Coverage for Target Localization in Wireless Sensor Networks

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Overview

- Introduction
- Sufficient condition for full coverage for localization applications
- Estimating the necessary network density for localization
  -- Disk coverage model
  -- Sector coverage model
- Conclusion

Coverage problems in sensor networks

- Coverage problem: Find a way to deploy or schedule sensors so that the *information loss* of the sensor network is below a given bound
- Information loss: the differences between the sensed data and the physical world

  -- Depends on applications, can be measured as *target detection rate*, *localization error* or *data sampling rate* (in time or space)
- Conventional coverage models

  -- Disk coverage model

  -- Exposure model

Insufficiency of the disk coverage model

- Disk model

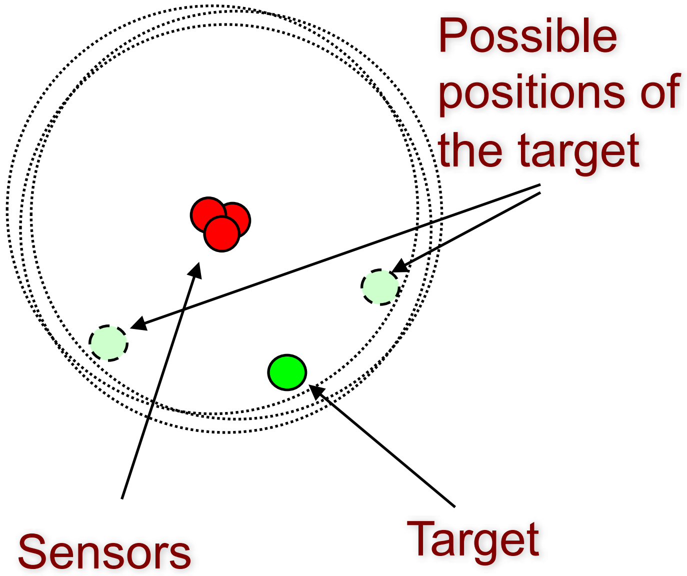
  -- Sensing area is a disk around sensors

  -- A point is deemed to be covered when it is within the sensing area

- Insufficient for localization

  -- Detected target can be localized with certain accuracy

  -- A *k*-covered target still may not be accurately localized



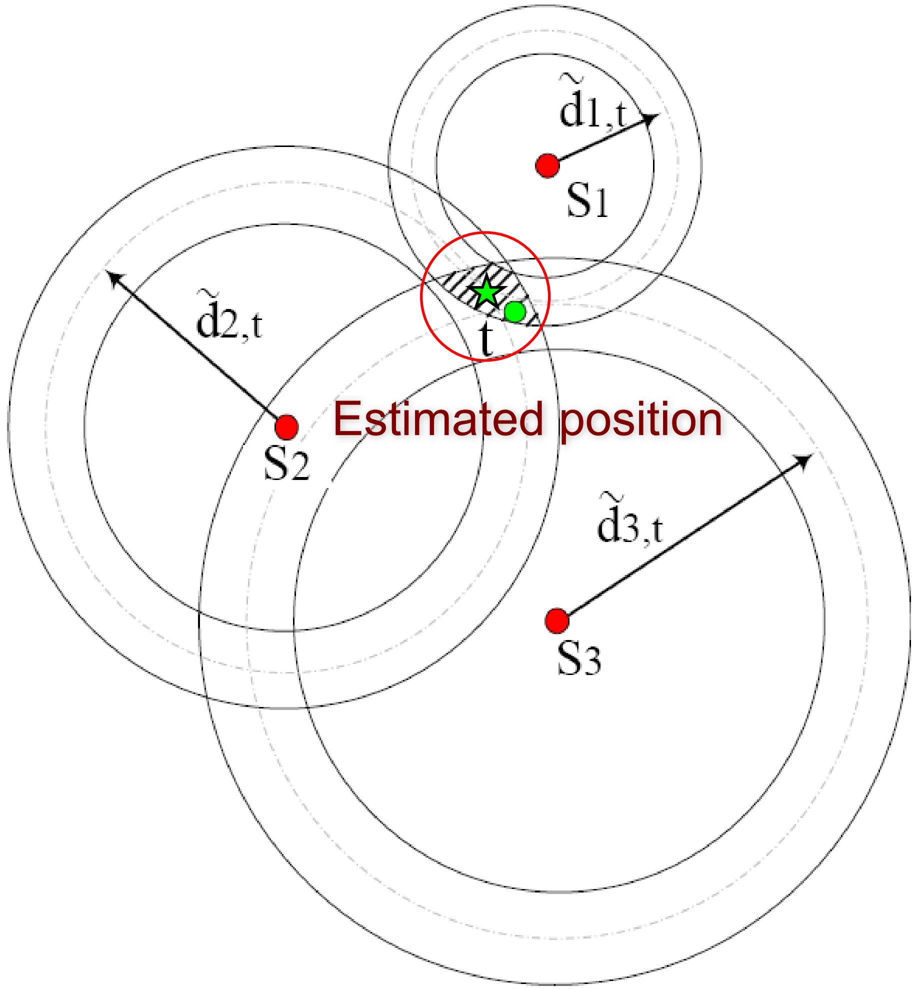
Problems addressed in this paper

- How to guarantee a localization error bound in a sensor network?
- The relationship between sensor density and the localization error in a random network
- Methods for estimating sensor density when given the localization error requirement. Can we apply disk model in this case?

Localization model used in this paper

- The locations for sensors are known
- Sensors can measure its distance to the target
- When the estimated distance is $\tilde{d}_{i,t}$, then the true distance between sensor *i* and target *t* is within $[\tilde{d}_{i,t} - e, \tilde{d}_{i,t} + e]$ with high probability, where *e* is the error bound when target is within detection range

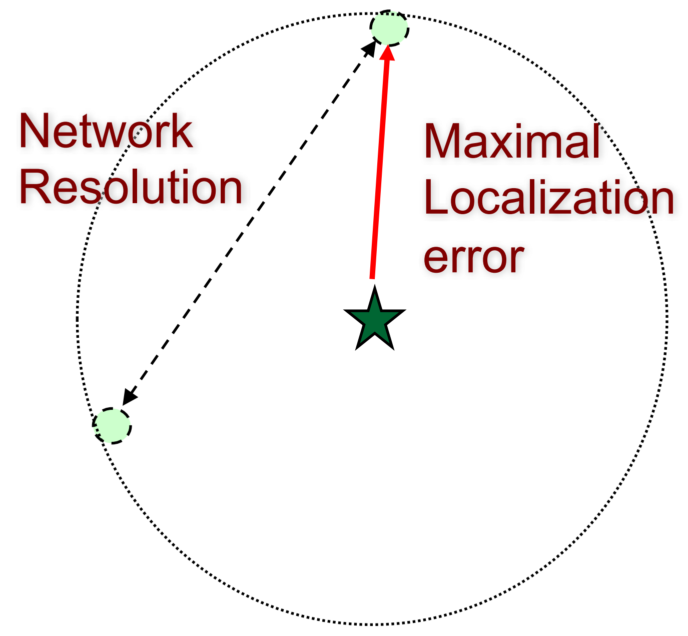
Localizing through multiple sensors



- Each sensor can localize the target within a ring of 2*e*
- Use the center of the intersection area as the estimated target location
- Localization error depends on the size of intersection area

Network resolution

- The network can distinguish any pair of two point, which are departed more than the *network resolution*, through the distance measurements
- Relationship between network resolution and localization error



Network resolution < $\sqrt{3}\varepsilon$ ⇒ Localization error < ε

Network resolution > 2ε ⇒ Localization error > ε

Sufficient condition for localization coverage

Theorem 1:

If there is no $(r, \frac{2}{3})$ sector shaped void in the network

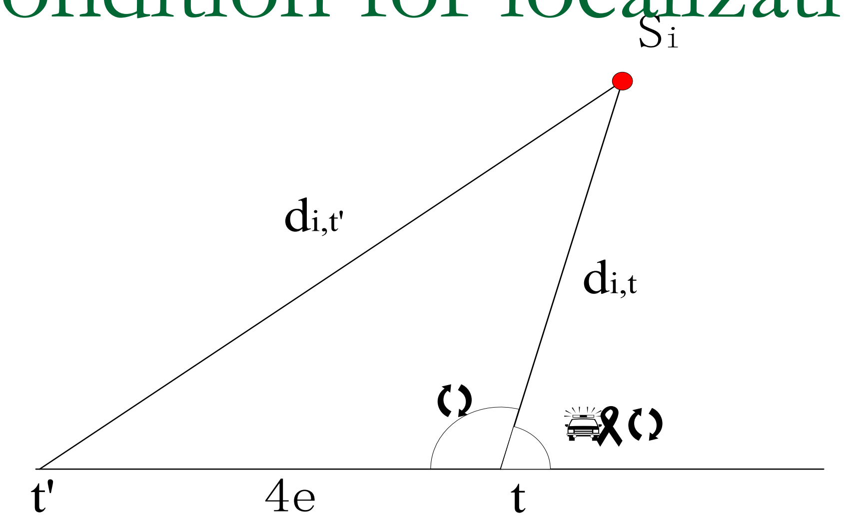
↓

Every pair of points can be distinguished by at least one sensor when they are depart by more than 4*e*. Thus the network resolution is smaller than 4*e*

↓

The localization error over the network is bounded by $\frac{4\sqrt{3}}{3}e$

Sufficient condition for localization coverage

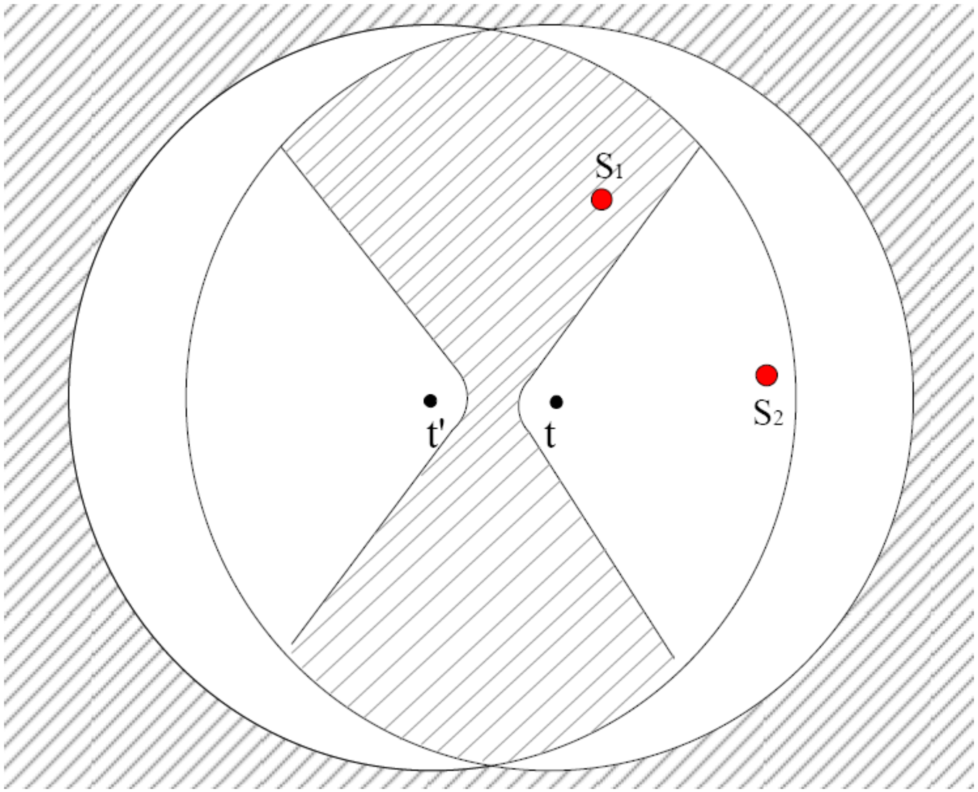


Suppose sensor Si can not distinguish t and t’

$$d_{i,t} \quad d_{i,t'} + 2e \quad \Rightarrow \quad \cos \quad = \frac{d_{i,t}^2 + (4e)^2 \quad d_{i,t'}^2}{2d_{i,t} \cdot 4e} \quad \frac{1}{2}$$

Then will be larger than $/3$

Sufficient condition for localization coverage



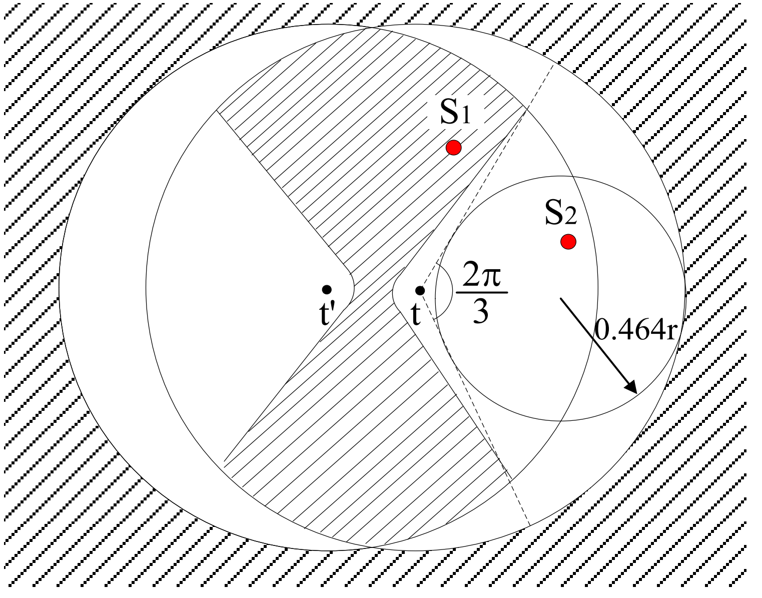
- Sensor S_1 can not distinguish point t and t', but sensor S_2 can
- If there are any sensor in the white area, as a $2\ /3$ sector, the two point can be distinguished

Link back to disk coverage

Disk coverage model

-- Ensure at least one sensor in every disk with radius of 0.464*r* (*r* is the detection range)

-- In other words, need more than **4** times sensor for coverage than detection



Benefits

-- Disk model is well studied

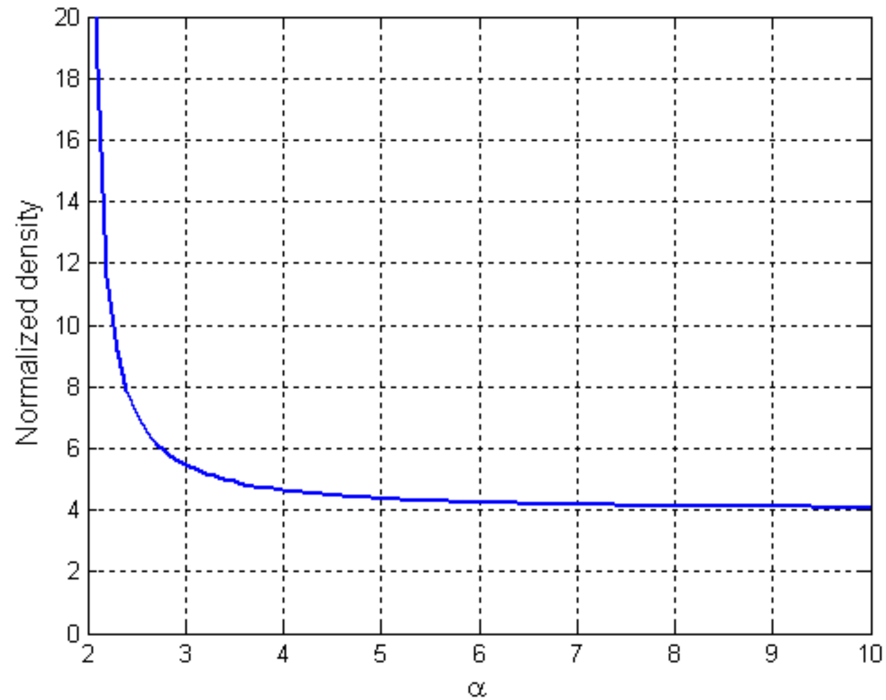
-- Can use simple algorithms to check coverage

Drawbacks

-- overestimates the density

Why select network resolution as 4e

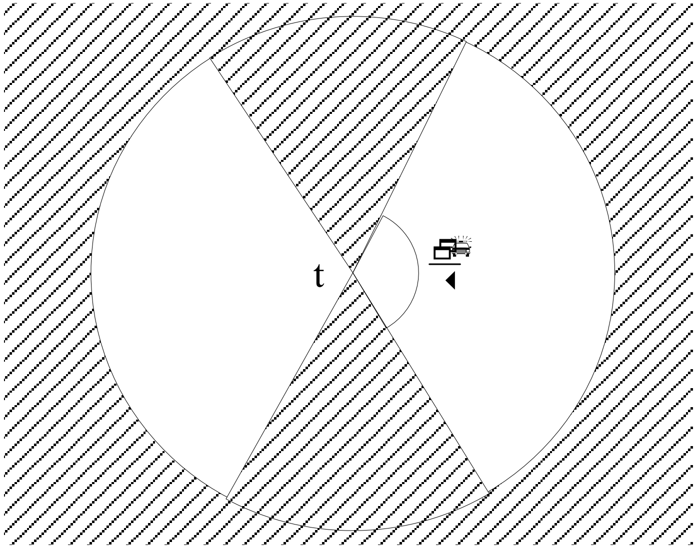
- Network resolution can be selected as αe
- We need extremely high density to guarantee a small α
- Even if we select α as much larger than 4, we still need nearly same density as α=4



Relationship between density and network resolution

Sector coverage

- Disk model is too strict and overestimates the density

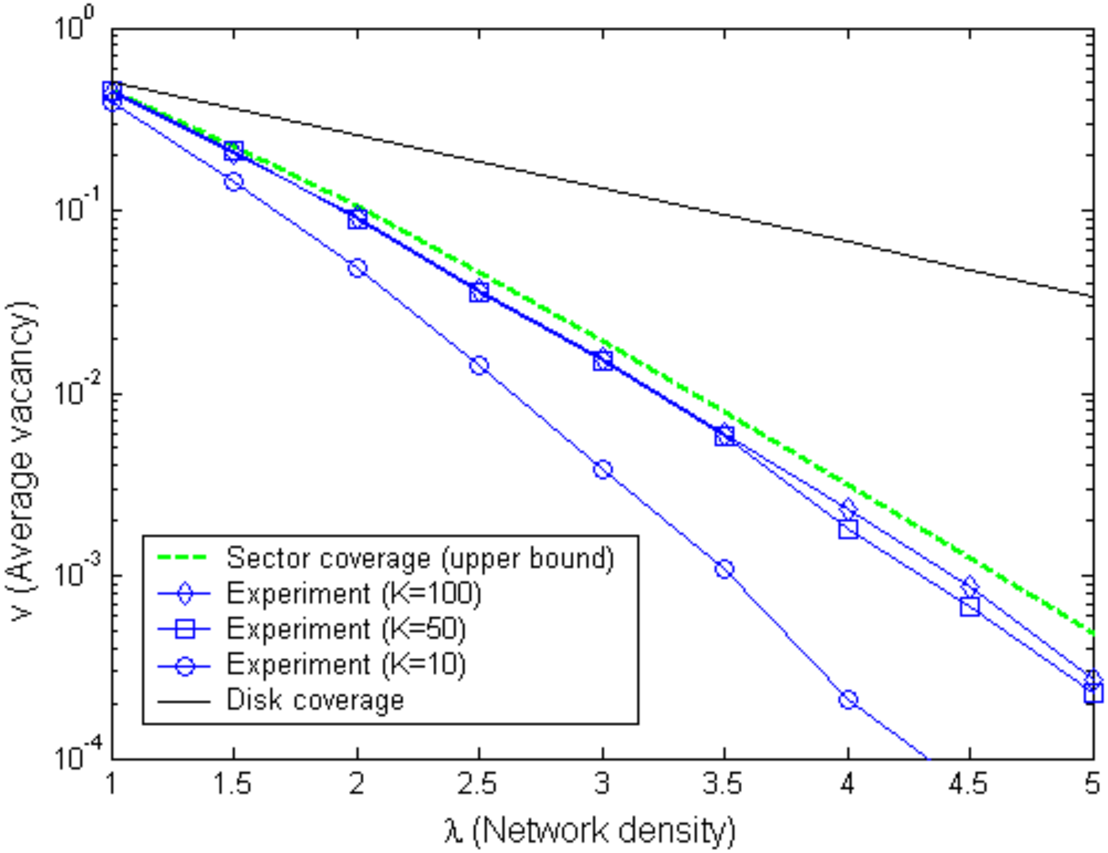


- Sector coverage:
  -- approximate the void as two opposite sectors
  -- meet the coverage condition by ensuring nonexistence of such sector shaped void

Estimating density through sector coverage

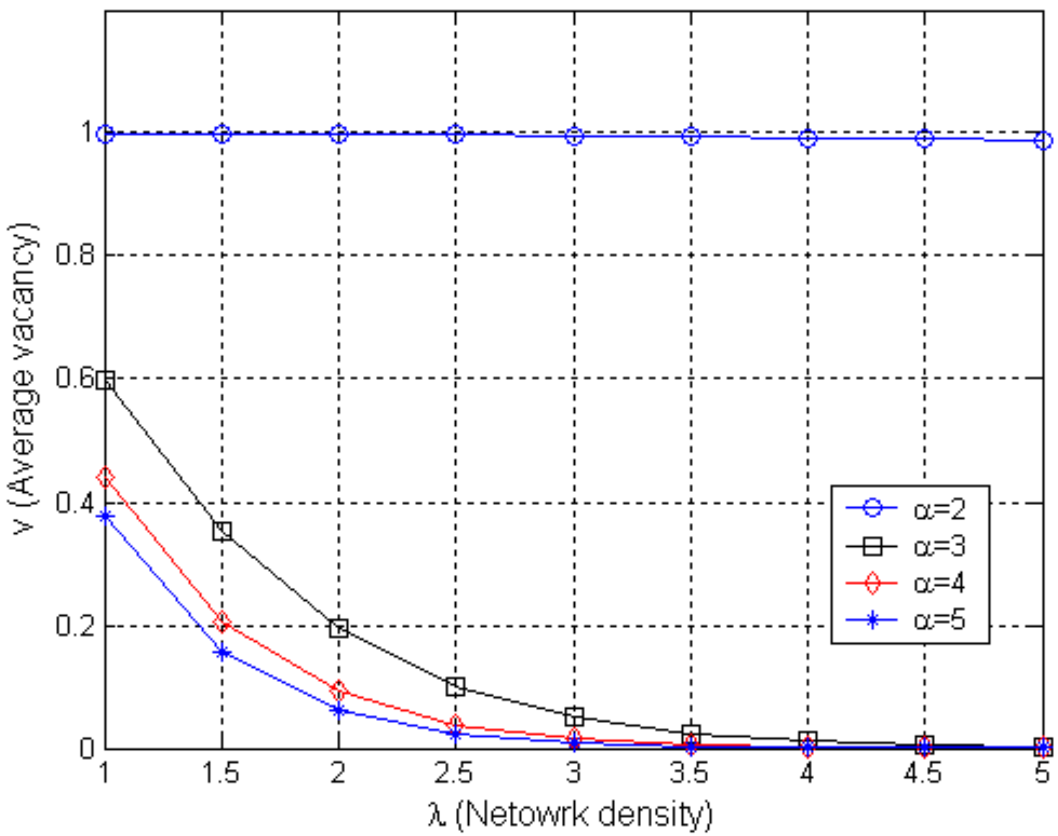
- Assume sensors are uniformly distributed (Poisson Point Process)
- Given the density of sensors, estimate the probability that there are two opposite sector void around one point
- Provides more accurate density estimations, require 2 times less sensor than disk model
- More complex than disk model

Simulation results



Estimation of vacancy through disk and sector coverage

Simulation results



Vacancy size with different network resolution requirements

Conclusion

- Disk coverage is insufficient for some applications
- We show the sufficient condition for coverage of localization
- Two methods for estimating the necessary density for localization

  Disk coverage: Require nearly 4 time more sensors than detection, low computational complexity

  Sector coverage: More accurate estimation, use 2 times less sensors, require complex algorithms

Thank you!

Supplementary slides

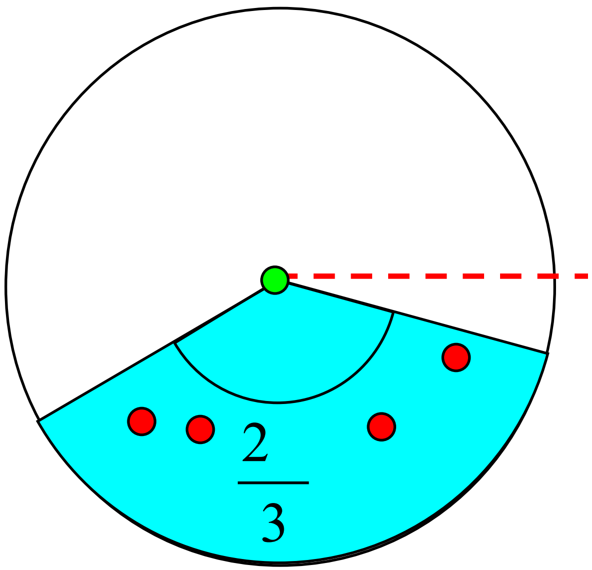
Estimate density through sector coverage

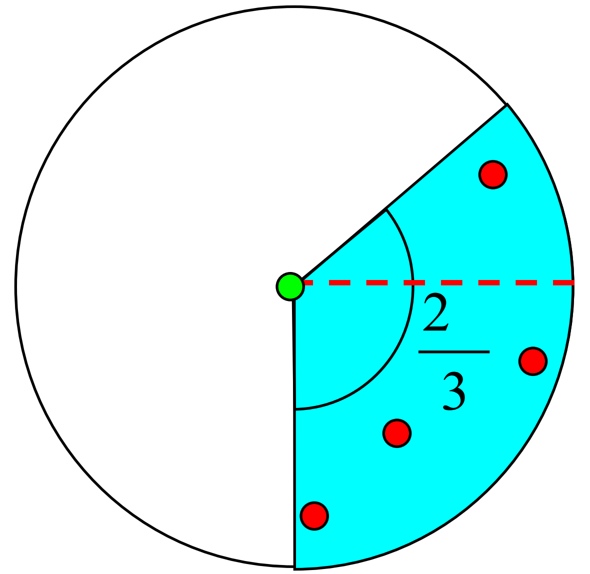
- The probability for there are *k* sensors within the detection range

$$P_k = e^{\quad r^2}\frac{(\quad r^2)^k}{k!}$$

- The probability that there are two 2π/3 sector voids given there are *k* sensors around
  -- k=0,1: probability=1
  -- k=2: probability=2/3
  -- k>2: probability=exist one 4π/3 sector void

Probability of 4π/3 sector void when k-covered





Q_k: All the *k* sensors in a 2π/3 sector not crossing the zero angle

$$Q_k = k\ \frac{1}{3}^{k\quad 1}\quad (k\quad 1)\ \frac{1}{3}^{k}$$

Q'_k: All the *k* sensors in a 2π/3 sector crossing the zero angle

$$Q'_k\quad \frac{1}{2}Q_k$$

Estimate density through sector coverage

- Overall the probability that a point is uncovered in sector model is bounded by

$$P_0 + P_1 + \frac{2P_2}{3} + {}_{k=3} Q_k P_K \qquad P_{\sec tor} \qquad P_0 + P_1 + \frac{2P_2}{3} + \frac{3}{2} {}_{k=3} Q_k P_K$$

- The probability that a point is uncovered in disk model

$$P_{disk} = e^{\quad (0.464r)^2}$$