A Comparison of Antenna Placement Algorithms

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March 27, 2015

Outline of this talk

- ▶ Part 1: Introduction to the antenna placement problem

- ▶ Part 2: Description of stochastic algorithms, and formulation of an instance of antenna placment problem

- ▶ Part 3: Results of our experiments

Part 1: Introduction to the antenna placement problem

Antenna Placement Problem

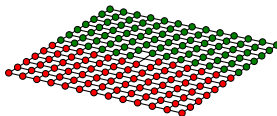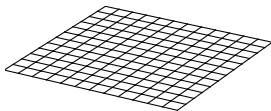Given, platform $+$ allowable placements of antennas

- Allowable placements for antenna 1
- Allowable placements for antenna 2
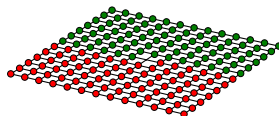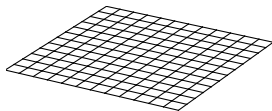
Antenna Placement Problem
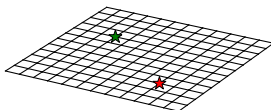
Given, platform $+$ allowable placements of antennas

- ● Allowable placements for antenna 1
- ● Allowable placements for antenna 2

- ★ Best placement for antenna 1
- ★ Best placement for antenna 2

Problem: find best antenna placements
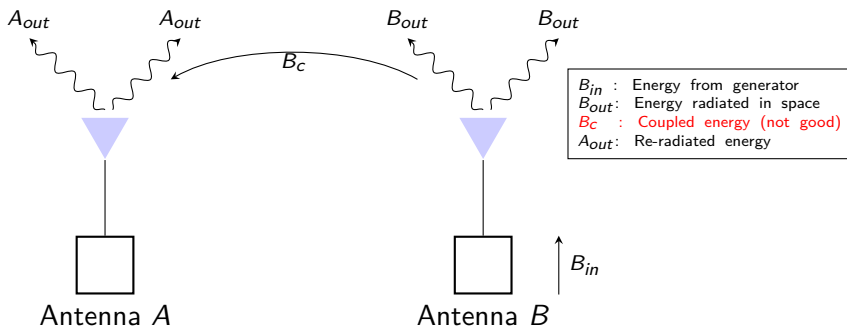
Antenna Placement Problem

Given:

- platform P with its surface gridded such that end points represent possible antenna placements

- set of m $(m > 1)$ antennas $A = A_1, A_2, \ldots, A_m$

- for each A_i, let L_i denote the set of allowable placements $\in \mathbb{R}^3$ such that $| L_i | = n_i$ and $\forall i, n_i > 1$;
  $L_i = \{(x_1, y_1, z_1) \ldots (x_{n_i}, y_{n_i}, z_{n_i})\}$

Problem: Find a set of n optimal antenna placements on P

Question: How is a good antenna placement quantified in the context of platform and other antennas?

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Mutual Coupling

When two antennas are in proximity, and one is transmitting, the second will receive some of the transmitted energy.

B_{in}	:	Energy from generator
B_{out}	:	Energy radiated in space
B_C	:	Coupled energy (not good)
A_{out}	:	Re-radiated energy

Antenna A Antenna B

Minimize Mutual Coupling

$$F_{MC} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} CP(A_i, A_j), \tag{1}$$

where

- $CP(\cdot)$ computes the coupling between two antennas via a simulator
- $i \neq j$

Example: If $n = 3$, then $F_{MC} = CP(A_1, A_2) + CP(A_1, A_3) + CP(A_2, A_3)$
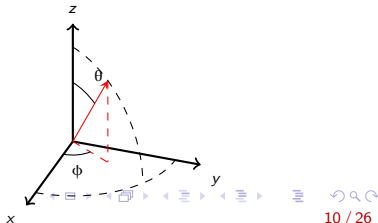
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Minimize Difference in Radiation Pattern

Pattern defines the ratio of energy radiated and input energy in a particular direction. For each antenna A_i:

$$F_{RP} = \sum_{i}^{n} \sum_{\theta} \sum_{\phi} \left(FSG_i(\theta, \phi) - ISG_i(\theta, \phi) \right)^2, \qquad (2)$$

where

- θ, ϕ spherical coordinates
- $FSG(\cdot)$ returns free-space gain pattern
- $ISG(\cdot)$ returns in-situ gain pattern

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Objective Function

Find a placement such that F is minimal:

$$F = \alpha F_{MC} + \beta F_{RP}, \qquad (3)$$

where $\alpha + \beta = 1$

Contributions

- Formulation of the antenna placement problem
- Evaluation of standard stochastic algorithms on a real-world problem
- Able to achieve global optimum with as low as 21% evaluations of search space
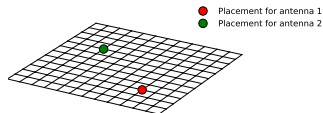
Part 2: Stochastic Algorithms

Stochastic Algorithms

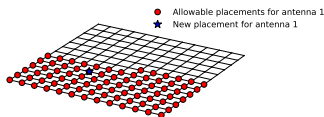We will consider algorithms which rely on *randomization* principle.

- ▶ Genetic Algorithm

- ▶ Evolutionary Strategy

- ▶ Simulated Annealing

- ▶ Hill Climbing

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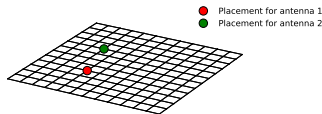# Stochastic Algorithms: Mutation Operator

1. From individual, select an antenna uniformly at random, let's say antenna 1:

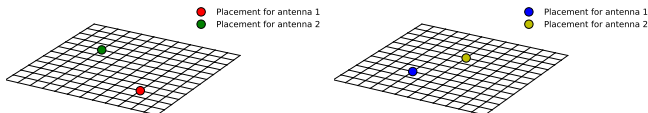2. For antenna 1, select any other placement:

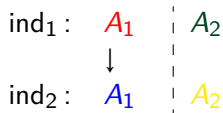3. Change position for antenna 1 in individual:
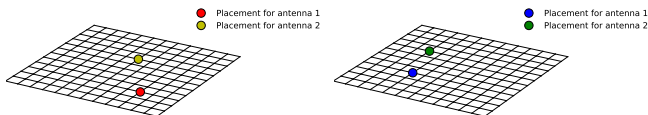
Stochastic Algorithms: Crossover Operator

1. Select two individuals from population:

2. Select a crossover point, and swap placements prior to the point:

$$\text{ind}_1: \quad \textcolor{red}{A_1} \quad | \quad A_2$$
$$\downarrow \quad |$$
$$\text{ind}_2: \quad \textcolor{blue}{A_1} \quad | \quad \textcolor{yellow}{A_2}$$

3. Two new offsprings created:

Genetic Algorithm

Algorithm 1: AP-GA

---

1   Initialize $P \leftarrow$ generate p random individuals. Compute the $fitness(h_i), i \in [1, p]$, and order P based on fitness;

2   $i = 0$;

3   **while** $i < gen_{max}$ **do**

4   Elitism: Select n_e fittest individuals to add to P' ;

5   **for** $(p - n_e)/2$ *times* **do**

6          $M \leftarrow select(P, 2)$;

7   **if** $rand(0, 1) < p_c$ **then**

8   Apply $crossover(M)$ to get two offsprings O ;

9   Add O to P' ;

10   **else**

11   Add M to P' ;

12   Uniformly select $p_m \cdot (p - n_e)$ individuals from P, and apply $mutate$ operator to each ;

13   Update $P \leftarrow P'$;

14   Compute $fitness(h_i); i \in [1, p]$, and order P based on fitness ;

15   Update $i \leftarrow i + 1$;

Evolutionary Strategy

Algorithm 2: ES

1 Initialize $P \leftarrow$ generate μ random individuals;

2 $i = 0$;

3 while $i < gen_{max}$ **do**

4   Create λ/μ offsprings from each μ individuals by applying mutation operator, and add all offsprings to P ;

5   Compute the $fitness(h_i), i = 1,\ldots,\lambda$;

6   Keep μ best individuals in P, and discard remaining $\lambda - \mu$ individuals ;

**7**   Update $i \leftarrow i + 1$

Simulated Annealing

Algorithm 3: SA

1   Initialize $C \leftarrow$ generate a random individual ;
2    $i = 0$;
3   **while** $i < i_m$ **do**
4       $N \leftarrow mutate(C)$;
5   **if** $fitness(C) < fitness(N)$ **then**
6   **if** $rand(0,1) < e^{-\delta f / T}$ **then**
7             $C \leftarrow N$
8   **else**
9          $C \leftarrow I$;
10      $T \leftarrow T \cdot f_{cooling}$;
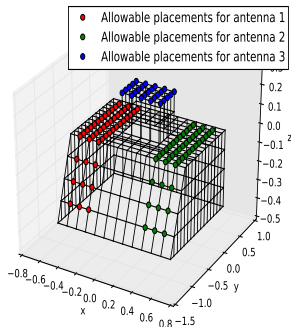11 $i \leftarrow i + 1$;

Experimental Setup

1. Create (s) such that each individual is defined by a placement for each of the m antennas
2. Run all individuals through *NEC* simulator [1] to get fitness parameters
3. Apply EA operators
4. Repeat till either global minimum is reached or 50% evaluations of search space
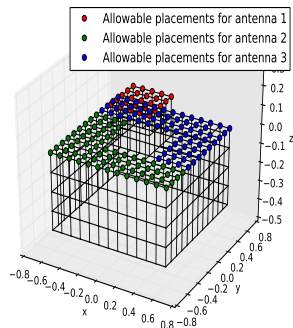
Experiments: Test Cases
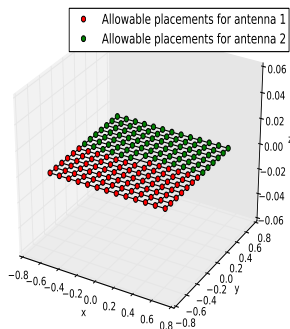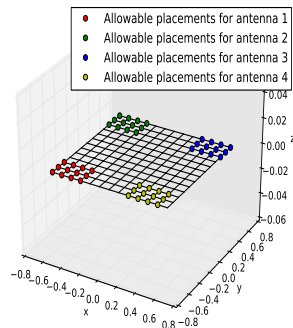

(a) Test Case 1 with 7056(83x83) allowable placements

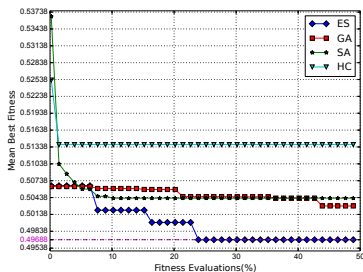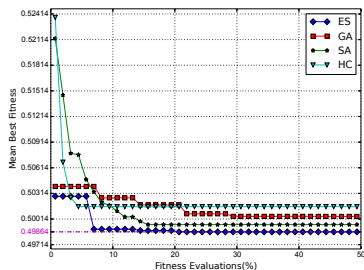(b) Test Case 2 with 50625(45x45x45) allowable placements

Experiments: Test Cases

(a) Test Case 3 with 126025(71x71x25) allowable placements

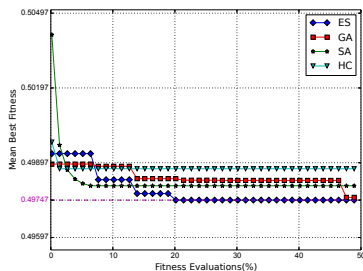(b) Test Case 4 with 20736(12x12x12x12) allowable placements

Results

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Results
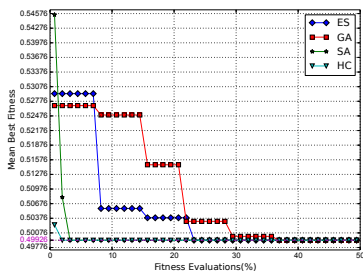
Equivalence of fitness to efficiency

For a particular test case, fitness change of 0.01 is equivalent to either the corresponding value under expected gain ($\mathbb{E}_g$) column, or difference in coupling (Δ_c).

ID	$\mathbb{E}_g$	Δ_c (dB)
tc1	872.277	0.5474
tc2	862.082	1.3034
tc3	861.845	1.5180
tc4	871.049	0.5693

$\mathbb{E}_g = \frac{1}{N \cdot m} \Sigma_i^m F_{RP}(A_i)$, where $N = |\theta| \cdot |\phi|$

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Conclusion

- Formulation of the antenna placement problem
- Generic problem formulation to accommodate multiple antennas and platforms
- Optimal placements found using stochastic algorithms