Pasqal Defining the quantum reality

Journée Pack Quantique

Projet AQUAPS

Mission planning for satellites

Quantum computing for earth observation

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esa European Space Agency

Mission Planning for a constellation of satellites

Problem Introduction

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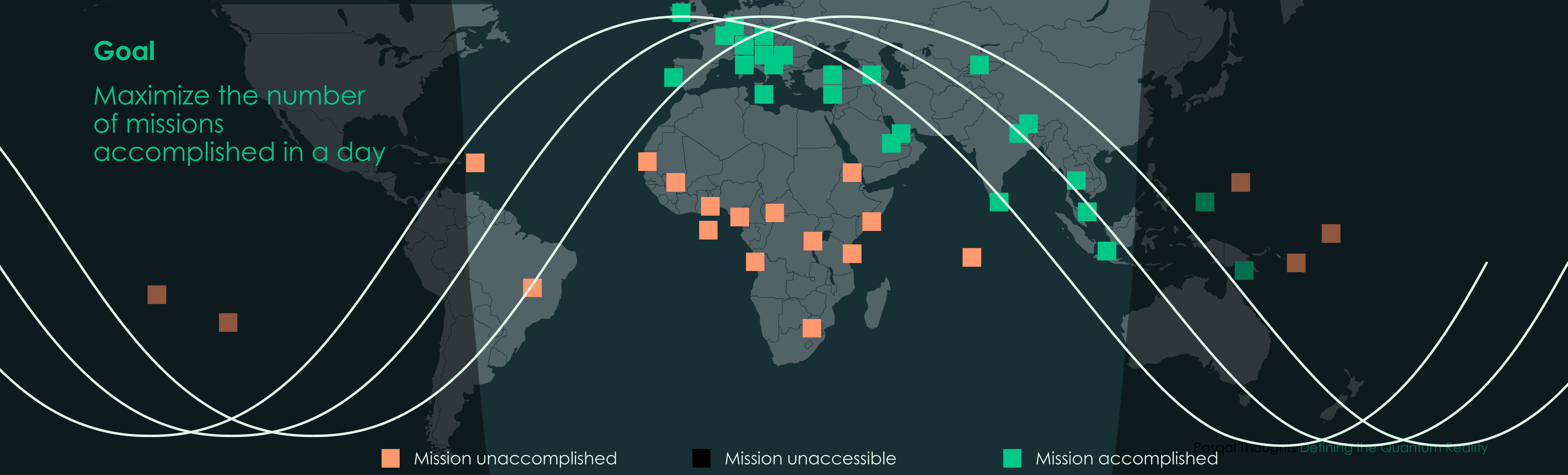
A constellation of satellites with defined trajectories

A set of missions to execute: pictures of specific cities to be taken

Goal

Maximize the number of missions accomplished in a day



Problem Constrains

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Optical satellite can only operate at day-time

Avoiding cloud coverage

Recharge batteries by orienting satellites panels towards sun

Dump observation data to ground stations (limited memory)

Maintain high resolution image

Limited speed to avoid vibration

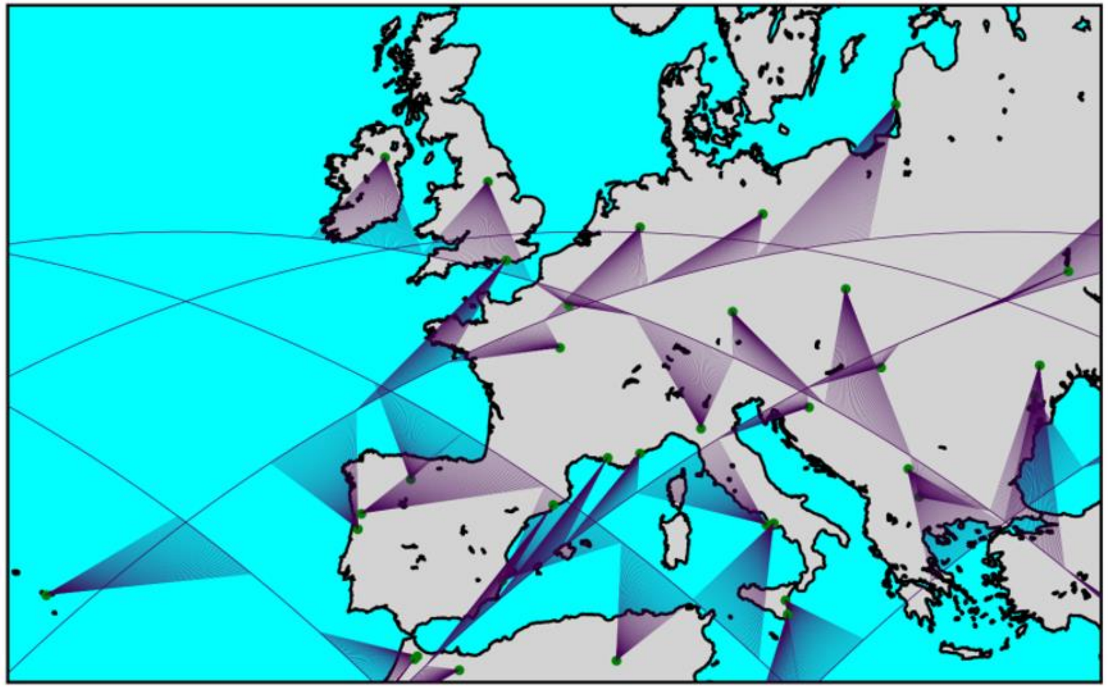
Favor missions with high priority

Flexibility: change mission plan during day

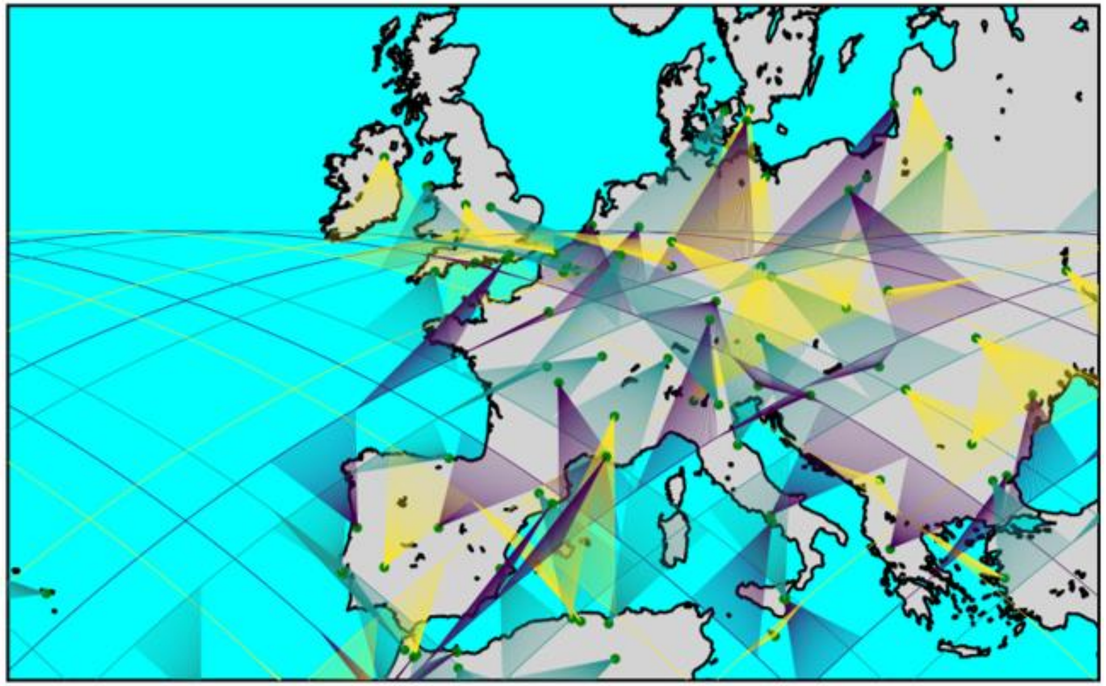
Extending the problem to multiple satellites requires better performing solutions

Results

1 satellite



3 satellites



We combined different approaches to a methodology that can benefit from the use of PASQAL QPUs

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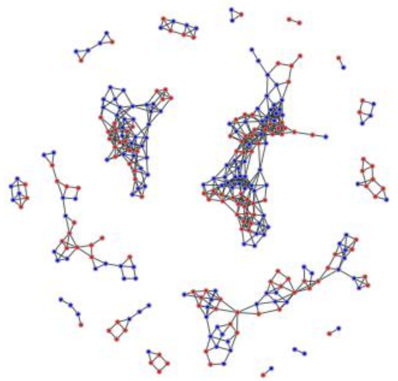
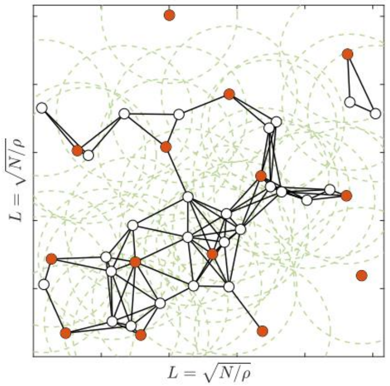


A maximum independent set method for scheduling earth observing satellite constellations, 2021, D. Eddy et al.



Quantum optimization of maximum independent set using rydberg atom arrays, 2022, S. Ebadi et al.

Our quantum solution is based on the application of the MIS problem in a graph encoding the problem of relevance

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MIS Approach

Encoding the problem in a Graph Structure

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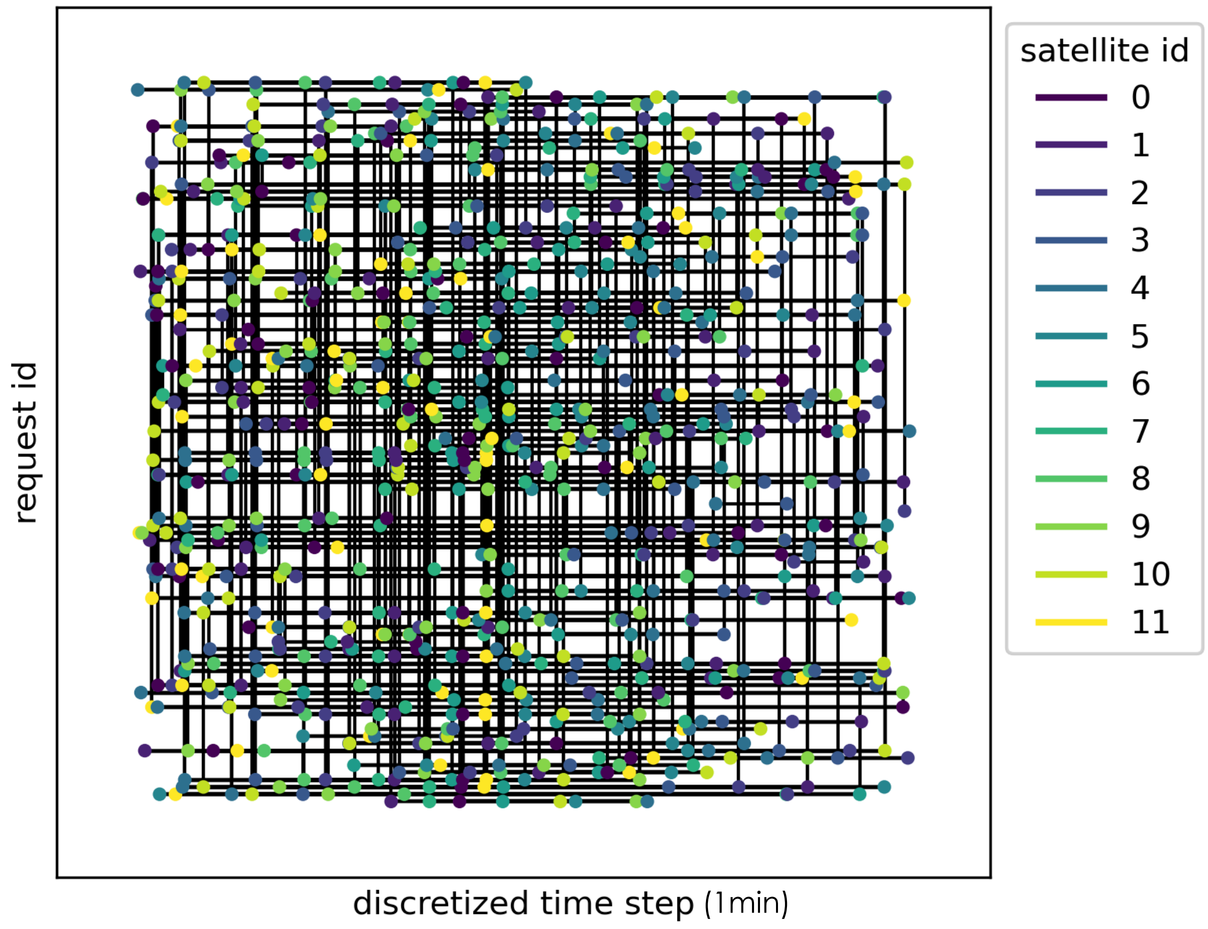
Graph Construction

- Nodes are equivalent to mission slots
- Colors represent unique satellites of the constellation
- Edges are equivalent to incompatibilities of constrains
    1. Only one request per satellite slot
    2. No overlapping time slots per satellite

400 nodes

Visiting capitals with 12 shifted ISS



Acquiring Solutions within the Encoded Graph

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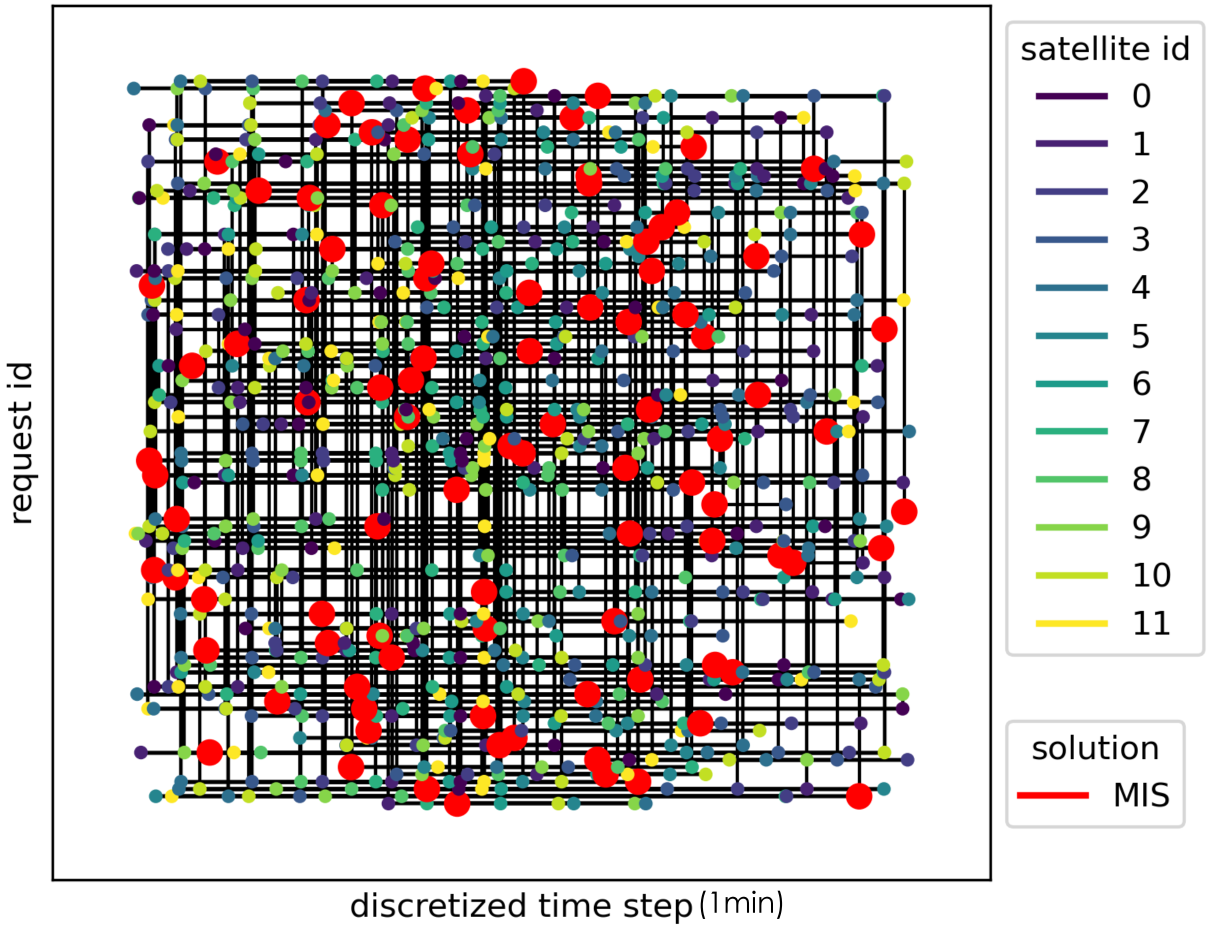
Optimization

Choice of data take opportunities

Classical Reference

MIS approximation algorithm

Visiting capitals with 12 shifted ISS



Solving the MIS on PASQAL QPUs

Maximum Independent Set (MIS) is a well-suited problem for Rydberg atoms

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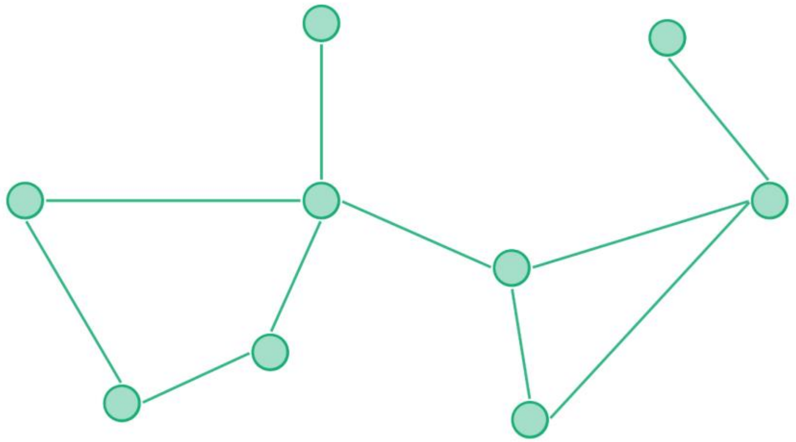
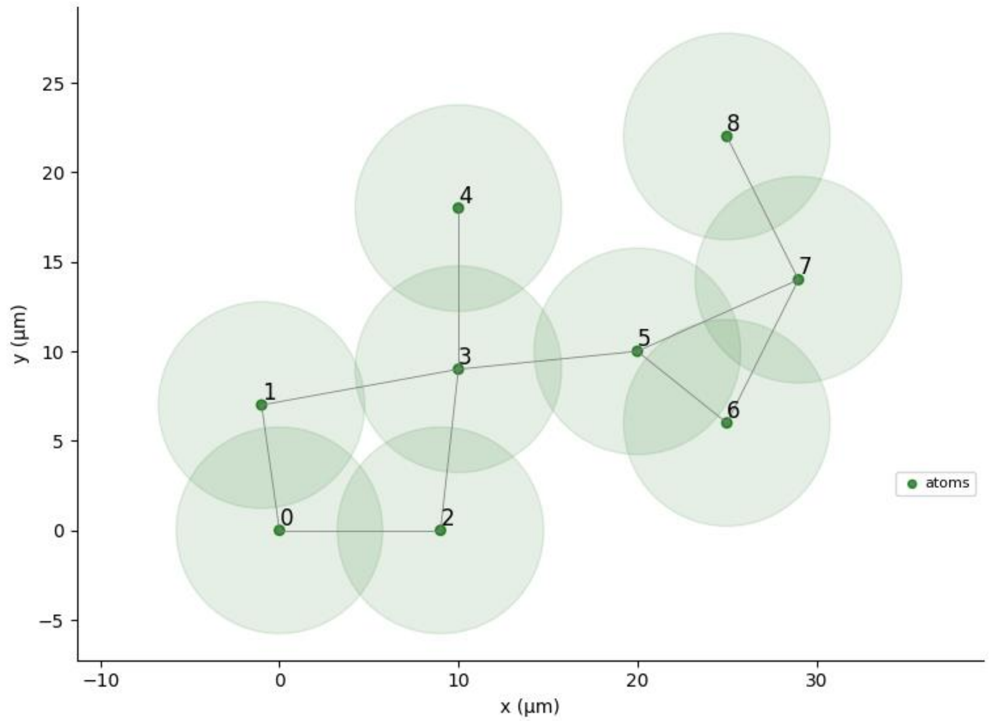
Flexible atoms positions allow us to easily tackle graph problems by directly encoding the graph with the positions of the atoms and the distances between them.





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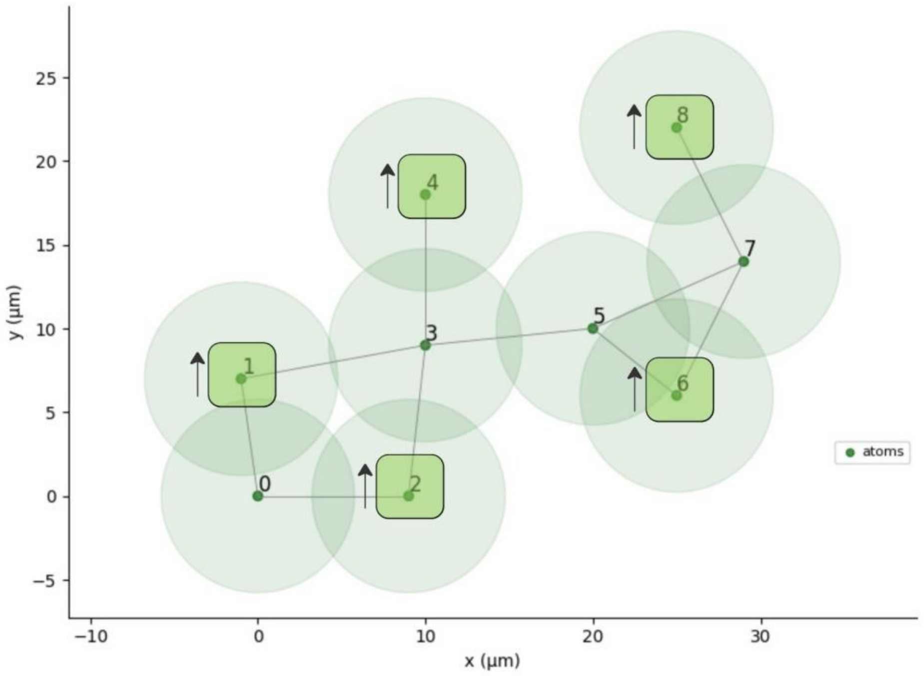
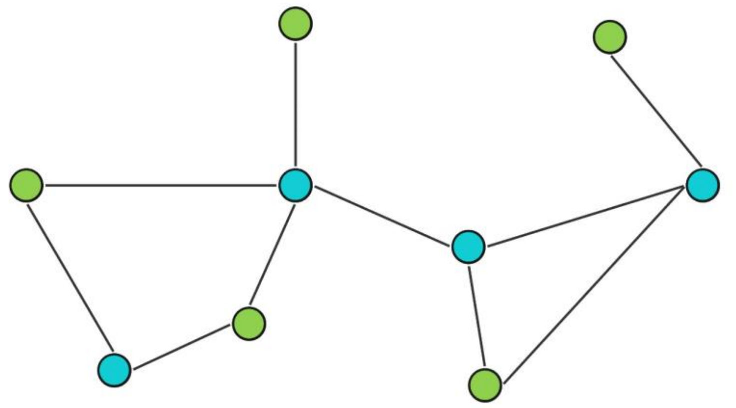
Rydberg dynamics can be leveraged to naturally encode the constraints and solution to the MIS problem for unit-disk graphs.

$$H/\hbar = \sum_i \frac{\Omega(t)}{2}\left(e^{i\varphi(t)}|g\rangle_i\langle r|_i + \text{h.c.}\right) - \Delta_i(t)\, n_i + \sum_{i<j} \frac{C_6}{r_{ij}^6} n_i n_j$$

Driving **Constraints** **Geometry**





Mission Planning for Satellites on Pasqal QPUs

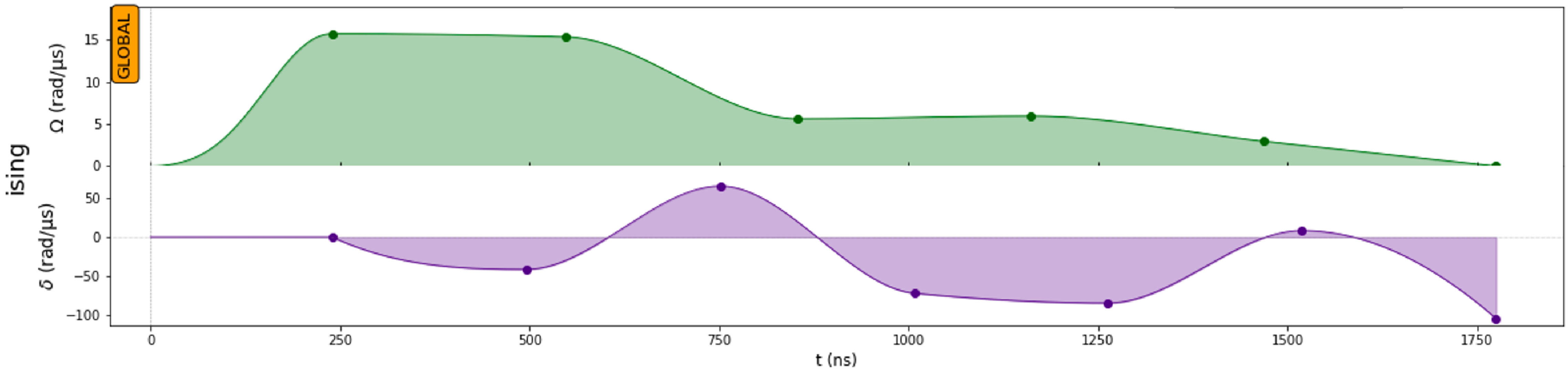
Pasqal Thoughts Defining the Quantum Reality

Solving the MIS on PASQAL QPUs

Maximum Independent Set (MIS) is a well-suited problem for Rydberg atoms

Devices operate in the analog mode

Using the natural dynamics of a system is more efficient and resilient to noise.



Encoding the problem in a Graph Structure

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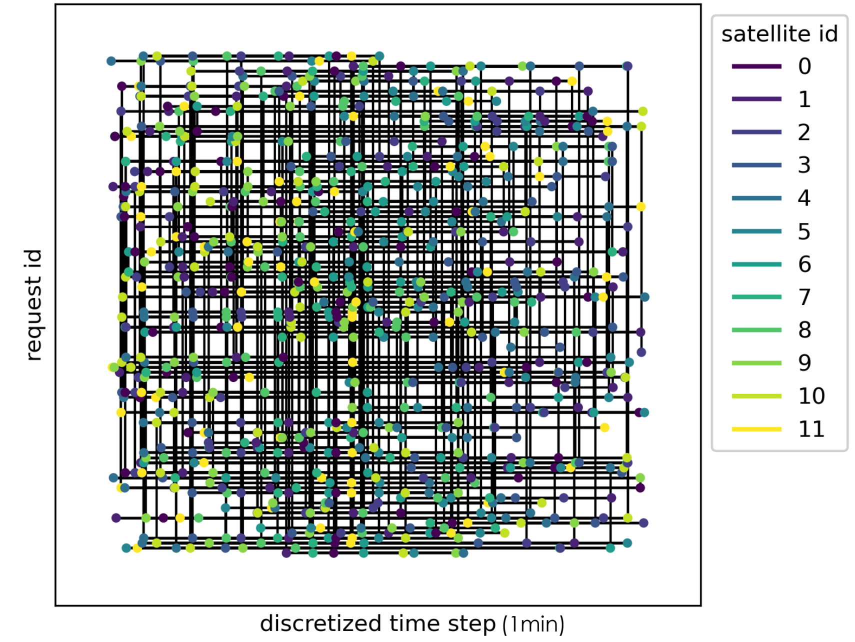
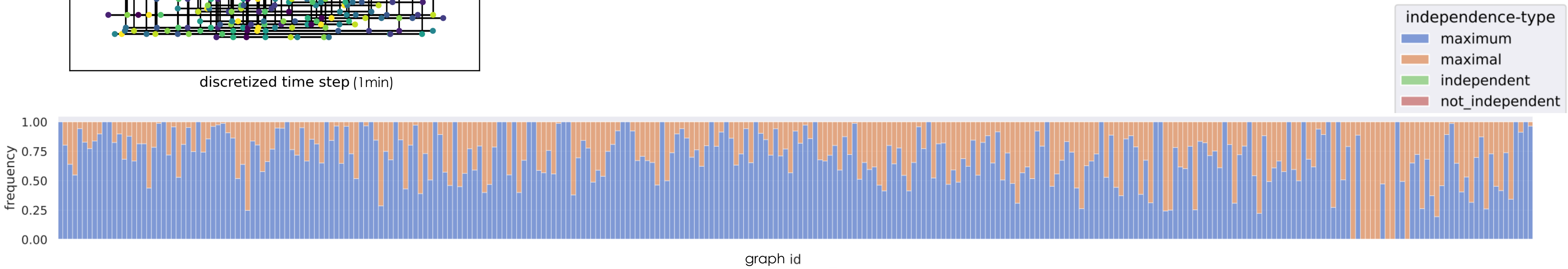


300 graphs of up to 25 nodes



Adiabatic state preparation of MIS configurations

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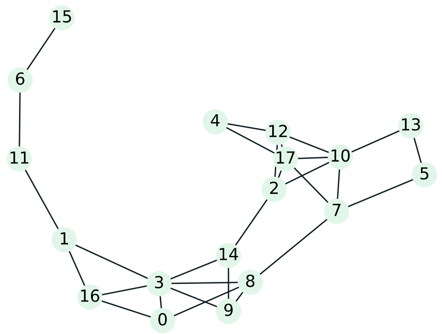
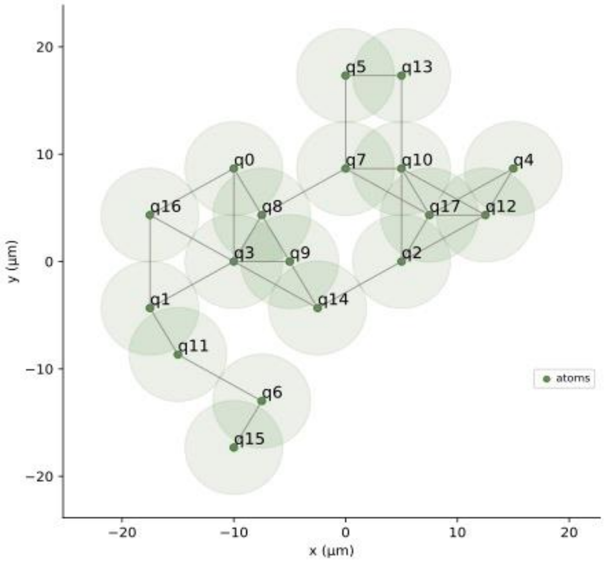
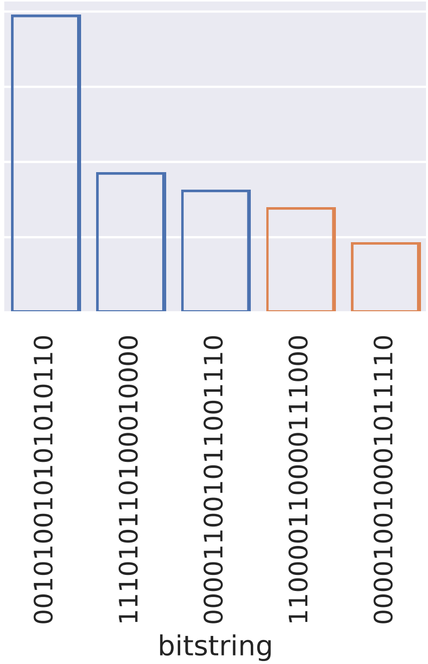
Original Graph



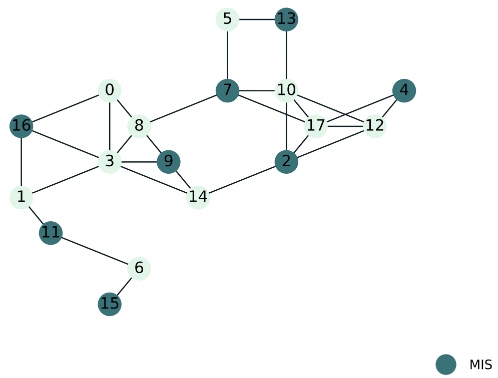
Embedding State preparation



Result Distribution



Maximum Independent Set



Perspectives

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A quantum solution to a real-world industrial problem running on a QPU today.
Thales is preparing the next steps to scale up the operational use of this method