A Comparison of Antenna Placement Algorithms

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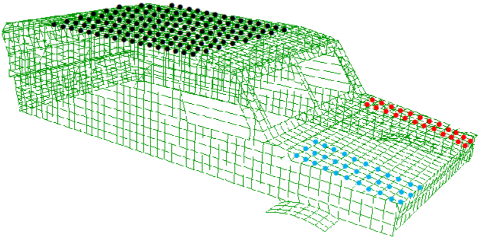
How can we automate the process by use of stochastic algorithms?

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

Antenna Placement Example



- A_1 has 24 possible antenna placements
- A_2 has 33 possible antenna placements
- A_3 has 136 possible antenna placements

Size of search space $= m^n$, where m is the number of allowable placements for one antenna, and n is the number of antennas.

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Goal: Find a set of n antenna locations on P

Stochastic Algorithms

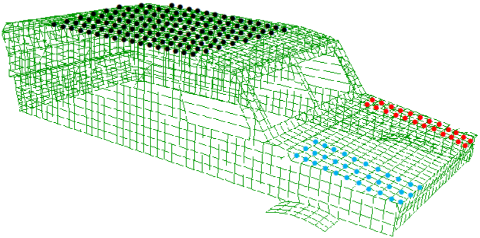
We will consider algorithms which rely on *randomization* principle.

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

Characterstics of Stochastic Algorithms

- 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 solutions

Representation



A hypothesis is represented by a set of antenna placements. For instance - $((x_i, y_i, z_i), (x_j, y_j, z_j), (x_k, y_k, z_k))$

Evolutionary Strategy

Algorithm 1: AP-ES

Data: Set of placements $L = \{L_1, \cdots, L_m\}$; μ; λ; gen_{max} - maximum number of generations

Result: H^* from P

```
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

Data: Set of placements $L = \{L_1, \cdots, L_m\}$; T - initial temperature; i_m - maximum iterations; $f_{cooling}$ - cooling factor

Result: H^* from P

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

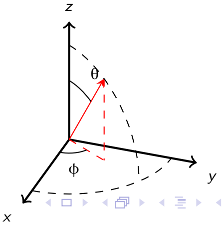
Minimize Difference in Radiation Pattern

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

$$F_{RP}(A_i) = \sum_{\theta} \sum_{\phi} \| FSG_i(\theta,\phi) - ISG_i(\theta,\phi) \|^2, \qquad (1)$$

where

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



Minimize Coupling

Coupling is the absorption of radiated energy by nearby antennas

$$F_{MC} = \sum_{i=1}^{m-1} \sum_{j=i+1}^{m} CP(A_i, A_j), \tag{2}$$

where

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

Overall Fitness Function

For an hypothesis, fitness is defined as:

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

where $\alpha + \beta = 1$

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

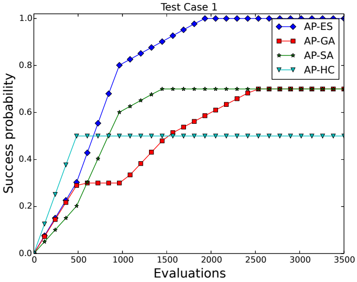
[1] http://www.nec2.org

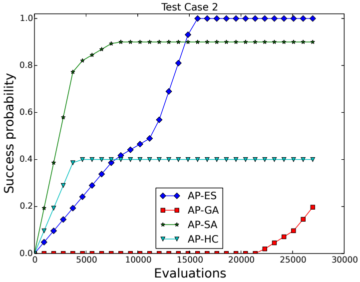
Experiments: Test Cases

Test Case	Antennas	Total allowable placements
1	2	7,056 (83x83)
2	3	50,625 (45x45x25)
3	3	126,025 (71x71x25)
4	4	20,736 (12x12x12x12)

*Allowable placements for each antenna are provided within parenthesis

Results - Success Probability





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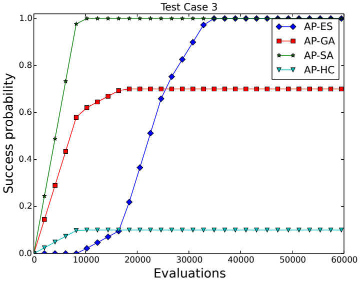

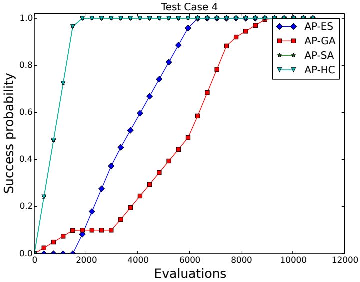

Equivalence of fitness to efficiency

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