A Comparison of Antenna Placement Algorithms

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March 27, 2015

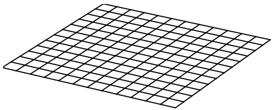
Outline of this talk

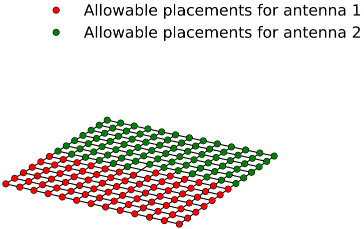
- Part 1: Introduction to the antenna placement problem
- Part 2: Description of stochastic algorithms, and formulation of an instance of antenna placment problem
- Part 3: Results of our experiments

Part 1: Introduction to the antenna placement problem

Antenna Placement Problem

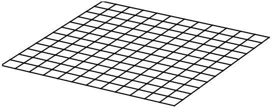
Given, platform $+$ allowable placements of antennas



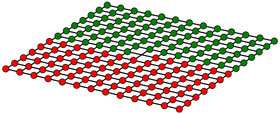


Antenna Placement Problem

Given, platform + allowable placements of antennas

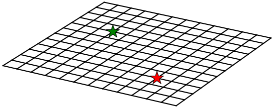


- Allowable placements for antenna 1
- Allowable placements for antenna 2



Problem: find best antenna placements

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



Antenna Placement Problem

Given:

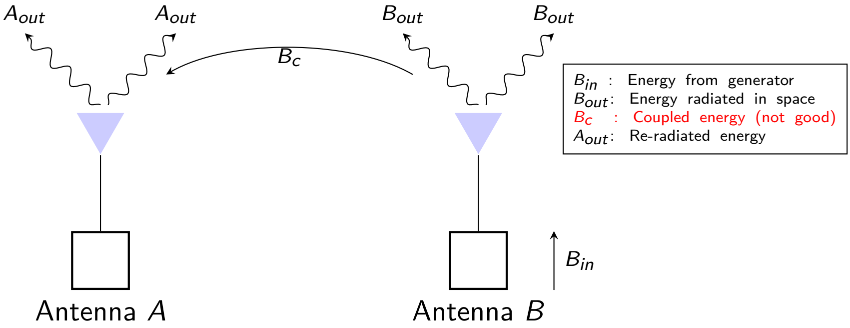
- platform P with its surface gridded such that end points represent possible antenna placements
- set of m $(m > 1)$ antennas $A = A_1, A_2, \ldots, A_m$
- for each A_i, let L_i denote the set of allowable placements $\in \mathbb{R}^3$ such that $\mid L_i \mid = n_i$ and $\forall i, n_i > 1$;
  $L_i = \{(x_1, y_1, z_1) \ldots (x_{n_i}, y_{n_i}, z_{n_i})\}$

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?

Mutual Coupling

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



Minimize Mutual Coupling

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

where

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

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

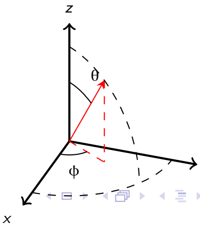
Minimize Difference in Radiation Pattern

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

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

where

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



Objective Function

Find a placement such that F is minimal:

$$F = \alpha F_{MC} + \beta F_{RP}, \tag{3}$$

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

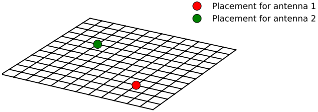
Stochastic Algorithms

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

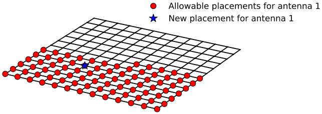
- Genetic Algorithm
- Evolutionary Strategy
- Simulated Annealing
- Hill Climbing

Stochastic Algorithms: Mutation Operator

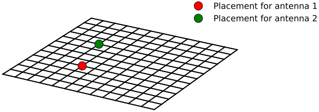
1. From individual, select an antenna uniformly at random, let's say antenna 1:



2. For antenna 1, select any other placement:

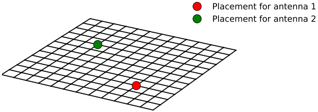


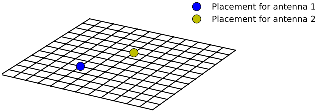
3. Change position for antenna 1 in individual:



Stochastic Algorithms: Crossover Operator

1. Select two individuals from population:

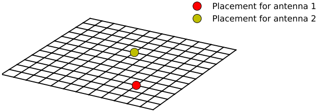


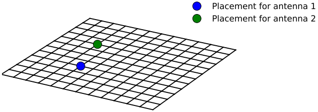


2. Select a crossover point, and swap placements prior to the point:

$$\begin{array}{lc|c} \text{ind}_1: & {\color{red}A_1} & {\color{darkgreen}A_2} \\ & \downarrow \quad \uparrow & \\ \text{ind}_2: & {\color{blue}A_1} & {\color{yellow}A_2} \end{array}$$

3. Two new offsprings created:





Genetic Algorithm

Algorithm 1: AP-GA

Initialize $P \leftarrow$ generate p random individuals. Compute the $fitness(h_i), i \in [1,p]$, and order P based on fitness;
$i = 0$;
while $i < gen_{max}$ **do**
  Elitism: Select n_e fittest individuals to add to P' ;
  for $(p - n_e)/2$ *times* **do**
    $M \leftarrow select(P, 2)$;
    if $rand(0,1) < p_c$ **then**
      Apply $crossover(M)$ to get two offsprings O ;
      Add O to P' ;
    else
      Add M to P' ;
  Uniformly select $p_m \cdot (p - n_e)$ individuals from P, and apply *mutate* operator to each ;
  Update $P \leftarrow P'$;
  Compute $fitness(h_i); i \in [1,p]$, and order P based on fitness ;
  Update $i \leftarrow i + 1$;

Evolutionary Strategy

Algorithm 2: ES

Initialize $P \leftarrow$ generate μ random individuals;
$i = 0$;
while $i < gen_{max}$ **do**
    Create λ/μ offsprings from each μ individuals by applying mutation operator, and add all offsprings to P ;
    Compute the $fitness(h_i), i = 1, \ldots, \lambda$;
    Keep μ best individuals in P, and discard remaining $\lambda - \mu$ individuals ;
    Update $i \leftarrow i + 1$

Simulated Annealing

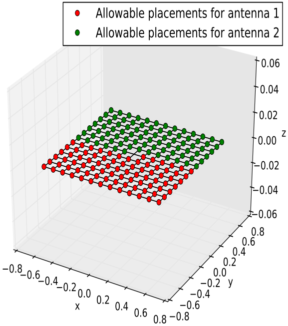
Algorithm 3: SA

```
Initialize C ← generate a random individual ;
i = 0 ;
while i < i_m do
    N ← mutate(C) ;
    if fitness(C) < fitness(N) then
        if rand(0,1) < e^{−δf/T} then
            C ← N
    else
        C ← I ;
    T ← T · f_cooling ;
    i ← i + 1 ;
```

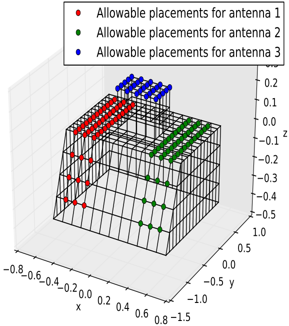
Experimental Setup

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

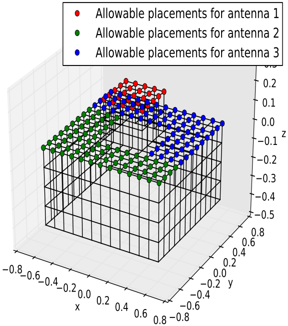


(a) Test Case 1 with 7056(83x83) allowable placements

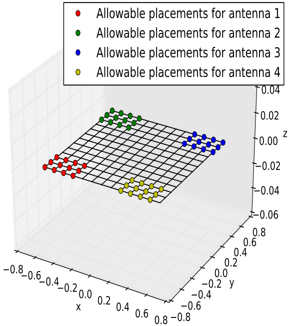


(b) Test Case 2 with 50625(45x45x45) allowable placements

Experiments: Test Cases

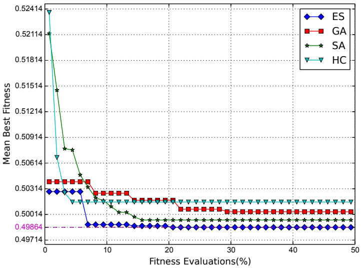


(a) Test Case 3 with 126025(71x71x25) allowable placements

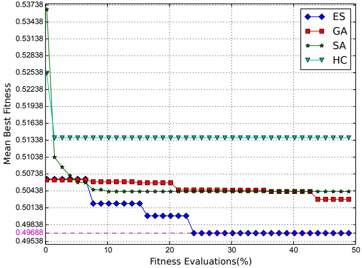


(b) Test Case 4 with 20736(12x12x12x12) allowable placements

Results

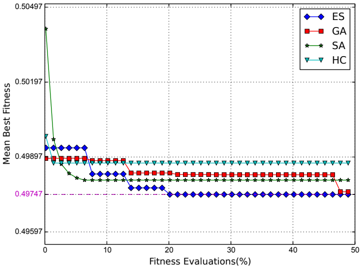


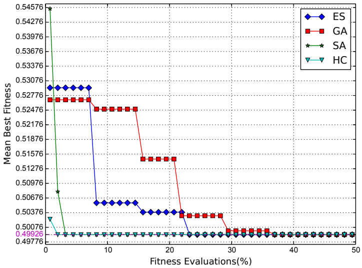
0.52414
0.52114
0.51814
0.51514
0.51214
0.50914
0.50614
0.50314
0.50014
0.49864
0.49714
Mean Best Fitness
0
10
20
30
40
50
Fitness Evaluations(%)
ES
GA
SA
HC



0.53738
0.53438
0.53138
0.52838
0.52538
0.52238
0.51938
0.51638
0.51338
0.51038
0.50738
0.50438
0.50138
0.49838
0.49688
0.49538
Mean Best Fitness
0
10
20
30
40
50
Fitness Evaluations(%)
ES
GA
SA
HC

Results


ES
GA
SA
HC
Mean Best Fitness
Fitness Evaluations(%)
0.50497
0.50197
0.49897
0.49747
0.49597
0
10
20
30
40
50


ES
GA
SA
HC
Mean Best Fitness
Fitness Evaluations(%)
0.54576
0.54276
0.53976
0.53676
0.53376
0.53076
0.52776
0.52476
0.52176
0.51876
0.51576
0.51276
0.50976
0.50676
0.50376
0.50076
0.49926
0.49776
0
10
20
30
40
50

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

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

Conclusion

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