

Nabila Abdessaied · Rolf Drechsler

Reversible and Quantum Circuits

Optimization and Complexity Analysis

This book presents a new optimization flow for quantum circuits realization. At the reversible level, optimization algorithms are presented to reduce the quantum cost. Then, new mapping approaches to decompose reversible circuits to quantum circuits using different quantum libraries are described. Finally, optimization techniques to reduce the quantum cost or the delay are applied to the resulting quantum circuits. Furthermore, this book studies the complexity of reversible circuits and quantum circuits from a theoretical perspective.

- Provides a comprehensive introduction to the field of reversible and quantum circuits;
- Discusses optimization and mapping technology of reversible and quantum circuits;
- Includes complexity analysis of reversible and quantum circuits.

Electrical Engineering

ISBN 978-3-319-31935-3



► springer.com



1	Introduction	1
1.1	Book Overview	4
1.1.1	Optimization of Quantum Circuits	4
1.1.2	Complexity Analysis	5
1.2	Outline	6
2	Background	9
2.1	Boolean Functions	9
2.2	Boolean Function Decomposition	10
2.2.1	Ashenhurst Decomposition	10
2.2.2	Curtis Decomposition	11
2.2.3	Bi-decomposition	12
2.2.4	Multiplexer Decomposition	12
2.3	Exclusive-OR Sum of Products	13
2.4	Boolean Satisfiability and SAT Modulo Theory	15
2.5	Reversible Logic	16
2.5.1	Reversible Function	17
2.5.2	Reversible Gates	20
2.5.3	Reversible Circuits	22
2.6	Quantum Computation	23
2.6.1	Quantum Systems	24
2.6.2	Quantum Libraries	26
2.6.3	Quantum Circuits	30
2.7	Cost Metrics for Reversible and Quantum Circuits	31
2.7.1	Quantum Cost	31
2.7.2	Number of Gates	33
2.7.3	Number of Lines	34
2.7.4	Depth	35
2.7.5	Nearest Neighbor Cost	36

2.8	Decision Diagrams	36
2.8.1	Binary Decision Diagrams	36
2.8.2	Quantum Multiple-Valued Decision Diagrams	38
3	Optimizations and Complexity Analysis on the Reversible Level	45
3.1	Related Work	45
3.1.1	Optimization Approaches of Reversible Circuits	46
3.1.2	Complexity of Reversible Circuits	51
3.2	Exact Quantum Cost Optimization	52
3.2.1	General Idea	52
3.2.2	Encoding Using SMT	53
3.2.3	Experimental Results	59
3.3	Heuristic Quantum Cost Optimization	65
3.3.1	Simulated Annealing	66
3.3.2	Rewriting Rules	67
3.3.3	Algorithms	68
3.3.4	Experimental Results	71
3.4	Complexity Analysis of Reversible Circuits	83
3.4.1	Complexity of Single-Target Circuits	83
3.4.2	Complexity of MPMCT Circuits	84
3.4.3	Upper Bounds for Single-Target Gates	85
3.4.4	Upper Bounds for Reversible Circuits	87
3.5	Summary	89
4	Optimization and Complexity Analysis on the Mapping Level	91
4.1	Related Work	91
4.1.1	Mapping Approaches	92
4.1.2	Complexity of NCT Circuits	100
4.2	Improving the Mapping of Single-Target Gates	100
4.2.1	Motivation	101
4.2.2	Mapping of Single-Target Gates	101
4.2.3	Experimental Evaluation	104
4.2.4	Remarks and Observations	111
4.3	Improving the Mapping of MPMCT Gates to Clifford + T Circuits	112
4.3.1	Clifford + T Aware Reversible Circuit Mapping	112
4.3.2	Proposed Mapping Approaches	113
4.3.3	MPMCT Gates Mapping	114
4.3.4	Experimental Results	122
4.4	Complexity Analysis of NCT Circuits	127
4.4.1	Upper Bounds for MPMCT Gates	128
4.4.2	Upper Bounds for Single-Target Gates	129
4.4.3	Upper Bounds for NCT Circuits	138
4.5	Summary	140

5	Optimizations and Complexity Analysis on the Quantum Level	141
5.1	Related Work	141
5.1.1	Optimization of Quantum Circuits	141
5.1.2	Complexity of Quantum Circuits	145
5.2	Depth Optimization for NCV Circuits	145
5.2.1	General Idea.....	147
5.2.2	Optimization Approaches	148
5.2.3	Experimental Results	153
5.3	NCV-Cost Optimization	156
5.3.1	Proposed Idea	157
5.3.2	Application.....	158
5.3.3	Experimental Results	159
5.4	Complexity Analysis of Quantum Circuits	163
5.4.1	Complexity of NCV Quantum Circuits.....	163
5.4.2	Complexity of Clifford+ T Quantum Circuits.....	169
5.5	Summary	174
6	Conclusions	175
	References.....	179