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

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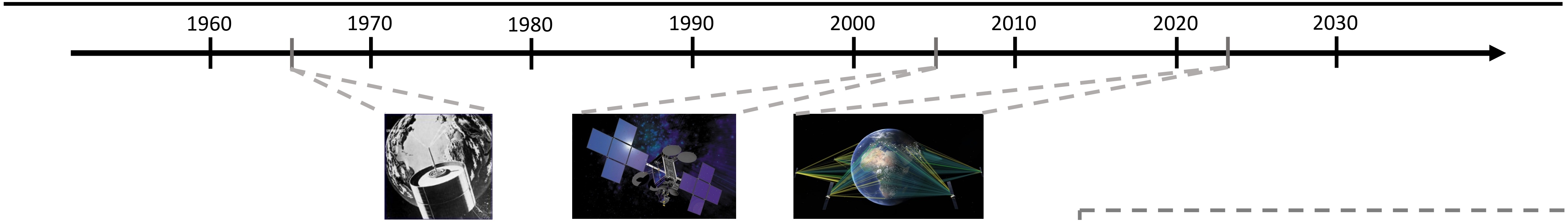
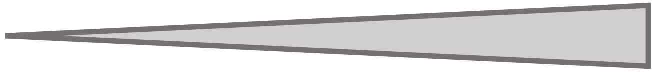
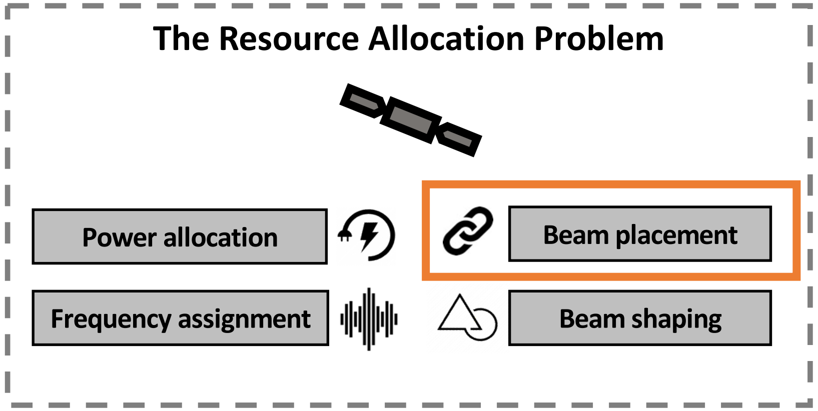
Motivation



	Early Bird	Thaicom 4	O3b mPower
Number of beams	1	~100	>1000 (per satellite)
Power Allocation	Prefixed	Dynamic	Dynamic
Frequency Reuse	None	Low	High
Beam Allocation	Prefixed	Prefixed	Dynamic



Flexibility & Complexity

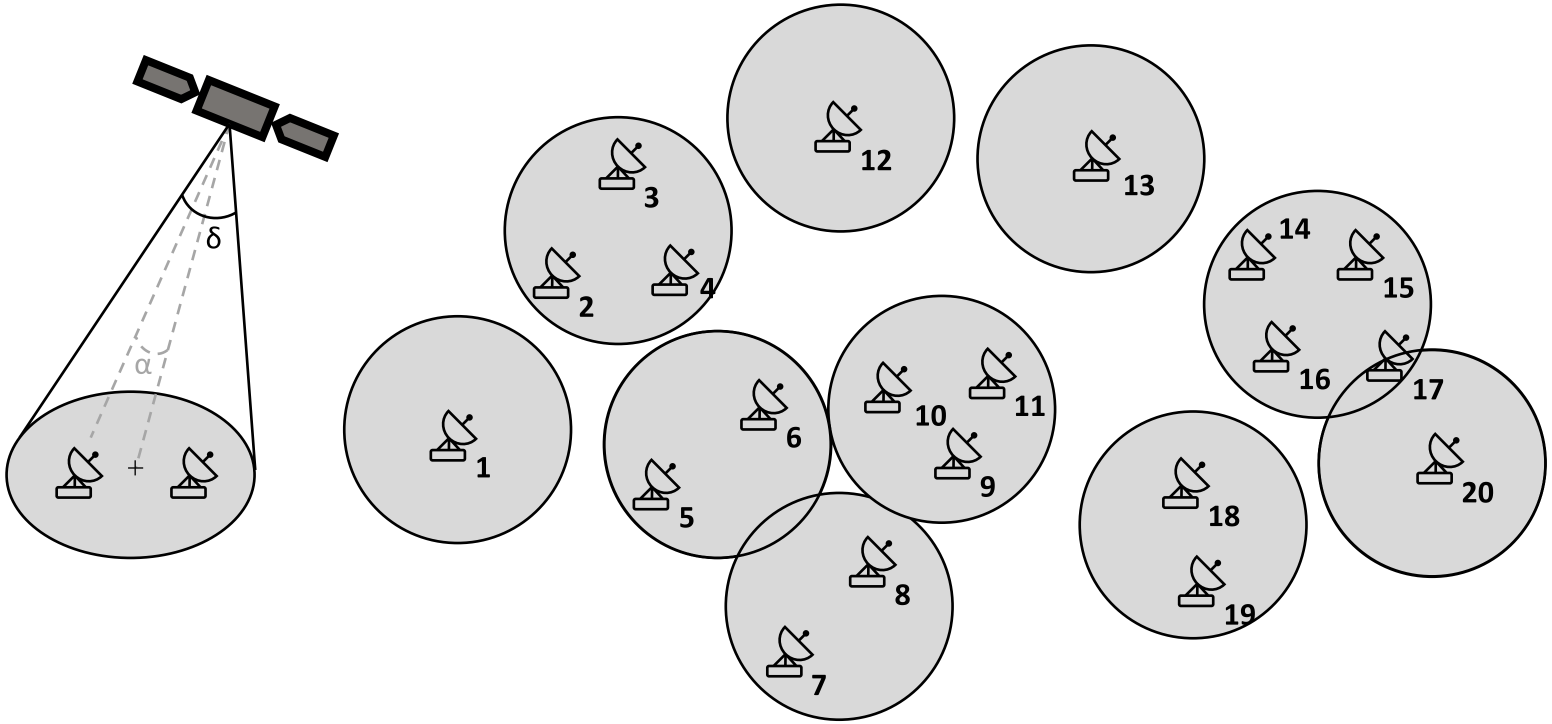


While **manual resource allocation** techniques could be used for previous communications satellites, the **new generation** requires **automatic** and **optimized** processes to **dynamically allocate** resources in real-time

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:

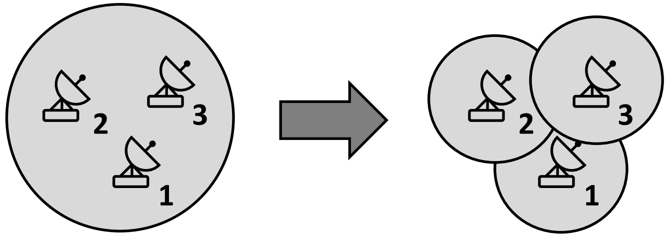
- Enumerating all options has an **exponential** cost
- Current techniques use **traditional methods** (k-means, linearizations, etc) for low number of beams (<500)
- Methods for higher number of beams (>500) rely on **heuristic approaches**

The beam placement problem

Dual Objective

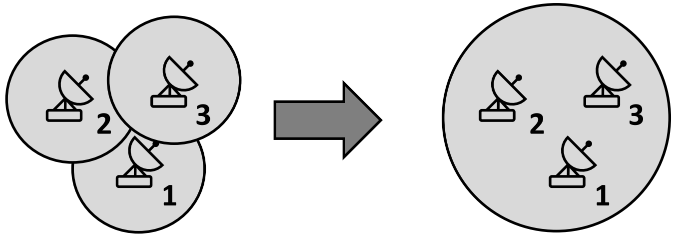
Maximize number of beams

- Less pointing loss
- Less loaded beams



Minimize frequency consumed

- Less frequency usage

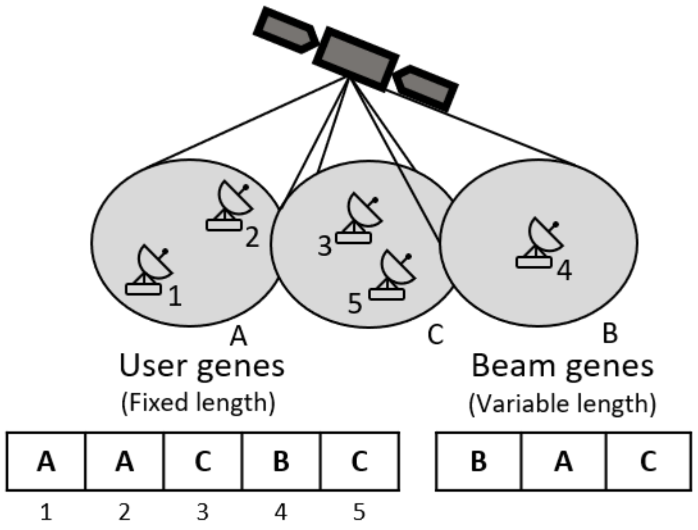


- This formulation has **two seemingly opposite objectives**, but we want to obtain the set of solutions with the **best trade-offs**
- This formulation is **NP-hard**

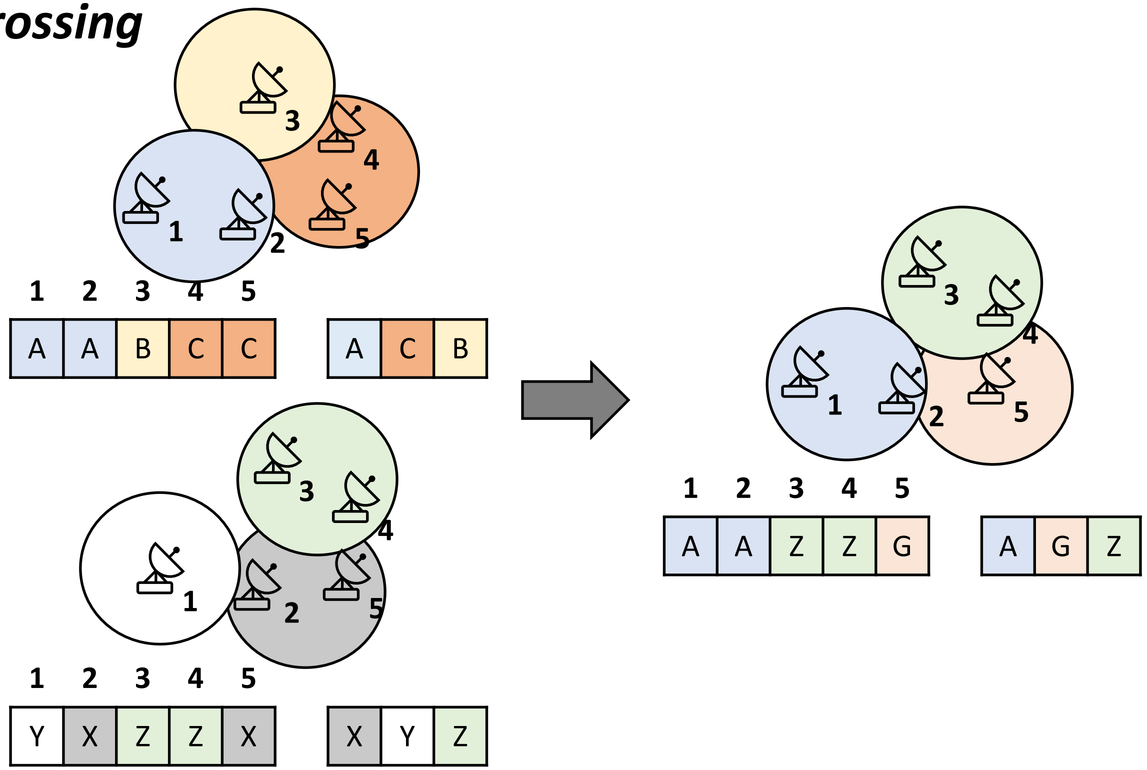
The Genetic Algorithm approach

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

Individual definition



Crossing



[1] M. Mitchell, An introduction to genetic algorithms. The MIT Press, 1996.

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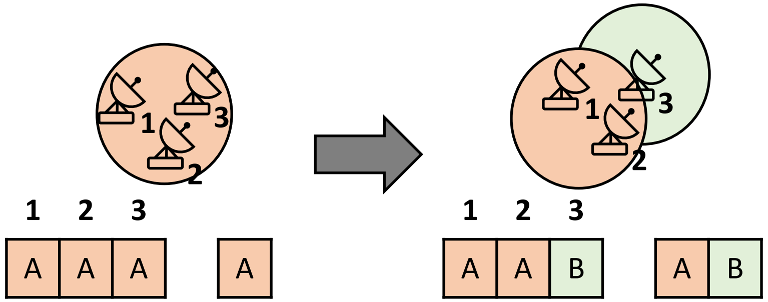
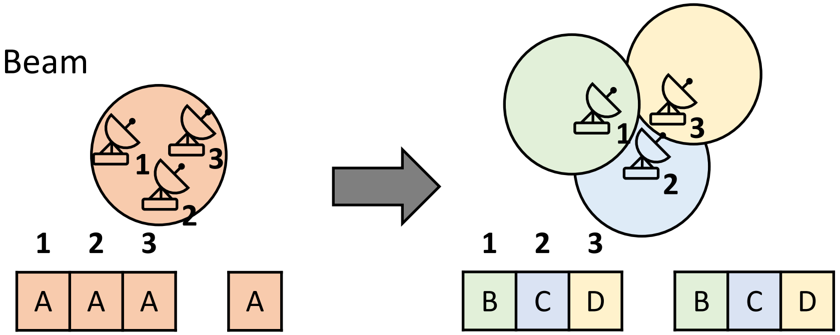
Mutation

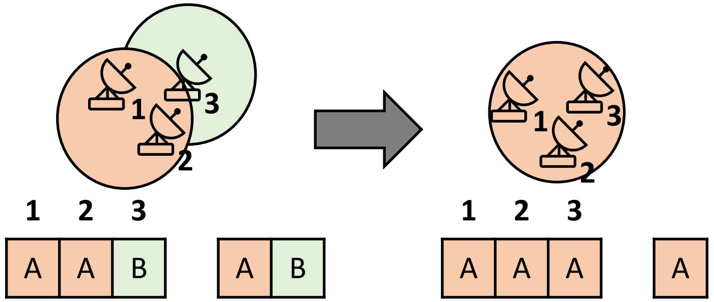
- Create Beam



- Destroy Beam

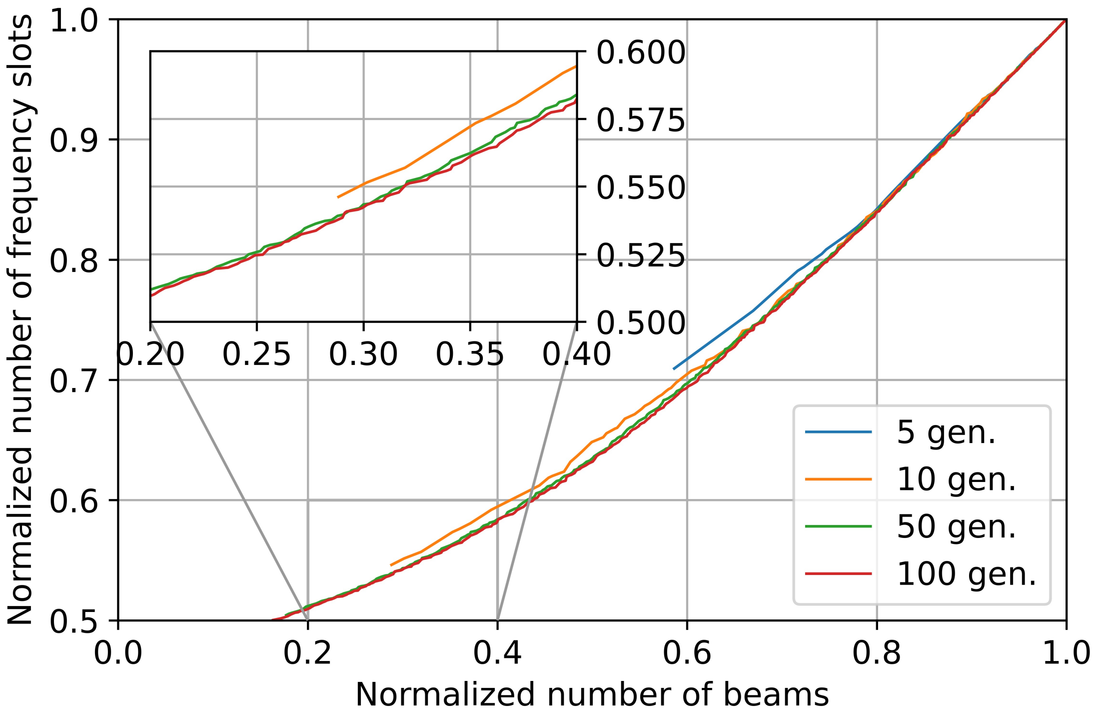


- Absorb Beam



[1] M. Mitchell, An introduction to genetic algorithms. The MIT Press, 1996.

Results: Convergence



- Constellation: O3b mPower (10 MEO satellites)
- Users: Tens of thousands of users across the world

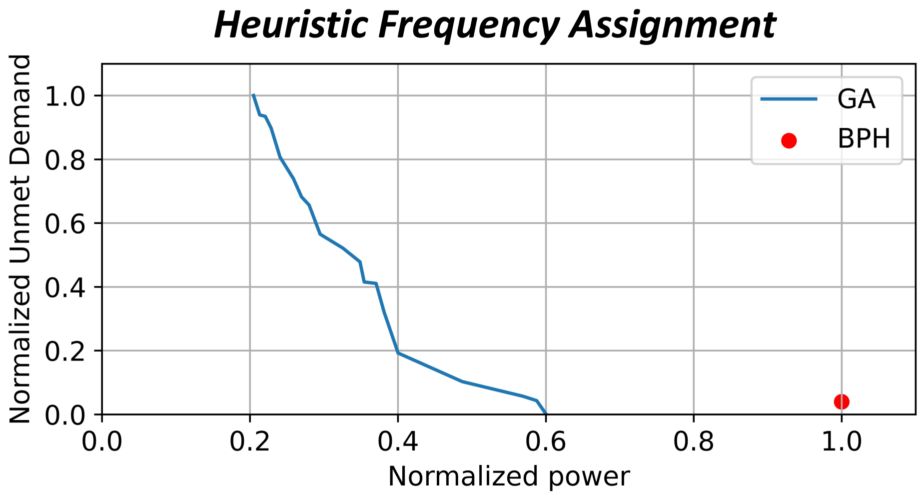
- Results significantly improve going from 5 to 10 generations
- Results improve slightly when going from 10 to 50
- Results almost do not improve from 50 to 100

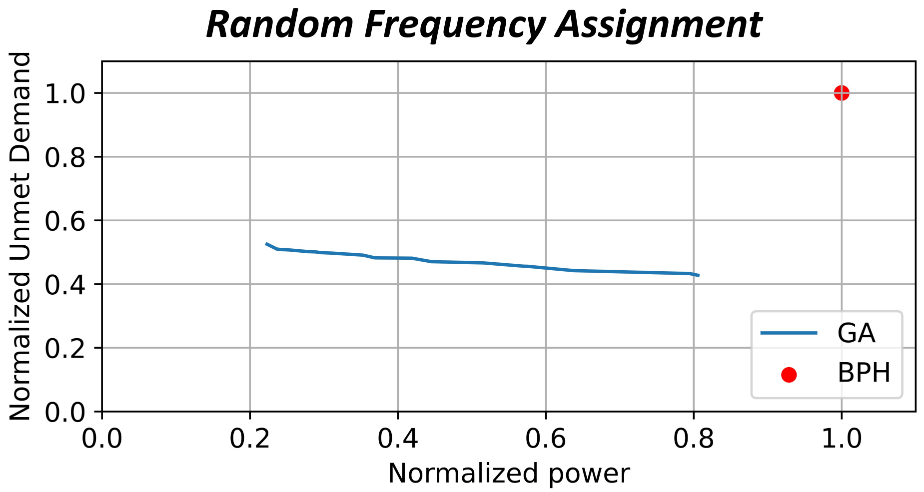
➡ **GA** is an **efficient technique** to explore the **solution space** without evaluating all the options

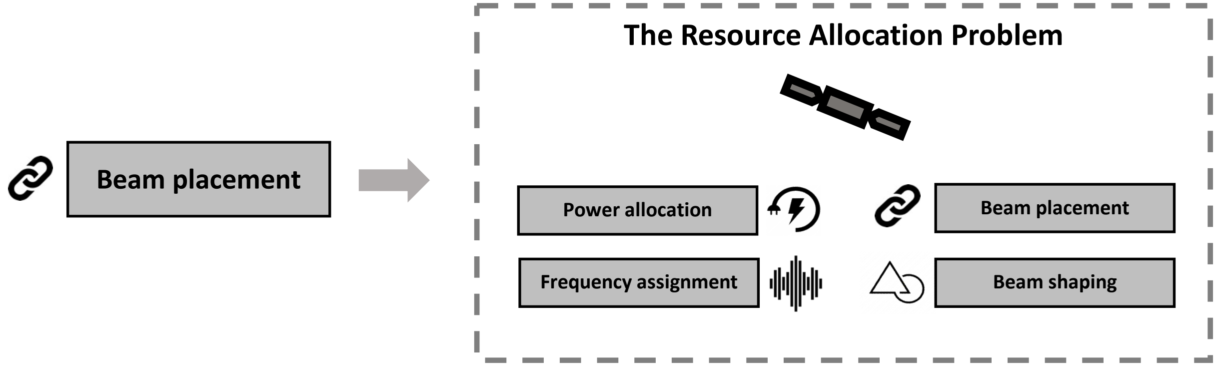
Parameter	Value
Generations	50
Population size	50
Crossing probability	80%
Genes crossed	10%
Mutation probability	20%
Mutated genes	5%
Absorb probability (p_{abs})	25%
Direction probability (p_{dir})	50%

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

GA: Genetic Algorithm
BPH: Beam Placement Heuristic

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 (>500). 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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