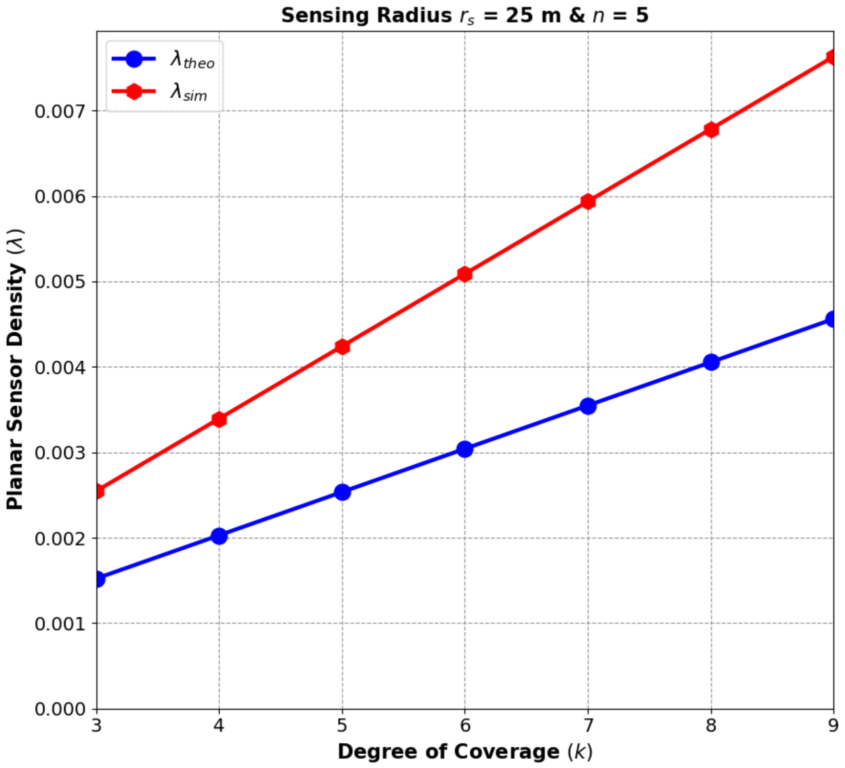


k-InDi Results

Planar sensor density λ vs. Sensing radius r_s

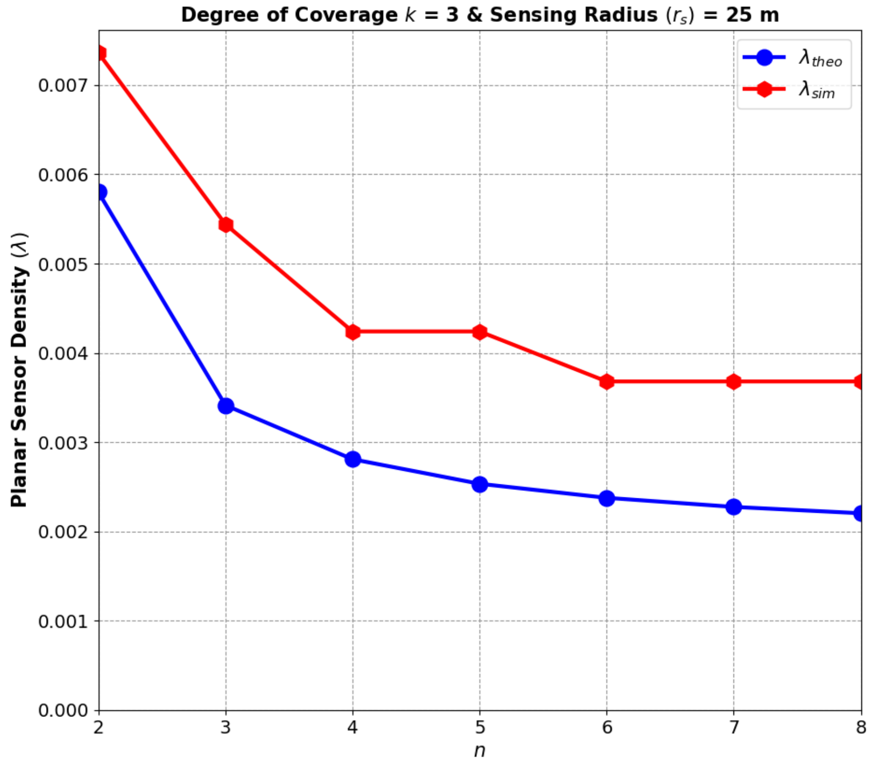


Planar sensor density λ vs. Degree of coverage k

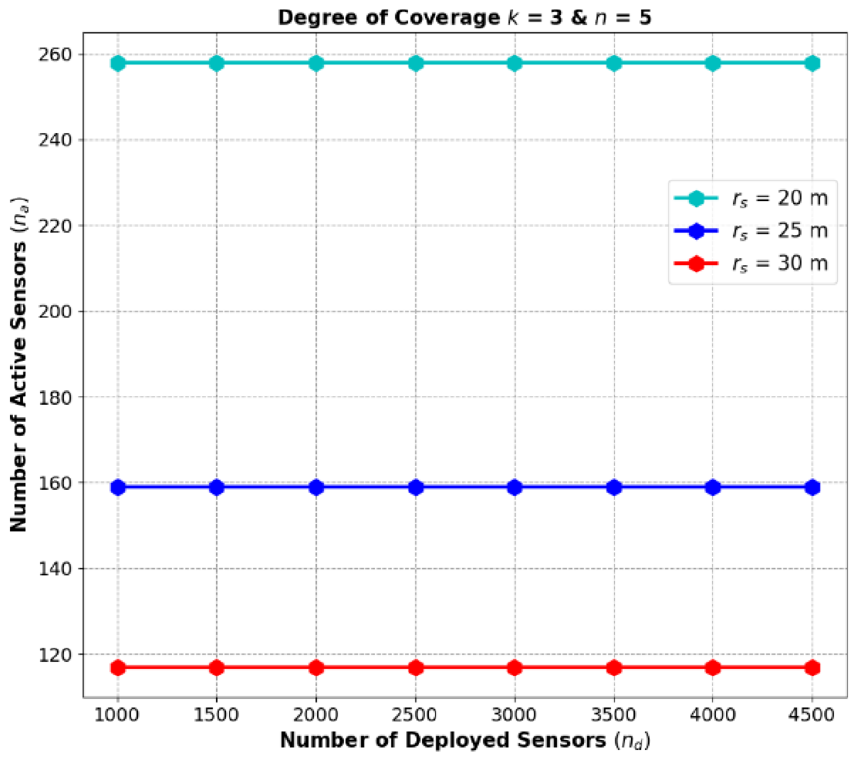


k-InDi Results

Planar sensor density λ vs. factor n

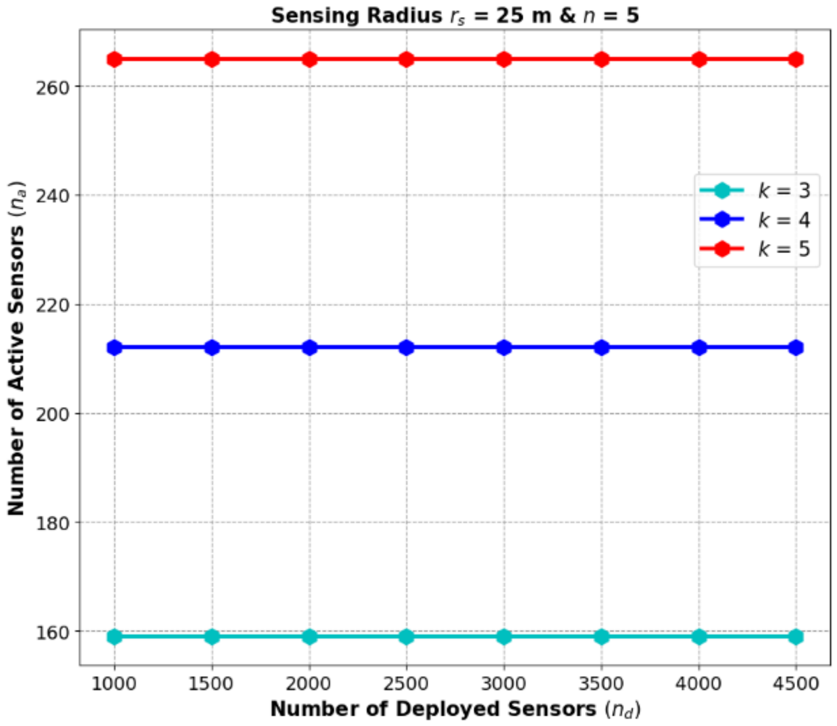


Number of active sensors n_a vs. Number of deployed sensors n_d for different Sensing radius r_s

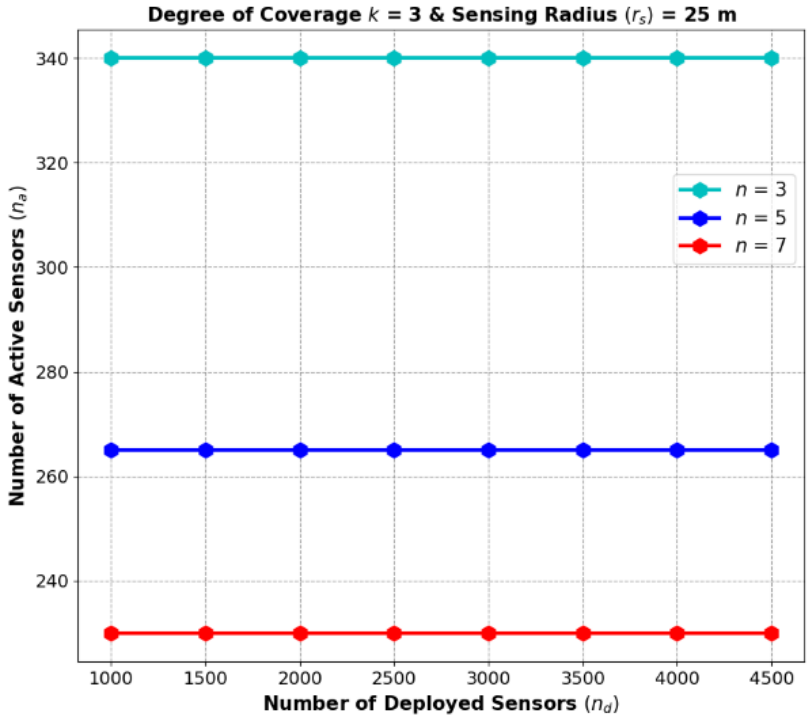


k-InDi Results

Number of active sensors n_a vs. Number of deployed sensors n_d for different Degree of coverage k

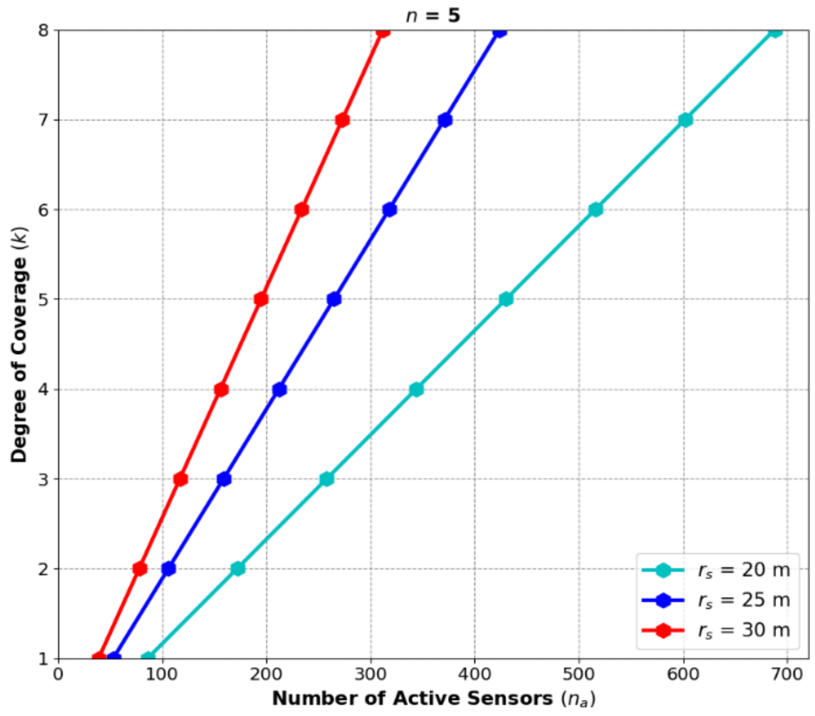


Number of active sensors n_a vs. Number of deployed sensors n_d for different factor n

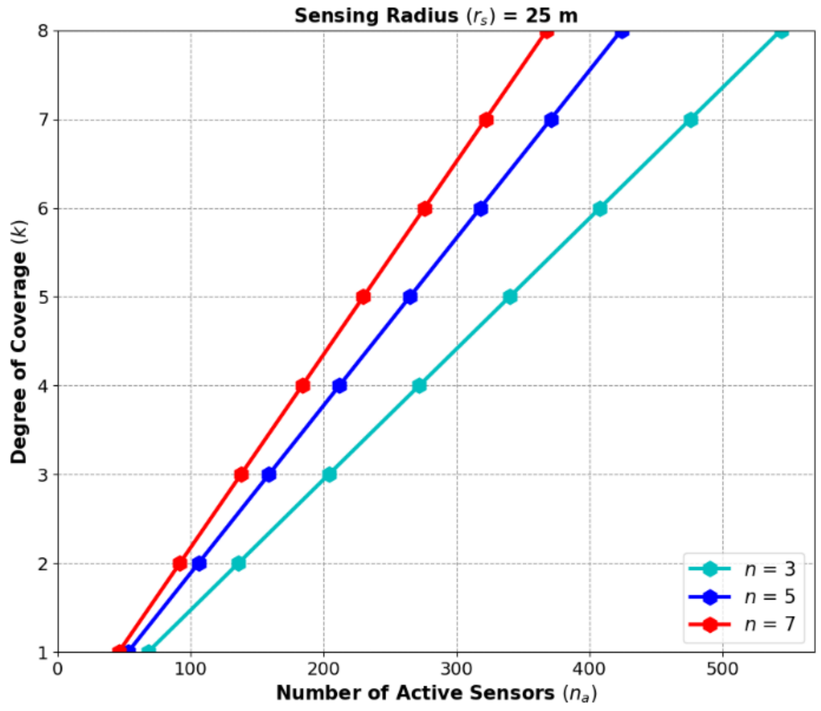


k-InDi Results

Degree of coverage k versus Number of active sensor n_a for different Sensing radius r_s

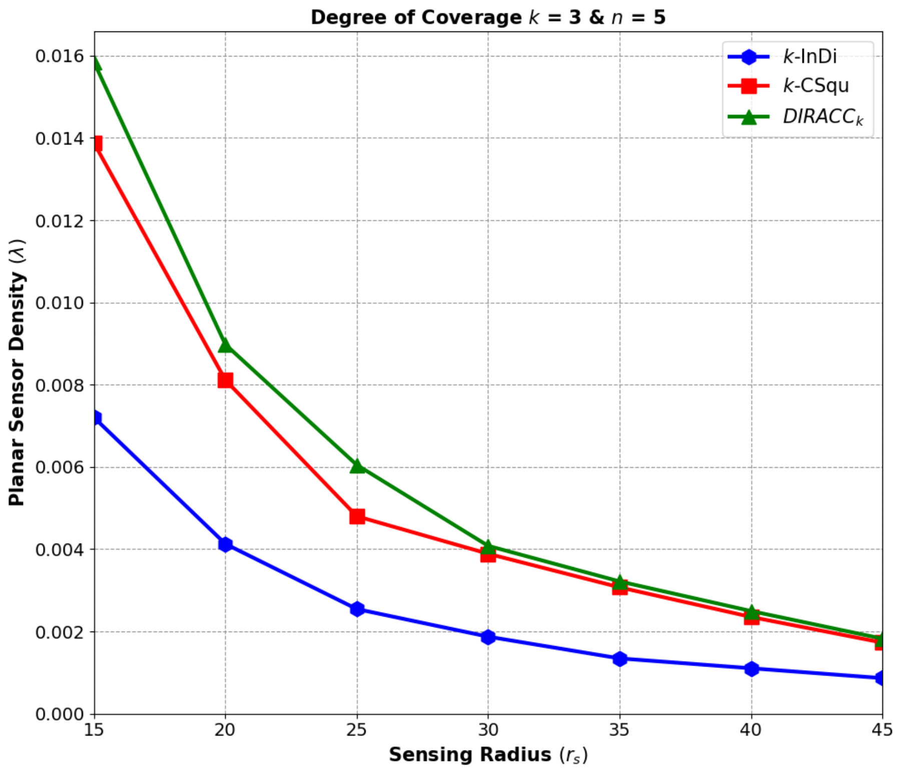


Degree of coverage k versus Number of active sensor n_a for different factor n

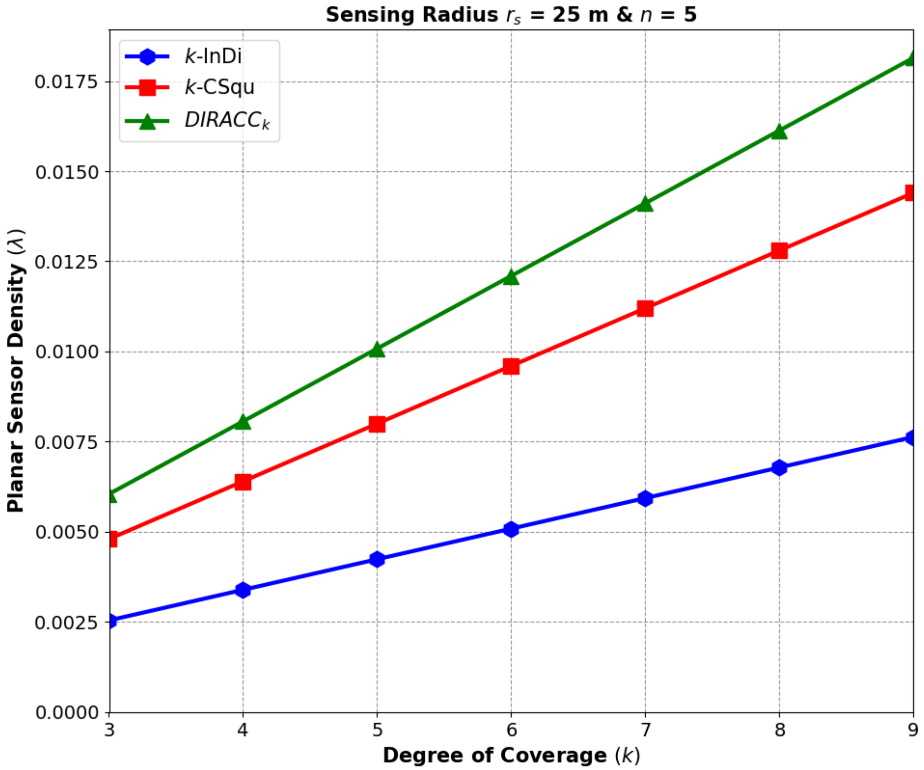


Comparison of *k*-CSqu and *k*-InDi with $DIRACC_k$

Planar sensor density λ vs. Sensing radius r_s

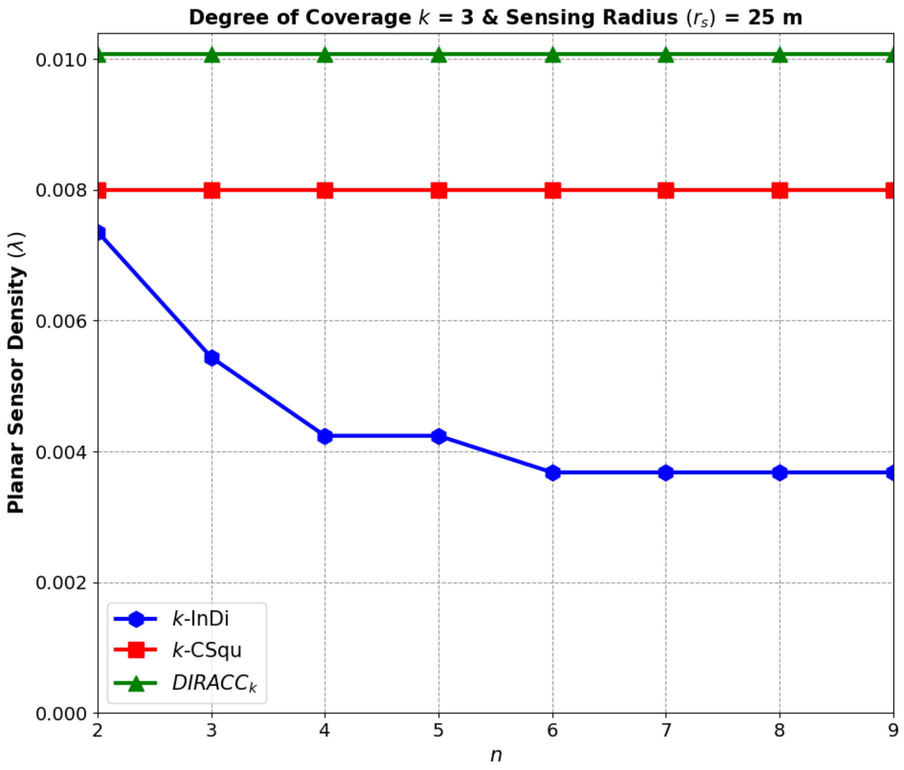


Planar sensor density λ vs. Degree of coverage k

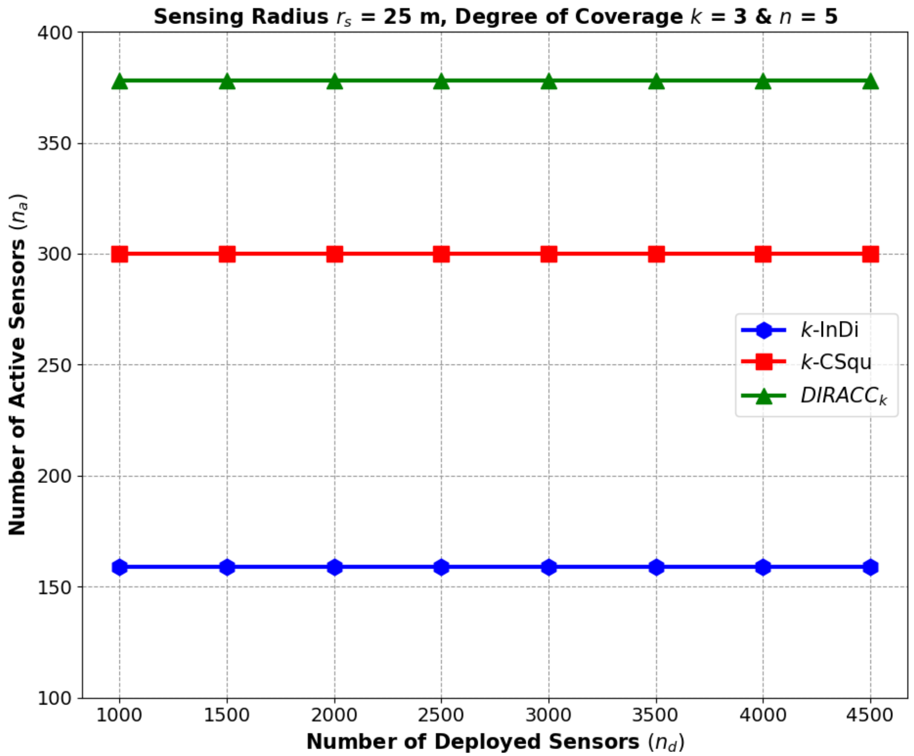


Comparison of *k*-CSqu and *k*-InDi with DIRACC_k

Planar sensor density λ vs. factor n

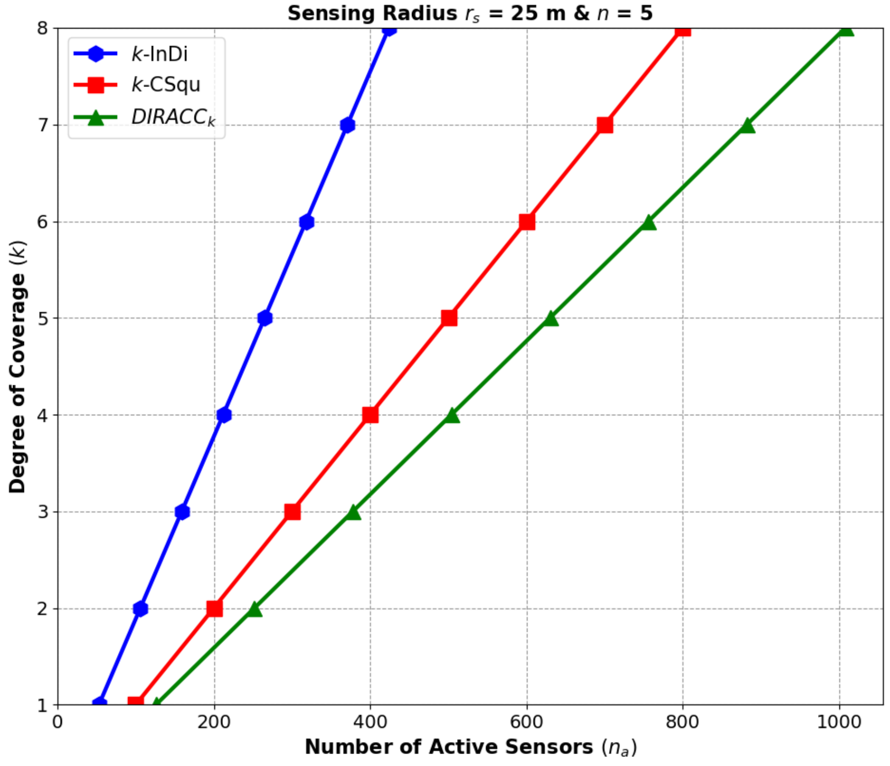


Number of active sensors n_a versus Number of deployed sensors n_d

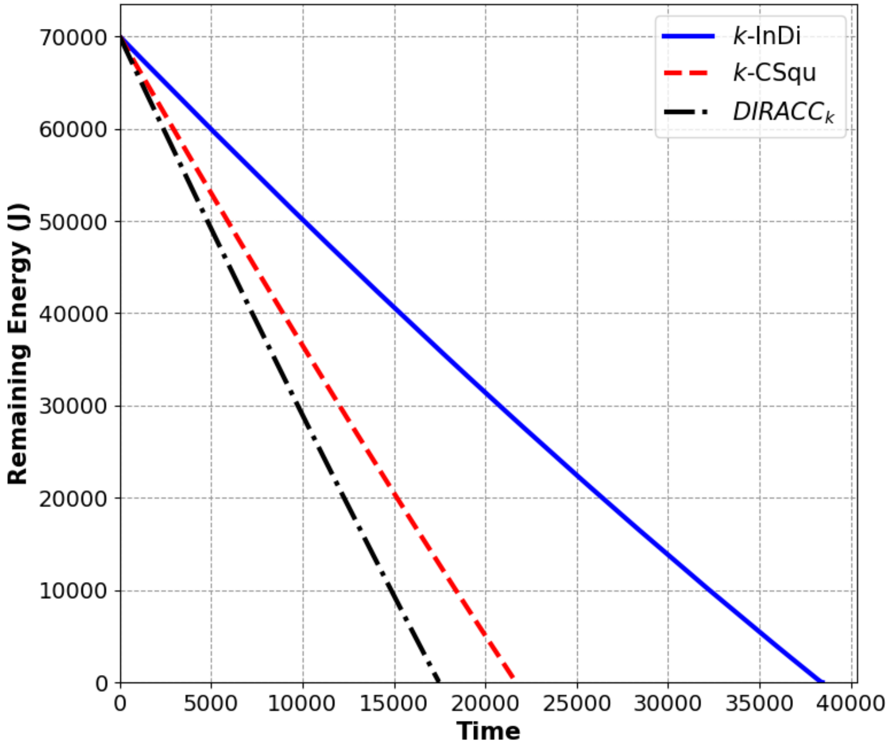


Comparison of *k*-CSqu and *k*-InDi with DIRACC$_k$

Degree of coverage *k* versus Number of active sensor n_a

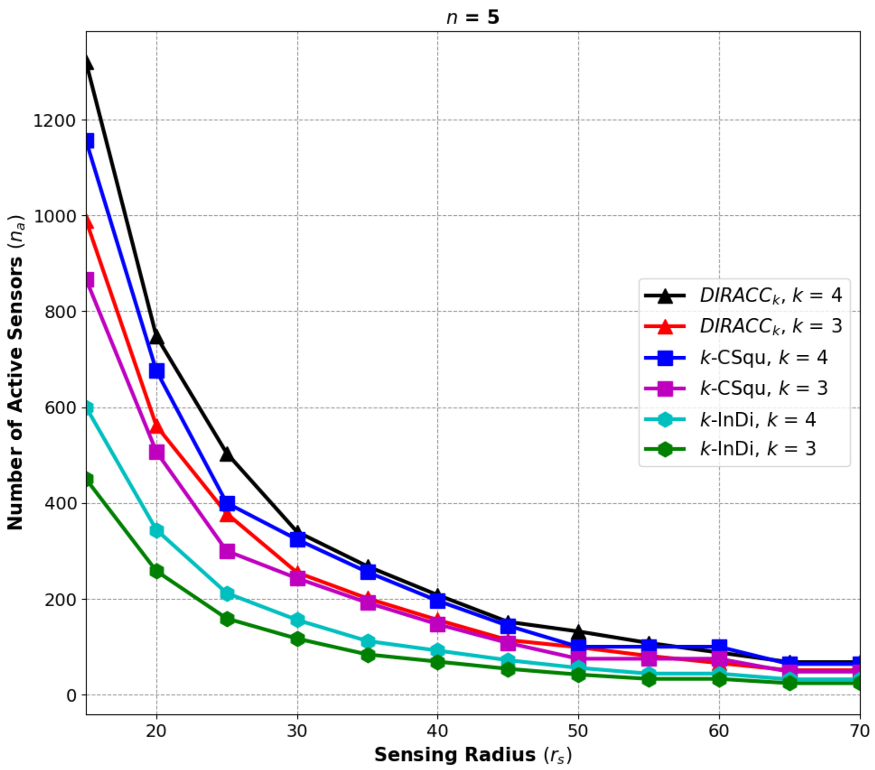


Remaining Energy vs. Time

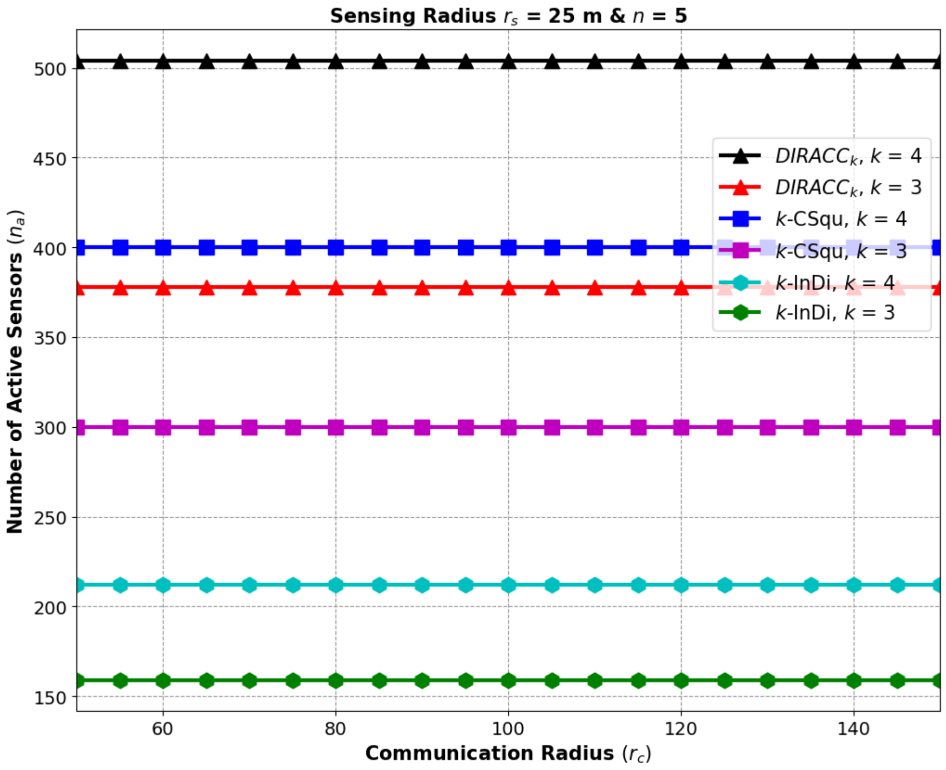


Comparison of *k*-CSqu and *k*-InDi with DIRACC$_k$

Number of active sensors n_a vs. Sensing radius r_s



Number of active sensors n_a vs. Communication radius r_c



Outline

- Introduction
- Dr. Ammari’s Research
- Preliminaries
- Square Tessellation Approach
- Hexagonal Tessellation Approach
- Results
- **Conclusion**

Summary of Research

- Investigated connected *k*-coverage problem of PWSNs.
- Addressed sensor placement issue for both tessellations.
- Calculated planar sensor density for *k*-coverage for both tessellations.
- Established network connectivity relation for both tessellations.
- Proposed centralized *k*-coverage protocols, *k*-CSqu and *k*-InDi.

Future scope of Research

- Find optimal value of n.
- Extend our k-CSqu and k-InDi approaches to heterogeneous sensors.
- Extend our k-CSqu and k-InDi approaches to stochastic sensing model.
- Extend our both theories to three-dimensional space.

Thank You !!!