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

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Outline

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 *partial 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 $= \frac{\text{Volume redundantly covered by neighbours}}{\text{Total volume of the sensor}}$.

Motivation

- 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

Problem statement

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

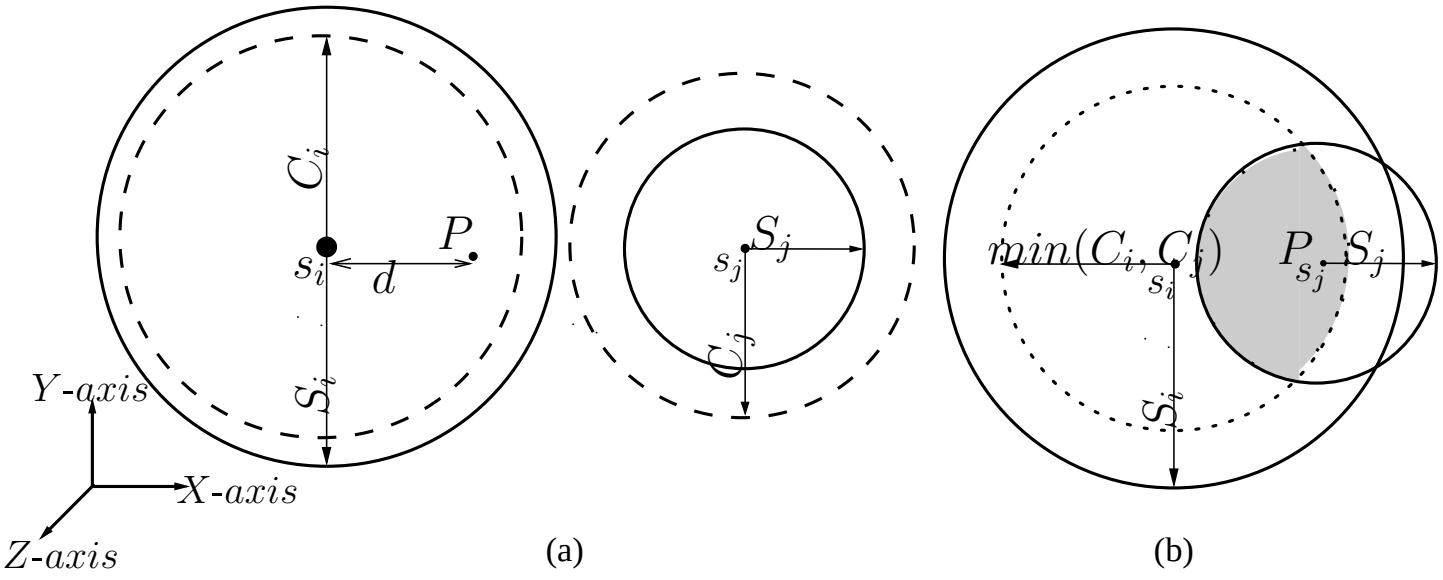

Figure: 2D projection of sensing region and communication region of sensors and the region of intersection between the sensors.

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.

Problem solution

- 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

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

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

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

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.

Numerical Example

Scenario: $t = 2$, $S_1 = 15m$, $C_1 = 15m$, $S_2 = 18m$, and $C_2 = 20m$

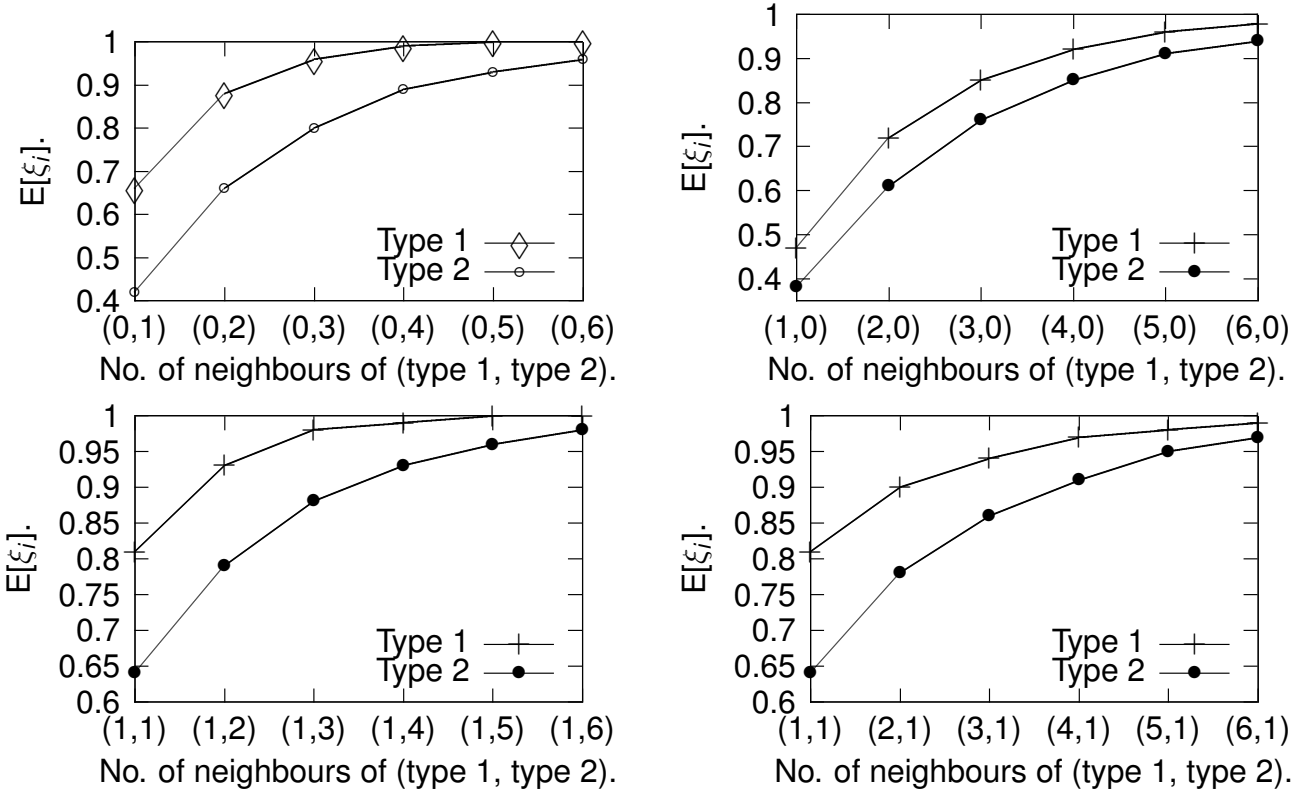

Figure: Variation in the expected redundancy degree of a type 1 and a type 2 sensor for different combinations corresponding to the number of type 1 and type 2 neighbours (shown in the form of (n_1, n_2)), $1 \leq i \leq 2$.

Conclusion and future work

- 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.