

Energy Efficient Area Monitoring Using Information Coverage in Wireless Sensor Network

S. Vashistha, [A. P. Azad](mailto:A.P.Azad@sophia.inria.fr) and A. Chockalingam

sumit,achockal@ece.iisc.ernet.in

amar.azad@sophia.inria.fr

WOWMOM 2007

19th June , Helsinki

Outline

- Introduction
- Background
- Coverage
 - Physical Coverage Vs Information Coverage
- Proposed GB-FAIC Algorithm
- Result and Discussion

Introduction

- Wireless Sensor Networks
 - Energy efficiency is crucial in battery operated tiny sensors(nodes).
 - Energy is consumed primarily in **Sensing** (coverage of a point/target), Communicating and Processing of data.
 - Depletion of battery causes
 - * End of Network lifetime

Background

- Coverage (sensing) - A point or target is said to be covered if a sensor node is able to sense it.
 - Physical Coverage (Classical sensing)
 - * Sensing a target within a fixed radius(PCR) with acceptable accuracy.
 - * Only one node takes part.
 - Information Coverage ^a
 - * Sensing a target is feasible even beyond the fixed radius with acceptable accuracy.
 - * Multiple nodes collaborate.

^aB. Wang, W. Wang, V. Srinivasan, and K. C. Chua, "Information coverage for wireless sensor networks," IEEE Commun. Letters, vol. 9, no. 11, pp. 967-969, November 2005.

Information Coverage

- A collaborative strategy to enhance feasible sensing range beyond physical coverage region.
 - Useful for low node density sensor network.
- Improvement in Coverage at the cost of excess energy expenditure (Sensing a target involves more than one node).

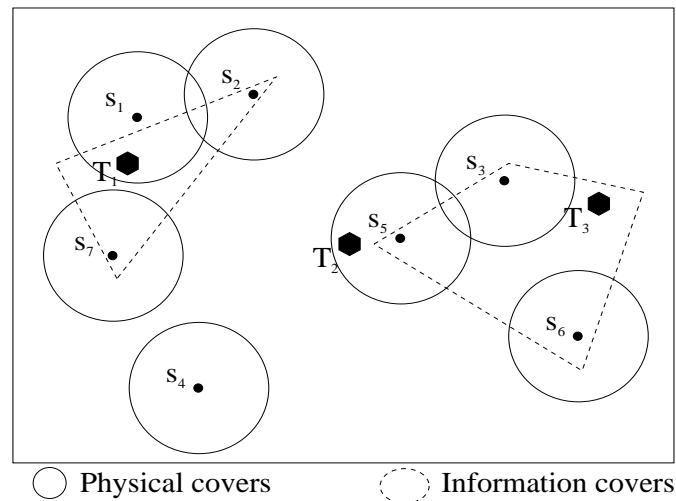


Figure 1: Target T_3 is out of Physical Coverage region

Information Coverage (Contd.)

- Measured value y_i ,

$$y_i = \frac{\theta}{d_i^\alpha} + n_i , i=1, 2, \dots, K(\text{sensor node})$$

α = exponential decay component ($\alpha > 0$)

θ = parameter to be sensed/measured

d_i = distance between sensor node i and target

n_i = additive noise at sensor node i .

- Estimation error

$$\tilde{\theta} = \hat{\theta} - \theta$$

$\hat{\theta}$ = estimation of the parameter θ

- $\tilde{\theta}_K$ is the estimation error when K nodes collaborate
- A target is said to be (K, ϵ) information covered if K sensor collaborate to estimate the parameter θ at the target ,such that

$$\Pr\{|\tilde{\theta}_K| \leq \epsilon\} \geq \epsilon , \text{ where } 0 < \epsilon < 1$$

Information Coverage -An Illustration

- Extension of coverage area (in black color) using information collaboration of 2 and 3 nodes

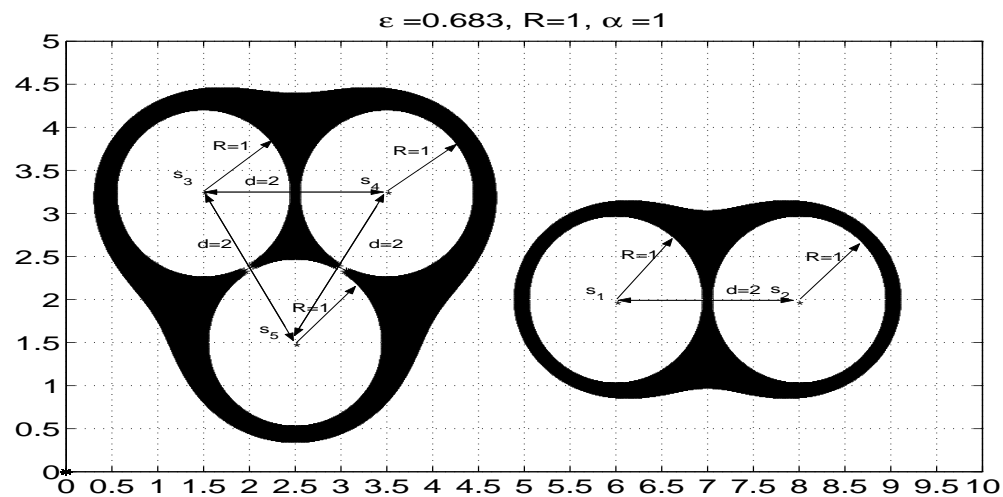


Figure 2: Illustration of area covered by physical coverage and information coverage.

Full Area Information Coverage

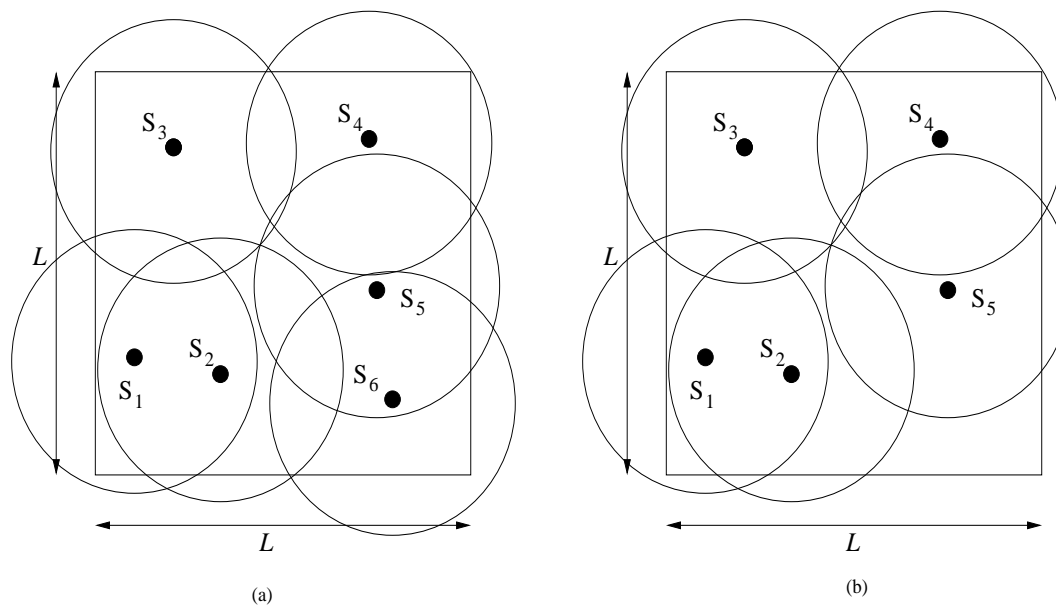


Figure 3: Illustration of full and partial area physical coverage. (a) Full area physical coverage by sensors s_1, s_2, \dots, s_6 . (b) Partial area physical coverage by sensors s_1, s_2, \dots, s_5 .

Full Area Information Coverage (Contd.)

- Ensuring sensing/monitoring of the full area-to-monitor essentially guarantees sensing/monitoring of any number of targets lying inside the area-to-monitor irrespective of their locations.
- The full area-to-monitor can be viewed as a collection of large number of densely populated point targets.

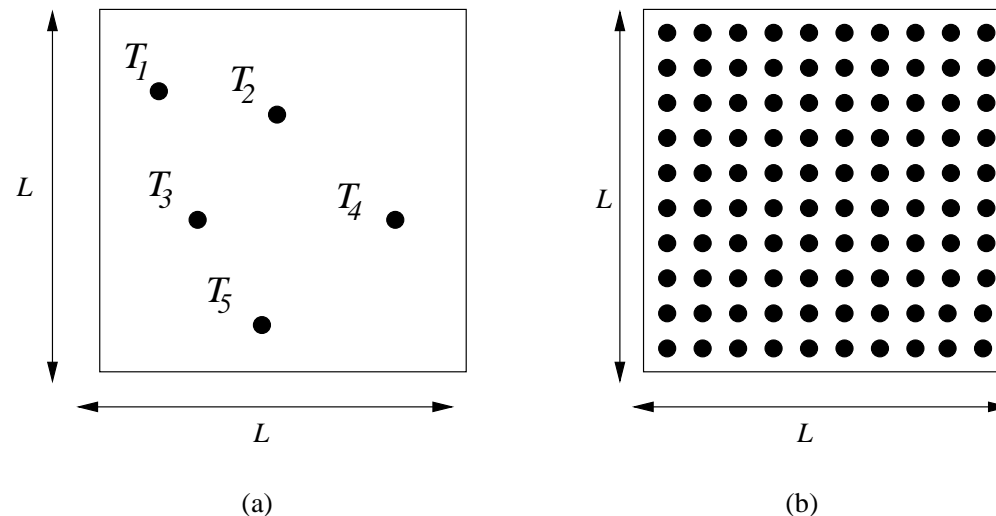


Figure 4: (a) Point targets coverage problem. →(b) Full area coverage problem viewed as a point targets coverage problem.

Point target coverage → Full area coverage

- Coverage
 - Point target Coverage
 - * Objective is to cover one or more(few) point target by using information collaboration of multiple nodes.
 - Full Area Coverage
 - * The whole sensor network area to be covered. Assume large number of densely populated targets depending on the PCR.
- Algorithms developed for point targets information coverage (e.g., EGEH and DSIC) can't be used to achieve full area information coverage.
 - Complexity in these algorithms for large number of targets is prohibitively high.
 - Complexity in the DSIC algorithm grows exponentially in the number of targets.
- Our Contribution
 - A two step scheme(first) for area coverage using information coverage.

Proposed GB-FAIC Algorithm

- Step I
 - We propose a low-complexity heuristic approach to achieve full area information covers(FAIC).
 - * An exhaustive search for FAICs among all sensors is expensive. Search only through those sensor combinations that are more likely to be beneficial.
 - * Search for valid FAICs only among those sensors which are separated adequately apart so that
 - information coverage among them is more likely to be feasible
 - closely located sensors are given less preference to be in the same FAIC (since information coverage through very closely located sensors can be less beneficial).
 - Step II
 - * Optimally schedule these FAICs (by solving an integer linear program) so that the sensing lifetime is maximized.

System Model

- N homogeneous sensor nodes distributed uniformly in the sensing field of area $L \times L$.
 - $\mathcal{S} = \{s_1, s_2, \dots, s_N\}$
- $\mathcal{P} = \{p_1, p_2, \dots, p_{|\mathcal{P}|}\}$ denote the set of all pixels that characterize the full area.
- \mathcal{C} : Set of information covers^a.
 - $\mathcal{C} = \{C_1, C_2, \dots, C_{|\mathcal{C}|}\}$
- The j th FAIC $C_j, j = 1, 2, \dots, |\mathcal{C}|$, denotes a subset of \mathcal{S} such that *all* pixels in \mathcal{P} are information covered by using *all* sensors in C_j

$$C_j \cap C_k \neq \phi \text{ for } j \neq k$$

- (X_i, Y_i) : coordinates of the sensor s_i .
- $D((A, B), (C, D))$: the distance between two points with coordinates (A, B) and (C, D) .

^aAn information cover for a point target is defined as a set of sensors which collectively can sense that target accurately.

Proposed GB-FAIC Algorithm (Contd.)

- Partition the entire area-to-monitor into square grids of size $d \times d$ (Fig. 5) so that one sensor from each grid can be taken and checked if these sensors together form a valid FAIC.

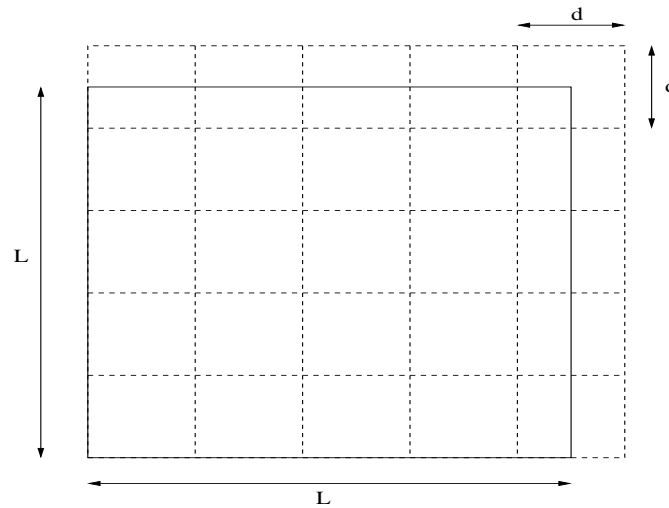


Figure 5: Dividing the $L \times L$ area-to-monitor into square grids of size $d \times d$.

Proposed GB-FAIC Algorithm (Contd.)

- Grid size ?.
 - Consider a square grid of size $d \times d$ with four sensors located at the four corners of the grid, as shown in Fig. 6.
 - Locate a point target at the center of the grid.
 - Find d_{max} (maximum value of d) for which all the four sensors together can sense the target.

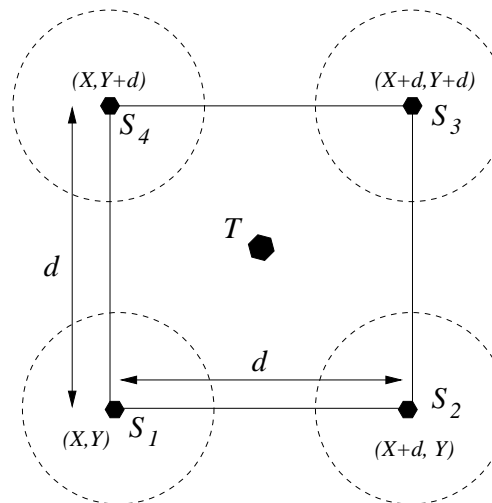


Figure 6: Choice of the grid size, d .

Proposed GB-FAIC Algorithm (Contd.)

- From the equation(Classical Information Coverage)

$$\Pr\{|\tilde{\theta}_K| \leq A\} \geq \varepsilon$$

- d_{max} can be calculated to be 2 for $\alpha = 2$ and $2\sqrt{2}$ for $\alpha = 1$.
- A grid size $\geq d_{max}$ will leave the target uncovered while grid size $\leq d_{max}$ will result in a larger search space without much coverage benefit.

Proposed GB-FAIC Algorithm (Contd.)

- The set of sensors for a valid FAIC test is chosen such that in each grid the sensor closest to its corner (if available) is chosen.
- The reference corner is alternatively taken to be the bottom left corner and top left corner (Fig. 7) to make the selected sensors in different sets to stay apart.

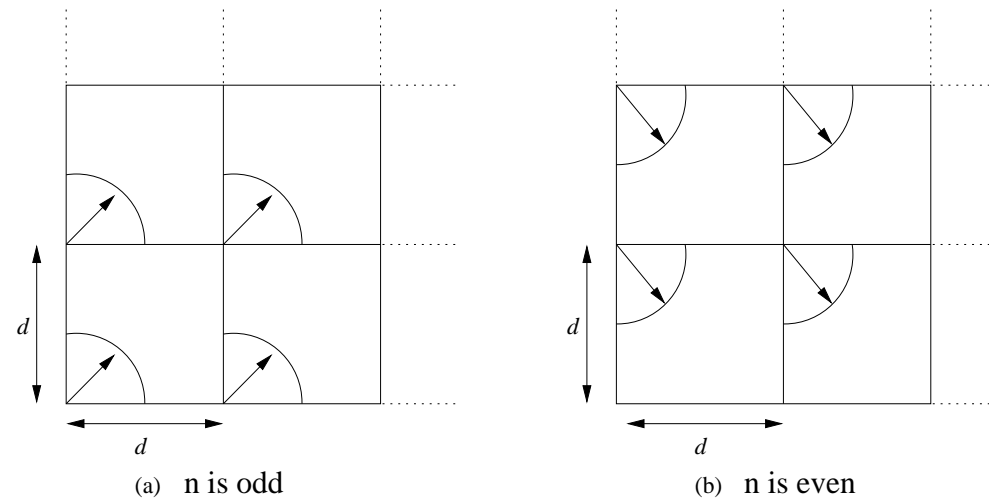


Figure 7: Illustration of how sensors are selected in each grid.

Proposed GB-FAIC Algorithm (Contd.)

$$C_j = \begin{cases} C_j \cup \{s_i : \min [D((X_i, Y_i), (X, Y))], i = 1, 2, \dots, |\mathcal{S}_t|\}, \\ \quad \text{for } j = \text{odd, and } (X \leq X_i \leq X + d, Y \leq Y_i \leq Y + d) \\ C_j \cup \{s_i : \min [D((X_i, Y_i), (X, Y + d))], i = 1, 2, \dots, |\mathcal{S}_t|\} \\ \quad \text{for } j = \text{even, and } (X \leq X_i \leq X + d, Y \leq Y_i \leq Y + d) \end{cases}$$

- \mathcal{A}_{C_j} denotes the area (set of pixels) covered by the j th set of sensors through information coverage, such that

$$0 \leq |\mathcal{A}_{C_j}| \leq |\mathcal{P}| \quad (1)$$

and

$$\mathcal{A}_{C_j} \supseteq \mathcal{A}_{s_1} \cup \mathcal{A}_{s_2} \cup \dots \cup \mathcal{A}_{s_{|C_j|}}. \quad (2)$$

For physical coverage,

$$\mathcal{A}_{C_j} = \mathcal{A}_{s_1} \cup \mathcal{A}_{s_2} \cup \dots \cup \mathcal{A}_{s_{|C_j|}}. \quad (3)$$

Proposed GB-FAIC Algorithm (Contd.)

- If $\mathcal{A}_{C_j} \neq \mathcal{P}$.
 - \mathcal{A}_{C_j} : area covered by the set of sensors C_j .
 - $\mathcal{A}' = \mathcal{P} - \mathcal{A}_{C_j}$ (area not covered) by the set of sensors C_j .
- Algorithm attempts to cover the uncovered pixels $\mathcal{A}' = \mathcal{P} - \mathcal{A}_{C_j}$ by including additional sensors to the set C_j .

$$C_j = C_j \cup \{s_i : \max[\mathcal{A}_{s_i} \in \mathcal{A}'], i = 1, 2, \dots, N\} \quad (4)$$

- A valid set of FAICs is obtained as the output of the algorithm.
- The worst case complexity of the algorithm can be shown to be of order $|\mathcal{P}|N^3$.

Scheduling

- FAICs obtained from the proposed GB-FAIC algorithm are not disjoint.
- We consider that a cover is activated for an integer number of time slots.
- Scheduling algorithm is formulated as an integer linear programming (ILP) problem:
 - N_c : number of FAICs obtained from the GB-FAIC algorithm presented above.
 - T_j : activation time of the j th FAIC in number of time slots.
 - E_i : battery energy of sensor node i .

Scheduling (Contd.)

- The optimum schedule is obtained as the solution to the following optimization problem:

Maximize

$$\sum_{j=1}^{N_c} T_j \quad (5)$$

s.t

$$\sum_{j=1}^{N_c} C_{i,j} T_j \leq E_i, \quad \forall i = 1, 2, \dots, N, \quad (6)$$

where

$$C_{i,j} = \begin{cases} 1 & \text{if } s_i \in C_j \\ 0 & \text{otherwise} \end{cases}$$

and

$$T_j \in \{0, 1, 2, \dots\}, \quad \forall j = 1, 2, \dots, N_c. \quad (7)$$

Simulation parameter

- A network with 5×5 square sensing area.
- Initial battery energy of each sensor $E_0 = 2$ Joules (i.e. $E_i = 2$ Joules for $i = 1, 2, \dots, N$).
- Each sensing operation when a sensor is activated to sense cost $4 nJ$.
- No energy is consumed when the sensor is not activated (i.e., left idle).
- In each slot exactly one cover is activated for sensing operation.
- Sensing lifetime is the number of active time slots till full area coverage is maintained.
- Physical coverage range $R = 1$, $\alpha=1$, and $\epsilon=0.683$.
- Optimum schedules (i.e., T_j 's) are obtained by solving the optimization problem in (5) using CPLEX 9.0.
- Assumptions
 - All sensor have fixed and equal physical coverage range.
 - Time axis is divided into contiguous intervals with equal duration.
 - Cover is invalid if any sensor of the cover is dead.

Simulation Results

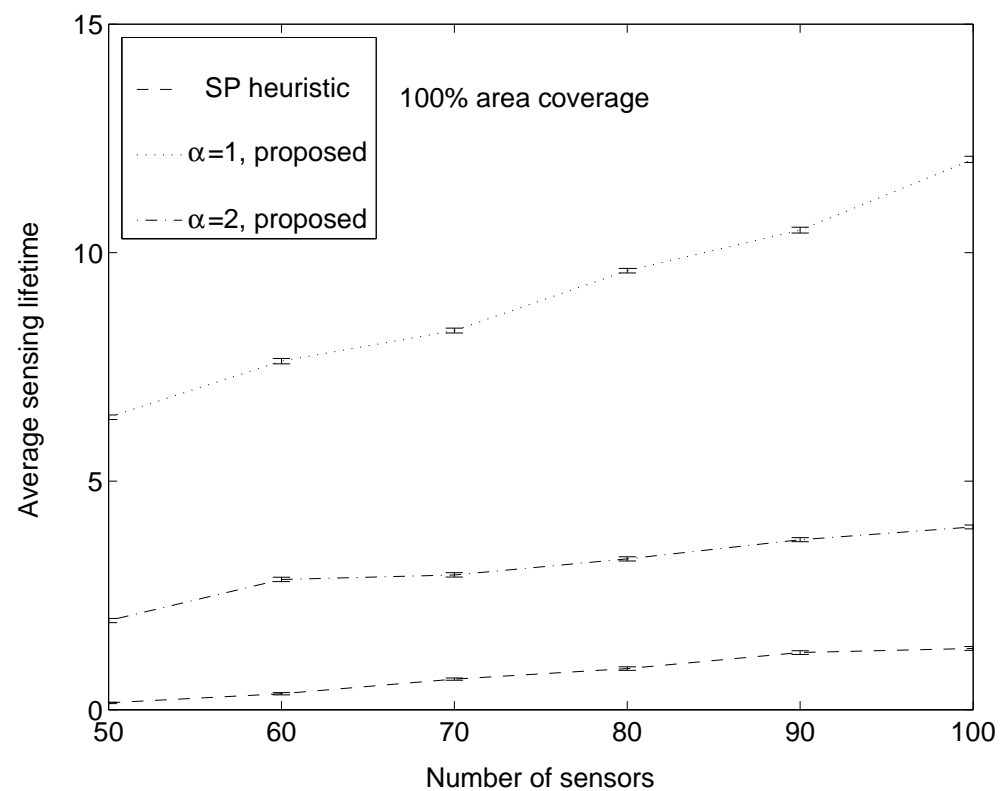


Figure 8: Average sensing lifetime as a function of number of sensors in the network. Physical coverage (SP heuristic) vs information coverage (proposed). 100% area coverage.

Simulation Results (Contd.)

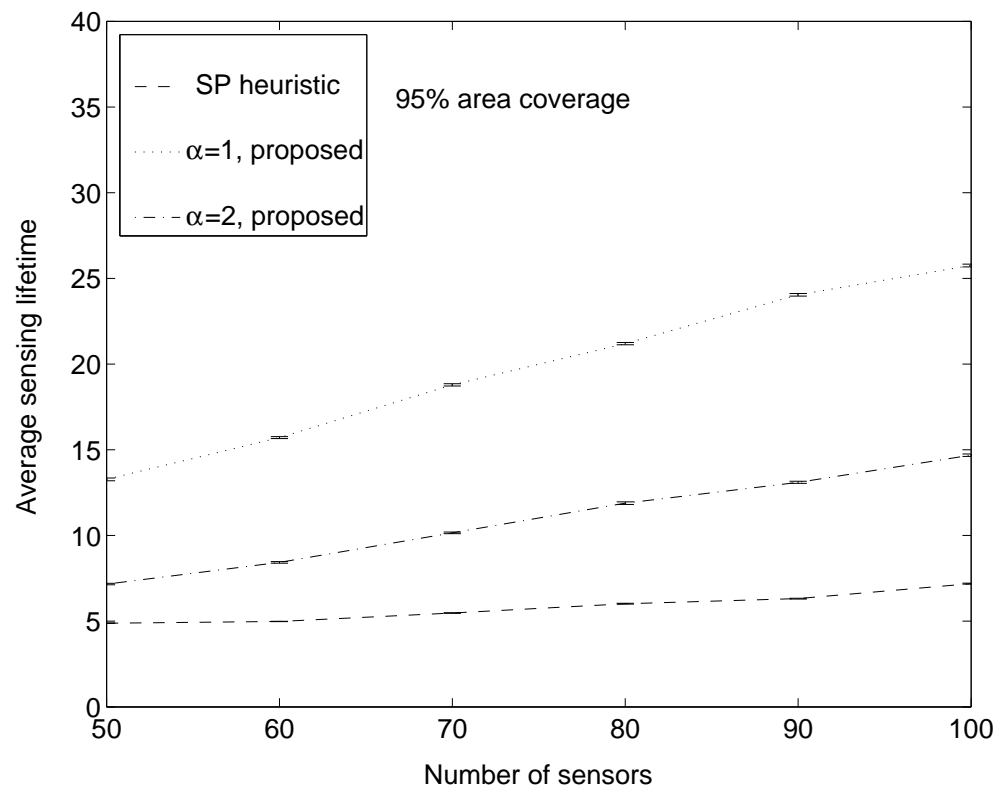


Figure 9: Average sensing lifetime as a function of number of sensors in the network. Physical coverage (SP heuristic) vs information coverage (proposed). 95% area coverage.

Simulation Results (Contd.)

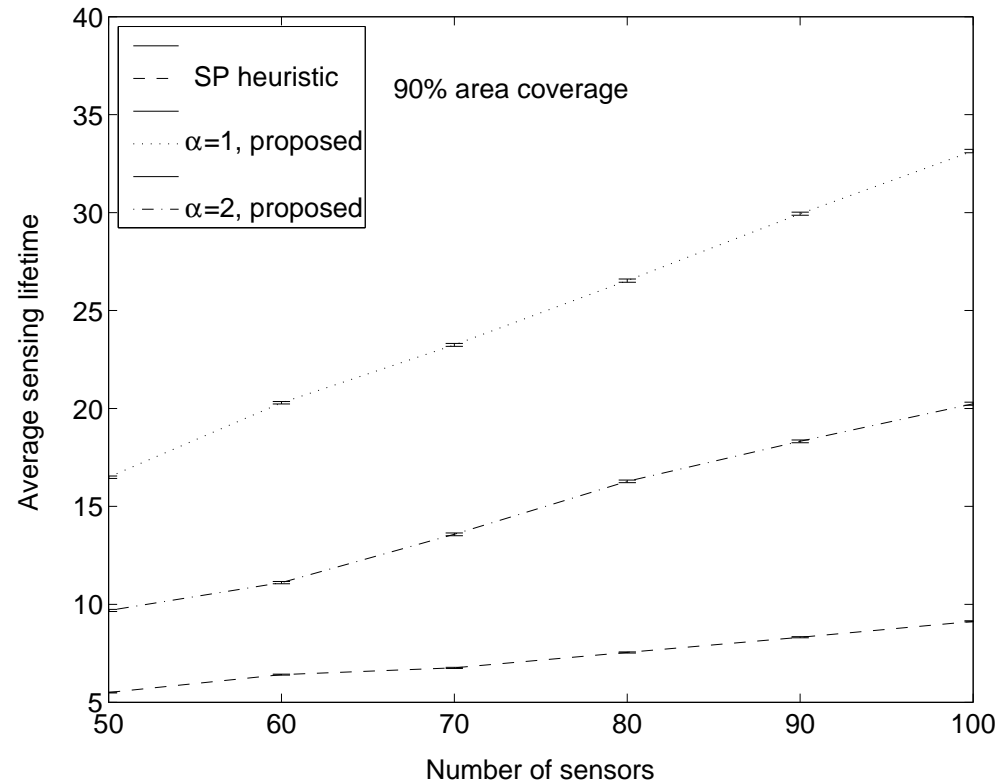


Figure 10: Average sensing lifetime as a function of number of sensors in the network. Physical coverage (SP heuristic) vs information coverage (proposed). 90% area coverage.

Conclusion

- Concept of information coverage is used to increase the network lifetime over physical coverage.
- We proposed GB-FAIC algorithm and compared the lifetime of network with physical coverage algorithm.
- Algorithm is proposed to cover the entire sensing field rather than point coverage.
- Simulation results shows the increase in sensing lifetime of network using information coverage.