Layout Optimization in Quantum Circuit using Simulated Annealing

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Abstract- The placement is one of the main steps of the quantum physical design process. It has prominent effects on the total area and the delay of a circuit. However, this process is an NP-complete problem. Therefore, we need some heuristics to solve the placement problem. Focusing on this issue, in this paper a placement algorithm is proposed based on Simulated Annealing heuristic. Experimental results show that the proposed technique decreases the average area of quantum circuits up to 43% against maximum 3% latency penalty for the attempted benchmarks.

Keywords- Quantum Circuits, Placement, Simulated Annealing (SA), Ion Trap Technology.

I. Introduction

IN layout generation, one of the main challenges of accurately modeling of large-scale quantum architecture is the ability to generate a layout for a quantum application by taking into account the area and the maximum parallelism that can be exploited [1]. Most of the important works [2]-[6] performed on quantum algorithms and its physical platform have focused on the constant layout and a few numbers of works [1][7]-[10] have been done in designing and producing layouts for quantum circuits and improving of them. In most of methods, the layout is generated and improved manually. Although the proposed methods in the primary steps and in an overall point of view seem efficient, but when the scale of the quantum circuit gets bigger, producing and improving of layouts manually seems to be impractical[11].

The circuit model for quantum computation allows us to represent any application as a sequence of logic gates [4],[12] to which we will refer to as operations or instructions interchangeably. Several major differences between quantum logic circuits and their classical counterparts make accurate placement and scheduling of a sequence of quantum operations a challenging task. First, the inability to copy quantum data[13] makes it impossible for the data to be transmitted on a wire or distributed to multiple destinations without error. In addition, the no-copy rule forces multi-qubit operations to bring the participating qubits physically together across some distance by traversing an empty channel as in the ion-trap technology [14][15] or by successive swapping with adjacent qubits as in the Kane silicon-based technology [16],[17]. The second important difference is that operations can occur simultaneously, and any or all physical qubits used in those operations may need to be physically transported. The choice of which qubits to transport affects the time of execution and the reliability of the application. The third major difference is that unlike classical data, quantum data is inherently very unstable. Experimental failure rates of multi-qubit operations for ion-traps are as high as 3% [18].

In this paper, we propose a heuristic for layout optimization of quantum circuits which takes a netlist and a physical layout [10], and optimizes the layout. We use a modified and improved version of dataflow-based layout generation approach proposed by Withney et al. [10].

By studying the physical limits of quantum computing, we can prevent from some problems such as obstruction and congestion between qubits which lead to inordinate increase of execute time and find the best location for placement of gates. Furthermore, qubit movement in channels and gate locations have direct effect on the execution time that is one of the main metrics in quantum circuit design.

The rest of this paper is organized as follows: We describe some basic concepts about quantum computation and ion trap technology in section II, followed by an overview of prior work in the field in Section III. Section IV contains our CAD flow and placement strategy. Experimental results are mentioned in Section V. Finally, Section VI concludes the paper.

II. Basic Concepts

A. Quantum Computation

Quantum computation and quantum information is the study of the information processing tasks that can be accomplished using quantum mechanical systems. Quantum mechanics is a mathematical framework or set of rules for the construction of physical theories. Quantum computation certainly offers challenges aplenty to physicists, but it is perhaps a little subtle what quantum computation and quantum information offers to physics in the long term. It is built upon an analogous concept, the quantum bit, or qubit for short. The beauty of treating qubits as abstract entities is that it gives us the freedom to construct a general theory of quantum computation and quantum information which does not depend upon a specific system for its realization [19].

Changes occurring to a quantum state can be described

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