A Comparison of Antenna Placement Algorithms

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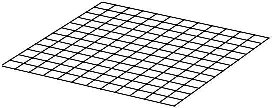
Outline of this talk

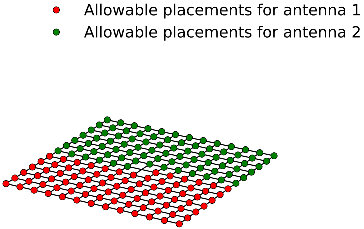
- Part 1: Introduction of the antenna placement problem
- Part 2: Description of stochastic algorithms, and formulation of an instance of antenna placment problem
- Part 3: Results of our experiments

Part 1: Introduction of the antenna placement problem

Antenna Placement Problem

Given, platform + allowable placements of antennas





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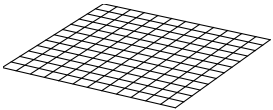
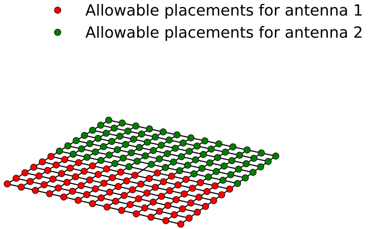
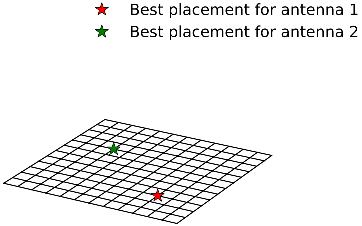




Problem: find best placements



Antenna Placement Problem

Given:

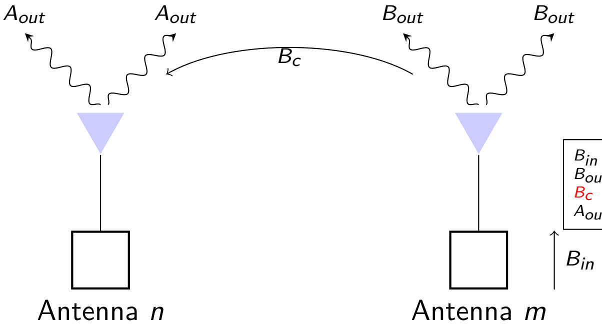
- platform P with its surface gridded such that end points represent possible antenna placement
- set of m $(m > 1)$ antennas $A = A_1, A_2, \ldots, A_m$
- for each A_i, let L_i denote the set of allowable placements locations $\in \mathbb{R}^3$ such that $|L_i| = n_i$ and $\forall i, n_i > 1$; $L_i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

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

Question: How is a good placement antenna placement quantified in 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.



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

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

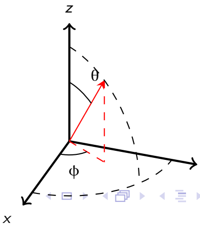
Minimize Difference in Radiation Pattern

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



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 $P \leftarrow$ 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 $fitness(h_i), i = 1, \ldots, \lambda$;

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

  Update $gen_{id} \leftarrow gen_{id} + 1$

end

Simulated Annealing

Algorithm 2: AP-SA

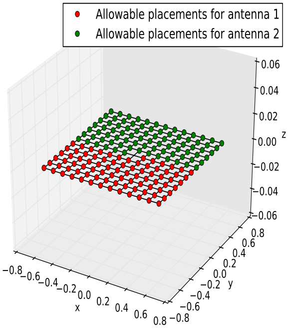
Initialize $H \leftarrow$ generate a random hypothesis ;
Compute *fitness*(H) ;
$i = 0$;
while $i < i_m$ **do**
    Mutation - Apply the operation on H as stated in Algorithm . Call the pertubrated/mutated hypothesis C ;
    Compute $\delta f = fitness(C) - fitness(H)$;
    if $\delta f > 0$ **then**
        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

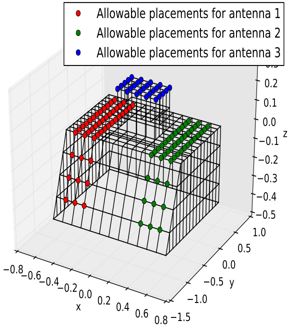
1. Create (s) such that each individual is defined by a placement for each of the *m* antennas
2. Run all individuals through *NEC* simulator [1] to get fitness parameters
3. Apply EA operators
4. Repeat till either global minimum is reached or 50% evaluations of search space

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

Experiments: Test Cases

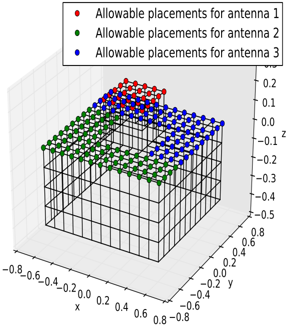


(a) Test Case 1 with 7056(83x83) allowable placements

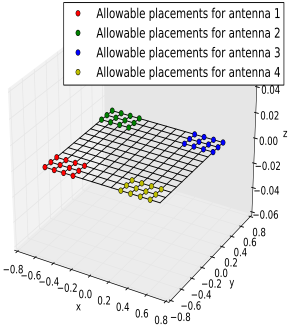


(b) Test Case 2 with 50625(45x45x45) allowable placements

Experiments: Test Cases

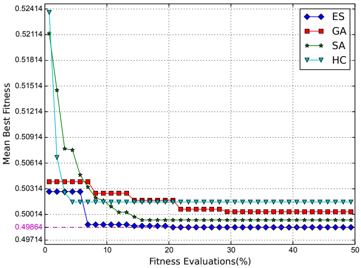


(a) Test Case 3 with 126025(71x71x25) allowable placements

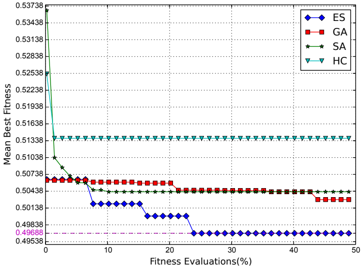


(b) Test Case 4 with 20736(12x12x12x12) allowable placements

Results

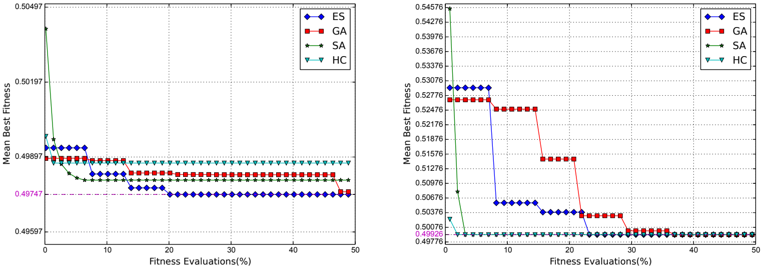


0.52414
0.52114
0.51814
0.51514
0.51214
0.50914
0.50614
0.50314
0.50014
0.49864
0.49714
Mean Best Fitness
0
10
20
30
40
50
Fitness Evaluations(%)
ES
GA
SA
HC



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


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