Combination of Quantum Optimization and Metaverse for Stable Power Grid

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ABSTRACT

Various difficulties may arise when feeding back solutions to optimization problems that address complex social issues to reality, and verification of the solutions is necessary. This study proposed a combination of quantum optimization and simulation within Metaverse to improve computational accuracy and configure a stable power grid.

Keywords: Combinatorial optimization, quantum computation, machine learning ,power grid, Metaverse.

1. Introduction

We think that the key technologies to solve social issues by using Metaverse is to implement its models in the Metaverse space in combination with solution tools and applications such as digital twin/optimization computation/annealing/AI and validate them through simulations. The research is one of the Metaverse solution for industry. This study describes an example of performing optimization calculations using quantum computation and Metaverse simulation.

As social issues have become more complex in recent years, it is expected to use Metaverse space to handle optimization problems incorporating many issues such as urban traffic congestion and material search. As a useful method for solving these problems, in order to obtain approximate solutions using quantum computers, we are studying problem optimization using QAOA[1].This presentation proposes how QAOA can obtain approximate solutions using the MaxCut problem as an example.

Due to the aging society in recent years, the number of workers and skilled workers is decreasing. Such a shortage of workers is very essential to sustain the socio-economy and their work activities need to be more efficient. Therefore, assuming the Metaverse space, a new employee training system using virtual reality is not necessary to use actual equipment. Able to master working procedures, research and implementation of maintenance training systems. However, because these systems are very expensive to implement, cost-effective authoring tools are beginning to be studied. Thus, while tools for mastering the work are becoming more and more substantial, it is still costly for non-experts to supervise the creation of business content when it comes to technologies based on the content that is best suited for each industry and site. It has become clear. In this paper, we do have a problem-solving method that reproduces this real-world on the Metaverse space, but rather a Metaverse method for quantum computer annealing technology, such as the creation of optimal safety routes for power or infrastructure grid and logistics, etc. By utilizing QAOA in the Metaverse space, it can be applied to the examination of infrastructure networks, such as optimization of the basic route of the power grid of disaster-resistant cities and power plants and verification of the next best route to quickly restore in the event of a failure through an optimization tool of a multidimensional parameter model. In addition, it is possible to verify the accuracy of optimization of multidimensional parameters such as dispatch of vehicles according to the optimal route and driver characteristics such as transportation, optimization of time zone, etc. It is also possible to apply future predictions using mathematical calculation models to industry.

As an example, we examined the contents related to safety and disaster resistant prediction from the mathematical analysis model of power grid, which is currently being studied, and the process and issues for applying it to industrial application.

QAOA is attracting attention as an approximation optimization algorithm that uses quantum and classical computers together. On the other hand, there are various problems with the accuracy of QAOA, barren plateau is a problem that the gradient of the cost function disappears in the problem of the size of the system, and the accuracy of QAOA deteriorates. Barren Plateau Phenomena [2] is related to setting the initial parameters, this time the proposed method to illustrate the usefulness of Parameters Fixing Strategy[3], use the MaxCut problem as an example.

A realistic application of the MaxCut problem is to consider the placement of stable power supply plants. As an example, consider a province with six major cities.

Suppose that the six major cities are arranged in a hexagonal configuration, and that the six cities are divided into two groups, each of which is served by two power supply plants. If one of the cities in one group is down due to a disaster or breakdown, the other city can supply power to the other group, saving the group whose power supply is down from the danger of a blackout. This kind of urban infrastructure is used as a model case. In this case, the most stable power network is the one that alternately groups the vertices of a hexagon. Figure 1 shows a conceptual model of the MaxCut problem and the results of optimization calculations: the more routes from Group A to Group B, the more stable the supply network between the two groups of cities, and the more disaster-resistant the urban infrastructure structure. The role of Metaverse is to check whether the power grid linked to the optimal solution is feasible in terms of regional characteristics and topography. For example, if we want to build a model for the entire region in Metaverse space and divide the major cities into two groups, we can use quantum optimization to divide them into Group A (3 cities: α, γ, ε) and Group B (3 cities: β, δ, ζ). By dividing the cities into two grid groups, we can find the largest connection between the groups. It is a secure and disaster-resistant urban infrastructure network concept to formulate a city plan in which power plants A (1) and B (2) are designed to supply electricity to the A and B groups of this quantum optimization, respectively. We will try to set up this power grid on the Metaverse space. However, even if a case arises where the power grid cannot be drawn due to complex topography such as high mountains or narrow terrain, or urban functions, the Metaverse space will allow verification. In this case, we will return to the process of quantum optimization by grouping the cities together and further limiting the condition settings under which the power grid cannot be drawn. Converge to a grouping that ensures as much as possible a power grid between the different groups of cities. This can be done automatically, but special conditions such as political relations and other city functions.

1. Research Methodology

In MaxCut, after numbering the nodes on the graph, we give each node a case where it belongs to one of the two parts, and a case belonging to the other, and considers the dimensional bit sequence, and the purpose is to find the bit string that maximizes the cost function $C(=\frac{1}{2}\sum_{<ij>}(1-z_iz_j))$.

Specifically, QAOA uses the following method to find an approximate solution of MaxCut. First, the classical computer prepares the two parameter sets $\gamma^{(i)}, \beta^{(i)}$ necessary for optimization; prepares the input of the quantum circuit as the initial state $|s>$, and creates a new state $|\beta, \gamma>$ by acting the gate on . After calculating the expected value in this state, it looks for a situation where the expected value in the classical computer is further increased.

By repeating the above, QAOA can obtain an approximate solution, and if the number of steps is large, the approximate solution is considered to approach a more accurate maximum value[2].

In general QAOA, the initial parameters are set randomly and approximate optimization is performed based on this. In the Parameters Fixing Strategy[3],the $p$optimal parameter set up to the layer is fixed and the $p+1$parameters of the set n are introduced $\gamma^{(p)},\beta^{(p)}$at the layer. Of these, the set with the best approximation accuracy is fixed. It is thought that repeating this will improve the approximation accuracy.

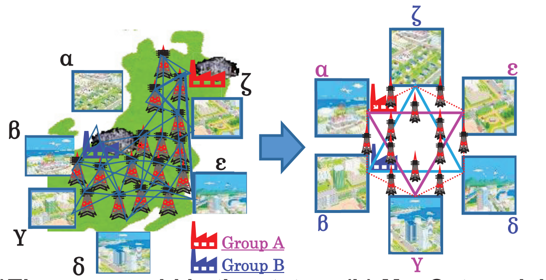
2. Experiment

In order to proceed with this research, it is first necessary to improve the optimization accuracy of the quantum computation for the MaxCut problem. Next, we will seek to construct a stable power grid using the improved optimization results.

2.1 Calculation MaxCut problem using QAOA

The following model is considered as an example of the construction of a power grid.

In this example experiment, the MaxCut problem is a combination of stable and safety power supply networks in the six cities and two power plants in a certain region. The vertices in the MaxCut problem correspond to the cities, the groupings correspond to the areas belonging to the power plants, and the edges correspond to the power grids between the cities.



(a)The power grid in the state (b) MaxCut model

Fig.1 The example for the power grid model in the state apply and replace to the MaxCut model.

2.2 Corresponding author's study

In this study, it was found that approximate solutions to the MaxCut problem are required using quantum computers, and the solutions for optimization is able to use for infrastructure routes which are water or gas grid, transportation, logistics routes, financial investments, manufacturing combinations, etc, which are one of the similar social issues. Therefore, by obtaining optimization solutions by QAOA, the visiting sale's route optimization and other methods of quantum computers and classical computers on models designed virtually to determine the efficiency of industries such as infrastructure routes in the Metaverse space, it is possible to reflect more efficient parameter feedback to the actual industrial structure. In addition, the network industry, virtual transit finance, OSS industry, etc, that close within the Metaverse space can be analyzed for optimization within the Metaverse space. It is possible to provide a method of aiming at the high efficiency of industries within each virtual space at any time.

2.3 QAOA computation

The result of solving the MaxCut problem on a second-order regular graph (hexagon) consisting of 6 nodes is shown in Figure 2. The MaxCut optimization calculation result was 4.5 when the number of steps was 1.Fig.2 is the probability distribution when projection measurement in the z-direction is applied to the state after one optimization has been applied. The approximate solution derived by QAOA $|010101>$, $|101010>$has a high probability of obtaining a state, and the results are 1,3,5 nodes and 2,4,6 nodes Splitting the node into two parts suggests a higher probability of getting the $|010101>$

largest $|101010>$ cut. Since the edges of the book can be cut, it can be seen that it matches the simulation results.

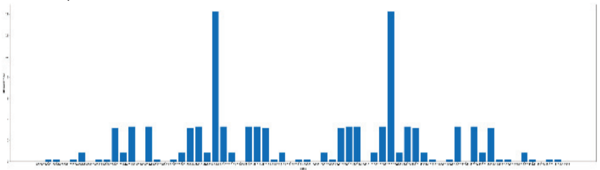


Fig.2 MaxCut in a 6-node quadratic regular graph (p=1)

2.4 Improving the accuracy of approximate solutions by QAOA

Since the number of QAOA steps in Result 1 was 1, there was variation in the probability distribution, and there was a possibility that the accuracy of the approximate solution by QAOA was insufficient. When QAOA was performed by increasing the number of steps to 5, the result was obtained as Figure 3. The MaxCut optimization calculation result was 5.4 when the number of steps was 5. Comparing Figure 2, Figure 3 has a probability of close to 100% that the exact solution is obtained. It can be seen that it exhibits double the accuracy. From the result 2, it is thought that the accuracy of the approximate solution increases by increasing the number of steps in QAOA.

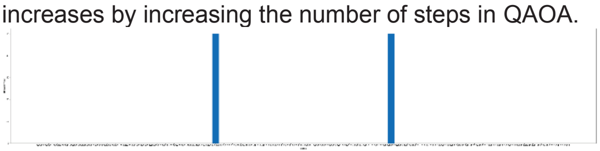
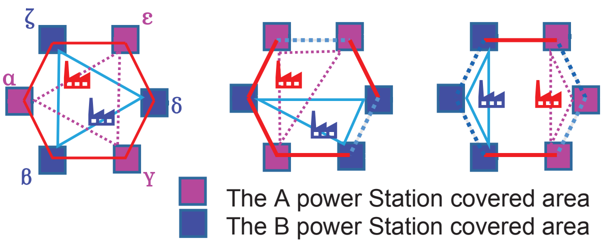


Fig.3 MaxCut in a 6-node quadratic regular graph (p=5)

2.5 Improving the accuracy of approximate solutions by QAOA



Cut model1 Cut model2 Cut model3

Fig 4. Example of Cut model.

When the MaxCut problem was grouped into six cities and two power plants in charge of the MaxCut problem, the MaxCut optimization was calculated to achieve the maximum number of routes that could be supplemented in an emergency between the separate groups. The calculated results are shown in Figure 4. In the case where each power plant is responsible for three cities each, the possible cases are model 1, 2, and 3. The MaxCut solution is model 1, and the maximum supply networks for each group are 6, 4, and 2 routes, respectively. From the above, the most secure power grid is model 1, and the most vulnerable power grid is model 3. It was found that Model 3 would experience a blackout if the power plant went down, which would make it difficult to supply power to the city α. Although this experiment considered a simple example of six cities, it can be extended to more cities as well.

3. Results

It is possible to show the following results from Chapter 2.

3.1 Visualization and application of QAOA methods in Metaverse space

From the results of Chapter 2, optimizations for the origin and sides of possible polygons can be easily calculated by quantum computers and visualized in Metaverse space. This allows stakeholders such as designers, operators, and workers to visualize (generate content as visual information) within the Metaverse space. It becomes possible to recognize not only the results of optimization but also assumptions such as route search. In addition, by experiencing the derived optimization route, it is possible to operate a virtual device that can be reoptimized in real time for real-time rehearsal training and countermeasures against new problems due to the occurrence of other factors. This will lead to higher efficiency of the industry, improved quality of life such as safety and comfort. Figure 5 show the example of the safety power grid metaverse model for the state which consist of 6 cities and 2 power stations by using MaxCut optimization. We could check and simulate that kind of the power grid model in the metaverse and reconstruct the power grid consider to solved real world connectivity challenges.

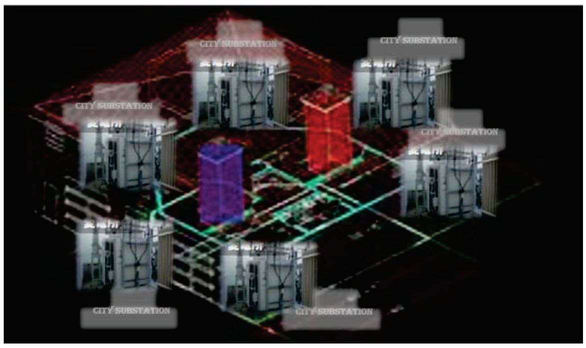


Fig 5. Example of the Metaverse simulation model of 6 cities safety power grid.

3.2 Improved accuracy of QAOA methods

An approximate solution to the MaxCut problem was obtained using QAOA, a method for solving combinatorial optimization problems, and it was found that the approximation accuracy improved by increasing the number of steps.

4. Discussion

On the other hand, in the case of this experiment, the graph in question was a very simple model, so I would like to think about the ability of QAOA when the input is complicated, and I am also considering research to analyze more complex problems than MaxCut using

QAOA. By increasing the number of cities from the current six to more cities, the QAOA method can obtained optimal solution rapidly than conventional one, and the model can be reproduced in the Metaverse to simulate the actual power supply to verify whether there are any flaws in the model. In addition, when supply networks are partially disrupted due to natural disasters or accidents, new constraints can be added to the calculation to optimize the supply to each city through real-time optimization. This optimization method using the Metaverse space can be used for simulating the implementation of inter-city infrastructure supply networks for water, gas, internet, etc.

5. Conclusions

This study is the first example of a proposal to apply quantum optimization in combination with Metaverse to the construction of a power grid.

(1) Increasing the number of QAOA steps in the hexagonal MaxCut problem improved the accuracy of the approximate solution by 20%.

(2) As a practical application of the MaxCut problem, we used QAOA to simulate the power supply networks of six cities in metaverse space, as an example, and found the optimal solution for a city model of a stable power grid that is resistant to chaos and accidents. This can be thought of as the arrangement of a stable power supply network that is resilient to disasters, and solving combinatorial optimization problems like this can be considered useful for solving social problems.

An approximate solution to the MaxCut problem was obtained using QAOA, which is one method of solving combinatorial optimization problems, and it was found that the approximation accuracy improved by increasing the number of steps. This QAOA method became a clue that can be applied to optimization for solving complex problems such as transportation routes, distribution routes, networks, and blockchain configurations. We will continue to study this research as a basic technology for optimization methods for Metaverse industrial applications using quantum computers as a basic tool.

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