A Genetic Algorithm for Beam Placement in High-Throughput Satellite Constellations

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Motivation

While manual resource allocation techniques could be used for previous communications satellites, the new generation requires automatic and optimized processes to dynamically allocate resources in real-time.
The beam placement problem

Problem definition

The beam placement problem consists of dividing a set of users into a collection of sub-sets that satisfies the spatiotemporal constraints, while minimizing the usage of resources.

Current challenges:

- Enumerating all options has an exponential cost
- Current techniques use traditional methods (k-means, linearizations, etc) for low number of beams (<500)
- Methods for higher number of beams (>500) rely on heuristic approaches
The beam placement problem

**Dual Objective**

- **Maximize number of beams**
  - Less pointing loss
  - Less loaded beams

- **Minimize frequency consumed**
  - Less frequency usage

- This formulation has **two seemingly opposite objectives**, but we want to obtain the set of solutions with the **best trade-offs**

- This formulation is **NP-hard**
The Genetic Algorithm approach

Genetic Algorithms (GA) are a subclass of Evolutionary Algorithms (EA), which are based on population evolution to obtain iteratively better and better solutions [1]

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Mutation

- Create Beam

- Absorb Beam

- Destroy Beam

Results: Convergence

- Constellation: O3b mPower (10 MEO satellites)
- Users: Tens of thousands of users across the world
- Results significantly improve going from 5 to 10 generations
- Results improve slightly when going from 10 to 50
- Results almost do not improve from 50 to 100

GA is an efficient technique to explore the solution space without evaluating all the options

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generations</td>
<td>50</td>
</tr>
<tr>
<td>Population size</td>
<td>50</td>
</tr>
<tr>
<td>Crossing probability</td>
<td>80%</td>
</tr>
<tr>
<td>Genes crossed</td>
<td>10%</td>
</tr>
<tr>
<td>Mutation probability</td>
<td>20%</td>
</tr>
<tr>
<td>Mutated genes</td>
<td>5%</td>
</tr>
<tr>
<td>Absorb probability ($p_{abs}$)</td>
<td>25%</td>
</tr>
<tr>
<td>Direction probability ($p_{dir}$)</td>
<td>50%</td>
</tr>
</tbody>
</table>

GA parameters
Results: Baseline comparison

We want to assess how the metrics developed in this work impact the global resource allocation problem by using published algorithms for the other subproblems.

Independently on the algorithms used, we show a reduction in both Power and Unmet Demand compared to previously published heuristics.
Conclusions

- The **beam placement problem** as formulated in this work is **NP-hard**. Thus, traditional optimization techniques tend to perform poorly.

- The **Genetic Algorithm** presented achieves a **high convergence factor**, being able to find a near-optimal Pareto-Front in around **50 generations** with only **50 individuals** (~20 min in a single-core standard computer).

- The **problem-specific metrics** developed in this paper represent a **trade-off** between **power** and **Unmet Demand**. Solutions with higher number of beams and higher number of frequency slots tend to have more UD and use less power, and vice-versa.

- Compared to previous heuristic methods, the approach presented in this work **highly reduces** the **UD** and **power usage** of the **complete resource allocation** for high number of beams (>

900). When using a Heuristic and Random frequency assignment algorithms, UD is reduced by 100% and 50%, respectively, while power is reduced by 40% and 20%.
Thank you!

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