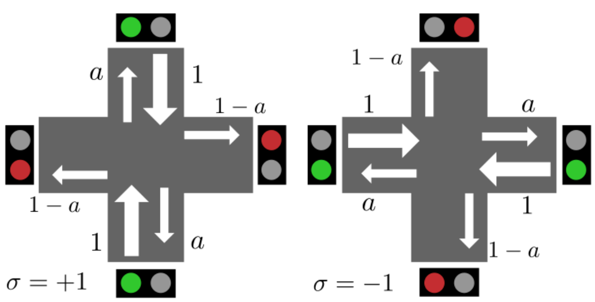
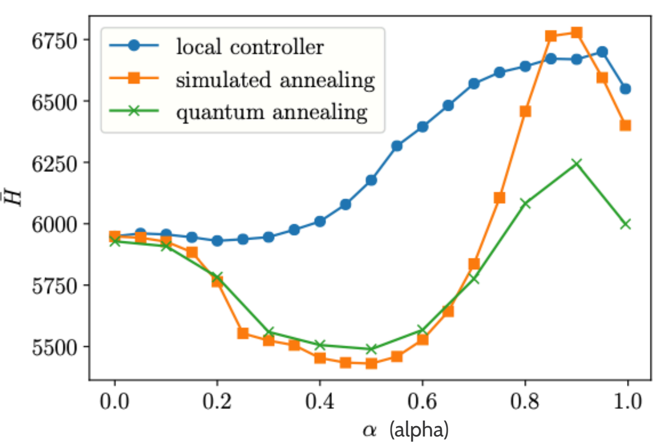
Toyota Central R&D Labs:
A Quantum Approach to Transportation

A Case Story

> ***"The spread of intelligent transportation systems in urban cities has caused heavy computational loads, requiring a novel architecture for managing large-scale traffic... the solutions to the global control method obtained with the quantum annealing machine are better than those obtained with conventional simulated annealing."***

From: Traffic Signal Optimization on a Square Lattice using the D-Wave Quantum Annealer (arXiv:2003.07527v1)





Lower values on the Y-axis correspond to more balanced traffic flow.

Shifting Gears on Traffic Signal Optimization

Coordinating traffic signals in a large city is a complex task to start with. Doing so in a way that minimizes the possibility of traffic jams and optimizes overall traffic flow is an almost impossible task using conventional computing methods. Various workarounds that have been proposed up to now require *local* control methods, which break the traffic grid into smaller pieces to control each signal according to the status of nearby intersections. Using the D-Wave quantum system, researchers at Toyota Central R&D Labs (Toyota CRDL), in collaboration with the University of Tokyo, set out to develop new *global* control methods, which consider the full grid when optimizing each signal, while responding quickly to changes in traffic flow patterns.

The Toyota CRDL researchers began by designing a simplified city diagram consisting of a 50 x 50 grid, in which streets run either east-west or north-south. As a car approaches a four-way intersection, it has a certain probability of turning right, left, or continuing straight on. To minimize congestion and the amount of time each car spends sitting unmoving at a red light, the researchers needed to determine which intersections should be green north-south, and which should be green east-west, at any given time. These signals needed to respond quickly to changing patterns as traffic moves through the grid.

By formulating the question as a combinatorial optimization problem, the researchers were able to run it on the D-Wave 2000Q™ quantum computer. Using quantum annealing, the team created a global control system that performed better than conventional computing methods under a broad range of traffic conditions. The results of the work show that the D-Wave system responds best to changing traffic conditions (changes in alpha, the probability that cars will move straight through intersections as opposed to turning left or right). Through much of the range of alpha, global strategies using simulated annealing and quantum annealing are much better at balancing traffic than the local strategy. Furthermore, when alpha is large, quantum annealing outperforms simulated annealing, and is the only one that responds well no matter the value of alpha.

The results also reinforce the value of global signal cooperation versus local control methods, and the importance of rapid responces to ensure smooth traffic flow.

Dynamic Process Control

In addition to traffic signal optimization, Toyota CRDL has launched new research into circumventing the issues of input size and compatibility between quantum computers and important application problems, in this case developing a hybrid quantum-classical algorithm for model predictive control (MPC). MPC algorithms are used in applications involving real-time control of dynamic processes; these problems require a control system that is able to return a sequence of solutions in response to rapidly changing conditions, leading to improvement in measures such as product quality, system throughput, or energy cost. As this method of sequential optimization is computationally intensive, MPC algorithms are usually applied only to systems that can tolerate slow response times.

Unlike the usual application scenario for MPC algorithms the research team used the D-Wave system for dynamic control problems in which solutions must be obtained at high speed. The team applied its work to two practical applications: stabilization of a spring-mass-damper system, such as the ones in our cars that absorb shock on uneven roads; and dynamic audio quantization for radios and GPS devices.

In both cases, the D-Wave method exhibited better performance than two classical approaches. The first was an exact method that returns optimal results and the second was simulated annealing, a well-known heuristic method that is designed to return good solutions fast. This performance gap increased as the number of iterations in the sequences increased. Detailed results were published in *Nature Scientific Reports.*

"Two practical applications, namely stabilization of a spring-mass-damper system and dynamic audio quantization, are demonstrated. For both, the D-Wave method exhibits better performance than the classical simulated annealing method. Our results suggest new applications of quantum annealers in the direction of dynamic control problems."

With the dramatic increase in the number of couplers and qubits D-Wave plans to offer in its next-generation quantum system, Toyota CRDL anticipates a corresponding increase in the accuracy and speed of the results compared to the classical alternatives.

D-Wave is the leader in the development and delivery of quantum computing systems, software, and services.

Our mission is to unlock the power of quantum computing by delivering customer value with practical quantum applications for problems as diverse as logistics, artificial intelligence, materials sciences, drug discovery, cybersecurity, fault detection and financial modeling. Learn more at www.dwavesys.com

Jumpstart your quantum application development through Leap, D-Wave's quantum cloud service. Leap provides:

- Live access to D-Wave quantum systems
- Quantum-classical hybrid solvers for complex problems of up to 10,000 variables
- Open-source software and a comprehensive online IDE for developing your own quantum applications
- Interactive demos, code examples, documentation, and a vibrant online community

Designed for developers, researchers, and forward-thinking enterprises, Leap speeds the development of real-world applications.

Sign up today at cloud.dwavesys.com/leap/signup/.