A Comparison of Antenna Placement Algorithms

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March 24, 2015

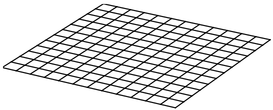
Outline of this talk

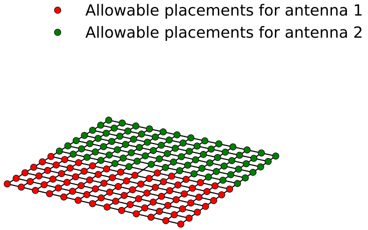
- Part 1: A quick introduction of the antenna placement problem
- Part 2: Description of stochastic algorithms, and formulation of an instance of antenna placment problem
- Part 3: Results of our experiments

Part 1: Introduction of the antenna placement problem

Antenna Placement Problem

Given, platform + allowable placements of antennas

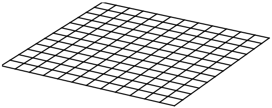


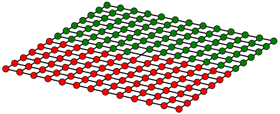


Antenna Placement Problem

Given, platform + allowable placements of antennas

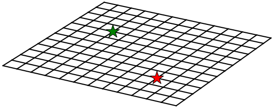
- Allowable placements for antenna 1
- Allowable placements for antenna 2





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

Problem: find best placements



Antenna Placement Problem

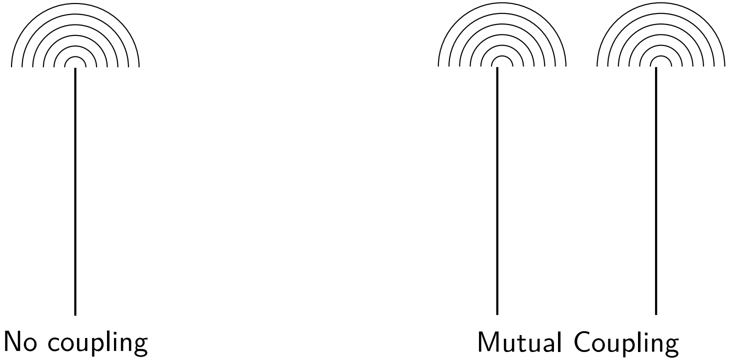
Given:

- platform P with its surface gridded such that end points represent possible antenna placement
- 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 locations $\in \mathbb{R}^3$ 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 locations on P

How is a good antenna placement defined?

Minimize energy absorbed by one antenna's receiver when another antenna operating nearby.



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 $F_{MC} = CP(A_1, A_2) + CP(A_1, A_3) + CP(A_2, A_3)$

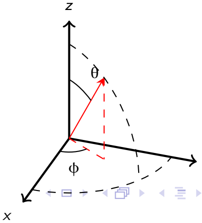
Minimize Difference in Radiation Pattern

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

Characteristics of EAs

- A set of solution candidates (or hypothesis) maintained
- Mating selection process is performed on the solution candidates
- Several solutions are combined to generate new candidate set solutions

Stochastic Algorithms

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

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

Evolutionary Strategy

Algorithm 1: AP-ES

```
Initialize P ← generate μ random hypothesis ;
gen_id = 0 ;
while gen_id < gen_max do
    Create λ/μ offsprings from each μ hypotheses by applying mutation operator, and
    add all offsprings to P ;
    Compute the fitness(h_i), i = 1,...,λ ;
    Keep μ best hypotheses in P, and discard remaining λ − μ hypotheses ;
    Update gen_id ← gen_id + 1
end
```

Simulated Annealing

Algorithm 2: AP-SA

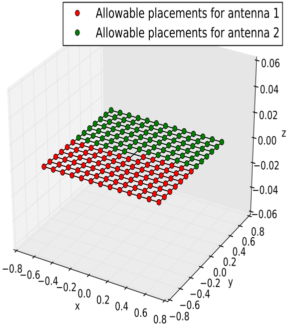
Initialize $H \leftarrow$ generate a random hypothesis ;
Compute $fitness(H)$;
$i = 0$;
while $i < i_m$ **do**
    Mutation - Apply the operation on H as stated in Algorithm . Call the pertubrated/mutated hypothesis C ;
    Compute $\delta f = fitness(C) - fitness(H)$;
    if $\delta f > 0$ **then**
        Generate a random number ϵ using a uniform distribution over $[0, 1]$;
        if $\epsilon < e^{-\delta f / T}$ **then**
            $H \leftarrow C$
        end
    else
        $H \leftarrow C$;
    end
    $T \leftarrow T \cdot f_{cooling}$;
    $i \leftarrow i + 1$;
end

Experimental Setup

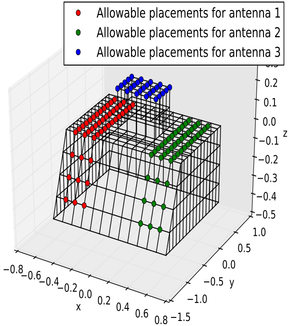
1. Create (s) such that each individual is defined by a placement for each of the *m* antennas
2. Run all individuals through *NEC* simulator [1] to get fitness parameters
3. Apply EA operators
4. Repeat till either global minimum is reached or 50% evaluations of search space

[1] http://www.nec2.org

Experiments: Test Cases

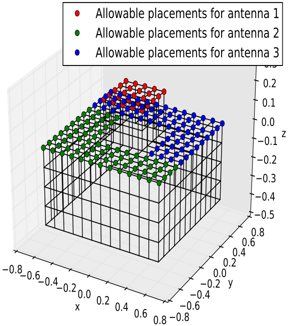


(a) Test Case 1 with 7056(83x83) allowable placements

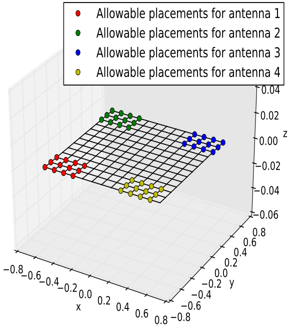


(b) Test Case 2 with 50625(45x45x45) allowable placements

Experiments: Test Cases

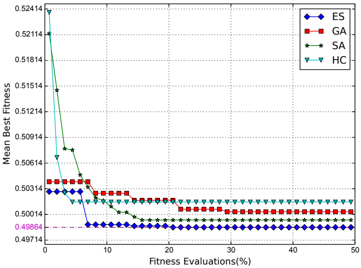


(a) Test Case 3 with 126025(71x71x25) allowable placements

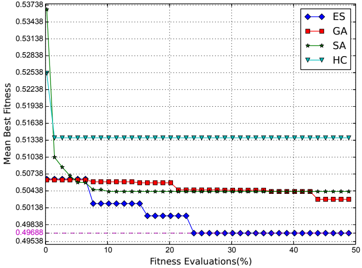


(b) Test Case 4 with 20736(12x12x12x12) allowable placements

Results

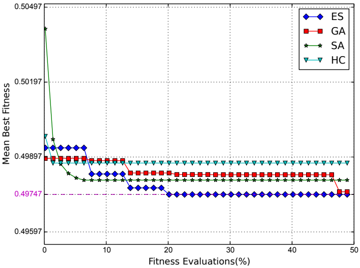


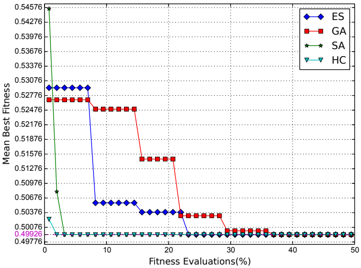
0.52414
0.52114
0.51814
0.51514
0.51214
0.50914
0.50614
0.50314
0.50014
0.49864
0.49714
Mean Best Fitness
0
10
20
30
40
50
Fitness Evaluations(%)
ES
GA
SA
HC



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