Analysis of the Coverage of a Three-dimensional Heterogeneous Wireless Sensor Network

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   - Motivation
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   - Numerical Example
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Wireless sensor network (WSN)

- WSN consists of autonomous sensor nodes
- **Functionality**
  - Sense task-specific environmental phenomenon
  - Perform in-network processing on the sensed data
  - Communicate wirelessly to other sensors or to a sink
- **Applications**
  - Oceanographic data collection
  - Pollution monitoring
  - Offshore exploration
  - Disaster prevention
- **Design issues**
  - Deterministic and random deployment
  - Sensor types
  - Two-dimensional and three-dimensional WSN
  - Maximizing the network lifetime
Definitions

- A point in a sensor field is said to be covered if it falls within the sensing region of at least one active sensor.

- If every point in the sensor field is covered by the WSN with a high probability, the field is said to be completely covered else it is partially covered.

- A part of the sensing region of a sensor is said to be redundantly covered if it is also covered by another neighbour sensor.

- Coverage ratio of the sensor field = $\frac{\text{Volume covered by the WSN}}{\text{Total volume of sensor field}}$.

- Redundancy degree of a sensor = $\frac{\text{Volume redundantly covered by neighbours}}{\text{Total volume of the sensor}}$. 
Most of the literature on coverage problem focus on:

- Two-dimensional WSN
- Homogeneous WSN
- Complete coverage of the sensor field
- Complete redundancy of a sensor
- Available geographical information
- Centralized approaches
- Fixed ratio of sensing and communication ranges
Objectives:

- Estimate the expected value of the redundancy degree of a sensor in a 3D heterogeneous WSN
- Determine if a sensor is redundant for a desired coverage ratio of the sensor field

Assumption:

- $t$ types of sensors
- Uniformly randomly deployed
- Binary sphere sensing and communication model
Problem solution

Figure: 2D projection of sensing region and communication region of sensors and the region of intersection between the sensors.

A point $P$ inside the sensing range of a type $i$ sensor also being covered by a neighbour of type $j$ sensor, i.e., the neighbour of type $j$ sensor must lies in the shaded region.
Probability of a point $P \in V(s_i, S_i)$ at a distance of $d$ from $s_i$, also being covered by a neighbour of type $j$

$$p_{ij}(d) = \frac{\| V(P, S_j) \cap V(s_i, \min(C_i, C_j)) \|}{\| V(s_i, \min(C_i, C_j)) \|}$$  \hspace{1cm} (1)

The expected value of the redundancy degree of a type $i$ sensor

$$E[\xi_i] = \frac{1}{\| V(s_i, S_i) \|} \iiint_{V(s_i, S_i)} 1 - \prod_{1 \leq j \leq t} (1 - p_{ij}(d))^{n_{ij}} dV$$ \hspace{1cm} (2)

Where $V(s_i, \min(C_i, C_j))$ and $n_{ij}$ are the effective communication region and type $j$ neighboring sensors of a $s_i$ sensor, respectively.
Scenario: $t = 2$, $S_1 = 15m$, $C_1 = 15m$, $S_2 = 18m$, and $C_2 = 20m$

**Figure**: Variation in the expected redundancy degree of a type 1 and a type 2 sensor for different combinations corresponding to the number of type 1 and type 2 neighbours (shown in the form of $(n_1, n_2)$), $1 \leq i \leq 2$. 
In this work, we proposed a probabilistic approach to determine the redundancy of sensors.

This work showed that different types of sensors have different utility in coverage redundancy.

This work motivates further research in the partial coverage problem for heterogeneous WSNs and particularly the design of energy-efficient 3D WSNs.