Railway Schedule Optimization using Gate Based Quantum Computers

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Abstract

Delays in rail networks necessitate the real-time rescheduling of train timetables to minimize disruption.
We introduce a novel approach for schedule optimization after an initial delay on gate-based quantum computers. We build on the foundational quantum annealing model by Gardas et al. [1]. Unlike current practices, where dispatchers manually select a schedule based on heuristics and empirical knowledge, our approach aims to automate and improve the re-planning process. Re-planning in real time reduces reliance on trained operators and ensures more optimal solutions.
For this task, we set up a Quadratic Unconstrained Binary Optimization (QUBO) model and solve it using the Quantum Approximate Optimization Algorithm (QAOA). To address hardware limitations, circuit knitting was also investigated to reduce the size of the QAOA circuit. This will enable execution of the model on systems with fewer qubits. Although our method so far offers only a trade-off between run time and accuracy, it represents an important step toward scaling quantum solutions.
We perform experiments on artificial data sets and a simplified model of the Munich rail system (Figure 1). The results demonstrated that gate-based quantum computers can effectively solve small-scale scheduling problems, although the approach faces limitations due to the number of usable qubits and the accuracy.
Future advancements in quantum hardware and software, including circuit knitting techniques and enhanced support in Qiskit [2], will expand the applicability of our method, making its use possible in real-world train timetable optimization.

References

[1] Domino, Krzysztof and Koniorczyk, Mátyás and Krawiec, Krzysztof and Jałowiecki, Konrad and Gardas, Bartłomiej; Quantum computing approach to railway dispatching and conflict management optimization on single-track railway lines; arXiv preprint arXiv:2010.08227 (2020)

[2] Ali Javadi-Abhari, Matthew Treinish, Kevin Krsulich, Christopher J. Wood, Jake Lishman, Julien Gacon, Simon Martiel, Paul D. Nation, Lev S. Bishop, Andrew W. Cross, Blake R. Johnson, and Jay M. Gambetta; Quantum computing with Qiskit; 10.48550/arXiv.2405.08810 (2024)

Figures

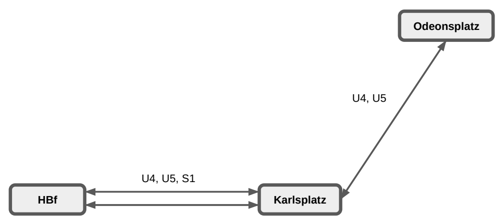

Figure 1: Simplified Model of the Munich Rail System