


QUANTUM COMPUTING AND ARTIFICIAL INTELLIGENCE

The Industry Use Cases

Edited By

**Pethuru Raj, B. Sundaravadivazhagan,
Mariya Ouaisa, V. Kavitha
and K. Shantha Kumari**

 **Scrivener
Publishing**

WILEY

Quantum Computing and Artificial Intelligence

Scrivener Publishing

100 Cummings Center, Suite 541J
Beverly, MA 01915-6106

Publishers at Scrivener

Martin Scrivener (martin@scrivenerpublishing.com)
Phillip Carmical (pcarmical@scrivenerpublishing.com)

Quantum Computing and Artificial Intelligence

The Industry Use Cases

Edited by

Pethuru Raj

Reliance Jio Platforms Ltd, Bangalore, India

B. Sundaravadivazhagan

*Dept. of Information Technology, University of Technology and Applied Sciences,
Al Mussanah, Sultanate of Oman*

Mariya Ouaissa

Cybersecurity and Networks at Cadi Ayyad University, Marrakech, Morocco

V. Kavitha

*Dept. of Computer Science with Cognitive Systems, Sri Ramakrishna College of Arts
& Science, Coimbatore, India*

and

K. Shantha Kumari

*Dept. of Data Science and Business Systems, SRM Institute of Science
and Technology, Chennai, India*



WILEY

This edition first published 2025 by John Wiley & Sons, Inc., 111 River Street, Hoboken, NJ 07030, USA and Scrivener Publishing LLC, 100 Cummings Center, Suite 541J, Beverly, MA 01915, USA

© 2025 Scrivener Publishing LLC

For more information about Scrivener publications please visit www.scrivenerpublishing.com.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, except as permitted by law. Advice on how to obtain permission to reuse material from this title is available at <http://www.wiley.com/go/permissions>.

Wiley Global Headquarters

111 River Street, Hoboken, NJ 07030, USA

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Limit of Liability/Disclaimer of Warranty

While the publisher and authors have used their best efforts in preparing this work, they make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of merchantability or fitness for a particular purpose. No warranty may be created or extended by sales representatives, written sales materials, or promotional statements for this work. The fact that an organization, website, or product is referred to in this work as a citation and/or potential source of further information does not mean that the publisher and authors endorse the information or services the organization, website, or product may provide or recommendations it may make. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for your situation. You should consult with a specialist where appropriate. Neither the publisher nor authors shall be liable for any loss of profit or any other commercial damages, including but not limited to special, incidental, consequential, or other damages. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this work was written and when it is read.

Library of Congress Cataloging-in-Publication Data

ISBN 978-1-394-24236-8

Cover image courtesy of Adobe Firefly

Cover design by Russell Richardson

Set in size of 11pt and Minion Pro by Manila Typesetting Company, Makati, Philippines

Printed in the USA

10 9 8 7 6 5 4 3 2 1

Contents

Preface	xxvii
Introduction to Quantum Computing	1
<i>Vinoj J., Swathika R., Gavaskar S. and K. B. Manikandan</i>	
1 History of Computing	2
2 A New Kind of Computing	5
3 Need for Quantum Computers	7
4 Fundamentals of Quantum Computing	8
5 “From Transistors to Qubits: The Evolution of Signal Processing and Noise Management in Classical and Quantum Computing”	9
6 Properties of Quantum Computing	11
7 The Topography of Quantum Technology	13
8 The Architecture of a Quantum Computer	14
9 Hardware and Software of Quantum Computers	16
10 Quantum Algorithm	18
10.1 Fourier Transform-Based Quantum Algorithms	19
10.2 Amplitude Amplification-Based Quantum Algorithms	20
10.3 Quantum Walks-Based Algorithms	21
10.4 BQP-Complete Problems	22
10.5 Hybrid Quantum/Classical Algorithms	23
11 Design Limitations of Quantum Computer	24
12 Approaches to Quantum Computing	26
13 Different Categories of Quantum Computers	27
13.1 Analog Quantum Computer	27
13.2 NISQ Gate-Based Computer	28
13.3 Gate-Based Quantum Computer with Full Error Correction	29
14 Advantages of Quantum Computing	30
15 Disadvantages of Quantum Computing	31
16 Applications of Quantum Computing	33

17	Major Challenges in Quantum Computing	35
18	Importance of Quantum Computing	37
19	Future Scope of Quantum Computing	41
20	Conclusion	43
	References	44

Part 1: Quantum Computing Fundamentals and Applications 47

1	Quantum Computers—Real-World Applications and Challenges	49
	<i>Gnanasankaran Natarajan, Shirley Chellathurai Pon Anna Bai, Sandhya Soman and Elakkiya Elango</i>	
1.1	Introduction	50
1.1.1	Introduction to Quantum Computing	50
1.1.2	Introduction to Quantum Mechanics and Its Core Principles	51
1.1.2.1	Wave–Particle Duality	52
1.1.2.2	Superposition	52
1.1.2.3	Uncertainty Principle	52
1.1.2.4	Quantum Entanglement	52
1.1.3	Comprehensive Introduction to Quantum Computers	53
1.2	Types of Quantum Computers	55
1.2.1	Superconducting Qubit Quantum Computers	55
1.2.2	Trapped Ion Quantum Computers	55
1.2.3	Topological Quantum Computers	55
1.2.4	Photon-Based Quantum Computers	56
1.2.5	Nuclear Magnetic Resonance (NMR) Quantum Computers	56
1.2.6	Diamond-Based Quantum Computers	56
1.3	Quantum Computer Architecture	57
1.3.1	Qubits	57
1.3.2	Quantum Gates	57
1.3.3	Control System	57
1.3.4	Quantum Registers	57
1.3.5	Quantum Measurement	58
1.3.6	Error Correction	58
1.4	Quantum Algorithms Used in Quantum Computers	58
1.4.1	Grover’s Algorithm	58
1.4.2	Shor’s Algorithm	59
1.4.3	Quantum Simulation Algorithms	59
1.4.4	Quantum Machine Learning Algorithms	59

1.4.5	Quantum Fourier Transform	59
1.4.6	Quantum Walk Algorithms	60
1.5	The Benefits and Drawbacks of Quantum Computers	60
1.5.1	Benefits	60
1.5.1.1	Exponential Computational Power	60
1.5.1.2	Quantum Simulation	61
1.5.1.3	Cryptographic Impact	61
1.5.1.4	Machine Learning and Optimization	61
1.5.2	Disadvantages	61
1.5.2.1	Scalability	61
1.5.2.2	Error Correction	62
1.5.2.3	Sensitivity to Environmental Factors	62
1.5.2.4	Limited Quantum Applications	62
1.5.2.5	Development and Cost	62
1.6	Real-Time Applications of Quantum Computers	63
1.6.1	Quantum Cryptography	63
1.6.1.1	How Does Quantum Cryptography Work?	63
1.6.2	Drug Design and Development	65
1.6.2.1	Various Pharma-Focused Quantum-Based Computing Startups	65
1.6.3	Financial Modeling	66
1.6.3.1	Risk Management	66
1.6.3.2	Portfolio Management	67
1.6.4	Weather Forecasting	67
1.6.5	Advertising	67
1.6.6	Traffic Flow Management	68
1.6.7	Better Mobile Network Coverage	68
1.6.8	Cyber Security	68
1.6.8.1	India's Next Quantum Computing Step in Cyber Security	69
1.6.9	Gaming	70
1.6.10	Computational Chemistry	70
1.7	Biggest Challenges in Quantum Computers	70
1.7.1	Error Correction	71
1.7.2	Scalability	71
1.7.3	Hardware Development	72
1.7.4	Software Development	72
1.7.5	Classical Computer Interfaces	72
1.7.6	Standards and Protocols	72
1.7.7	Trained Talent	73
1.7.8	Overall Expenses	73

1.8	Conclusion	73
	References	74
2	Post-Quantum Cryptography Methods	77
	<i>M. Kundalakesi and M. Renuka Devi</i>	
2.1	Introduction	78
2.2	Cryptography	79
2.2.1	Symmetric Cryptography	80
2.2.1.1	Data Encryption Standard	80
2.2.1.2	Advanced Encryption Standards	81
2.2.2	Asymmetric Cryptography	81
2.2.2.1	Rivest, Shamir, Adleman (RSA)	81
2.2.2.2	Protocol for Diffie–Hellman Key Exchange	82
2.2.2.3	Elliptic Curve Cryptography	82
2.3	Post-Quantum Cryptography	82
2.4	Quantum Cryptography	83
2.5	Quantum Computing	83
2.5.1	Quantum Mechanics	83
2.5.2	Quantum Computers	83
2.6	Fundamentals of Quantum Computing	84
2.6.1	Quantum Computing in Parallel	84
2.6.2	Efficient Quantum State Information Extraction	84
2.7	Security of Cryptography	84
2.7.1	DES Quantum Security	84
2.7.2	AES Quantum Security	85
2.7.3	RSA Quantum Security	85
2.7.4	ECC Quantum Security	85
2.7.5	RSA and ECC: Vulnerable to Shor’s Algorithm	85
2.8	Need of Post-Quantum Cryptography	86
2.8.1	Code-Based Cryptography	86
2.8.2	Hash-Based Cryptography	86
2.8.3	Multivariate Cryptography	87
2.8.4	Lattice-Based Cryptography	87
2.8.4.1	Challenges	88
2.8.5	Supersingular Elliptic Curve Isogeny Cryptography	88
2.8.6	Systems Based on Isogeny	88
2.9	Challenges in Post-Quantum Cryptography	88
2.9.1	Efficiency	89
2.9.2	Confidence	90
2.10	Quantum Algorithms	90
2.10.1	Shor’s Algorithm	90

2.10.2	Simon's Algorithm	91
2.11	Post-Quantum Cryptography Standardization Process	91
2.11.1	NIST	91
2.12	Migration Challenges with PQC	92
2.13	Quantum Computing and Artificial Intelligence: Industrial Use Case	93
	References	95
3	Unlocking Revolutionary Use Cases and Data Privacy Controls Throughout Quantum Computing and Blockchain	99
	<i>Rihab Benaich, Saida El Mendili and Youssef Gahi</i>	
3.1	Introduction	100
3.2	The Fundamentals of Quantum Computing	102
3.3	Quantum Gates and Quantum Circuits	104
3.4	Quantum Computing Algorithms	106
3.4.1	Quantum Fourier Transform-Based Algorithms	106
3.4.2	Amplitude Amplification-Based Algorithms	107
3.4.3	Quantum Walk-Based Algorithms	107
3.4.4	Hybrid Quantum/Classical Algorithms	107
3.5	Quantum Computing vs. Traditional Computers	107
3.6	The Fundamentals of Blockchain Technology	109
3.6.1	Properties of Blockchain	110
3.6.2	Workflow of Blockchain Technology	110
3.6.3	Types of Blockchain	112
3.7	The Motivation Behind the Fusion of Blockchain and Quantum Computing	113
3.8	Related Works	113
3.9	Quantum Computing Threats Toward Blockchain	118
3.10	Quantum Computing Advantages Toward Blockchain	126
3.10.1	Post-Quantum Cryptography	126
3.10.2	Secure Key Distribution	127
3.10.3	Enhanced Consensus Mechanisms	128
3.10.4	Efficient Data Analysis	129
3.11	The Combination of Blockchain and Quantum Computing for Enhanced Data Privacy and Anonymization	129
3.12	Application Domains for the Combination of Blockchain and Quantum Computing	131
3.13	Discussion	135
3.14	Conclusion	136
	References	136

4	Exploring Quantum Computing in Weather Forecasting: Leveraging Optimization Algorithms for Long-Term Accuracy	139
	<i>J. Loveline Zeema, Deepa S., Kirubanand V.B., Teena Jose and Kalpana P.</i>	
4.1	Introduction	140
4.1.1	Comprehensive Overview	140
4.1.2	Challenges in Achieving Accurate Long-Term Weather Predictions	141
4.2	Propulsion	142
4.2.1	Potential of Quantum Computing and Optimization Algorithms	142
4.2.2	Significance of Leveraging Quantum Computing	143
4.3	Scope of this Chapter	144
4.4	Applications of Quantum Algorithms	145
4.4.1	Factorization	146
4.4.2	Optimization Problems	146
4.4.3	Machine Learning	146
4.4.4	Simulation of Quantum Systems	146
4.4.5	Database Search	146
4.4.6	Cryptography and Security	147
4.4.7	Financial Modeling	147
4.4.8	Game Theory	147
4.5	Quantum Computing and Optimization	147
4.5.1	Quantum Computing	147
4.6	Quantum Optimization Algorithms	149
4.6.1	Quantum Annealing	149
4.6.2	Grover's Algorithm	151
4.6.2.1	Quantum Optimization with Grover's Algorithm	153
4.7	Weather Data Analysis Challenges	154
4.7.1	Weather Data Types and Importance	154
4.7.1.1	Atmospheric Observations	154
4.7.1.2	Satellite Imagery	155
4.7.1.3	Climate Models	156
4.7.2	Challenges in Weather Data Analysis	156
4.8	Leveraging Quantum Optimization for Weather Forecasting	159
4.9	Conclusion	161
	References	162

5	How AI Empowers Quantum Computing	163
	<i>S. Subbaiah and M. Kavitha</i>	
5.1	Introduction	164
5.2	Industrial Revolution 1.0 to 5.0	165
5.3	Quantum Computing	166
	References	175
6	Safeguarding Information Security: The Imperative Role of Quantum Random Number Generation	177
	<i>Thanga Helina Stalin, Sreejith Balakrishnan, Berin Jeba Jingle I. and Shirley Chellathurai Pon Anna Bai</i>	
6.1	Introduction	178
6.1.1	Literature Review	178
6.1.1.1	Background and Motivation	179
6.1.1.2	Scope and Significance of QRNG	181
6.1.2	Superposition in Quantum Random Number Generation	183
6.1.2.1	Entanglement	184
6.1.2.2	Quantum Bits (Qubits)	185
6.1.2.3	Quantum Measurement	187
6.1.2.4	Quantum Entanglement and Measurement	188
6.1.3	Basic Concepts of QRNG	189
6.1.3.1	QRNG Algorithms	191
6.1.4	Case Studies: Koashi and Ueda (2007), Yuan <i>et al.</i> (2008)	193
6.1.4.1	Case Study 1: Koashi and Ueda (2007)	193
6.1.4.2	Case Study 2: Yuan <i>et al.</i> (2008)	194
6.1.4.3	Other QRNG Approaches	195
6.1.4.4	Applications of QRNG	197
6.1.5	Quantum Random Number Generation in Practice	199
6.1.5.1	Future Directions and Emerging Trends	202
6.2	Conclusion	204
	References	205
7	The Establishment of Quantum Networks	207
	<i>Deepa S., Loveline Zeema J., Vinay M., Jayapriya J. and B. Sundaravadivazhagan</i>	
7.1	Introduction	208
7.1.1	Overview of Quantum Networks	208
7.1.2	Principles of Quantum Mechanics	208
7.1.2.1	Importance of Quantum Networks	210

7.1.2.2	Applications of Quantum Networks	211
7.1.3	Purpose and Scope of the Chapter	212
7.2	Fundamentals of Quantum Networks	212
7.2.1	Quantum Mechanics and Quantum Information Science	212
7.2.2	Quantum Entanglement	212
7.2.3	Quantum Superposition	213
7.2.4	Quantum Communication Protocols	213
7.2.5	Quantum Computing and Quantum Key Distribution	213
7.3	Building Blocks of Quantum Networks	214
7.3.1	Quantum Hardware	214
7.3.1.1	Qubits (Qubits)	214
7.3.1.2	Quantum Gates and Operations	214
7.3.1.3	Quantum Processor	214
7.3.2	Quantum Communication Channel	214
7.3.2.1	Quantum Optical Fibers	214
7.3.2.2	Free-Space Quantum Connections	215
7.3.2.3	Satellite-Based Quantum Communication	215
7.3.2.4	Satellite Deployment, Synchronization, and Atmospheric Conditions	215
7.4	Quantum Network Architecture	215
7.4.1	Quantum Network Topology	215
7.4.1.1	Point-to-Point Connection	215
7.4.1.2	Quantum Local Area Network (QLAN)	216
7.4.1.3	Quantum Metropolitan Area Network (QMAN)	216
7.4.1.4	Quantum Wide Area Network (QWAN)	216
7.4.2	Quantum Network Nodes	217
7.4.2.1	Quantum Repeaters	217
7.4.2.2	Quantum Switch	217
7.4.2.3	Quantum Memory	217
7.4.3	Quantum Network Protocol	217
7.4.3.1	Quantum Teleportation	217
7.4.3.2	Quantum Routing and Switching	218
7.4.3.3	Quantum Error Correction	218
7.4.3.4	Quantum Key Distribution Protocol	218
7.5	Challenges and Solutions in Building Quantum Networks	219
7.5.1	Quantum Noise and Decoherence	219
7.5.2	Quantum Error Correction	219
7.5.3	Quantum Network Scalability	219
7.5.4	Quantum Security and Encryption	220

7.5.5	Synchronization of Quantum Networks	220
7.5.6	Quantum Network Management and Monitoring	220
7.6	Current State of Quantum Network Development	221
7.6.1	Experimental Quantum Network	221
7.6.2	Implementation of a Real Quantum Network	221
7.7	Conclusion	222
7.7.1	Future Perspectives for Quantum Networks	223
	References	223
8	Foundations of Quantum Computing and Machine Learning	225
	<i>K.C. Prabu Shankar, Chandraprabha K., K. Senthil Raja and P. Kanmani</i>	
8.1	Introduction to Quantum Mechanics	226
8.2	Quantum Machine Learning: A New Paradigm	227
8.3	Literature Survey	228
8.4	Quantum Circuits and Operations	229
8.5	Comparison with Classical Computing	230
8.6	Machine Learning Landscape: From Algorithms to Data and Applications	231
8.7	Quantum Machine Learning (QML)	232
8.8	Challenges and Limitations of Classical Machine Learning	234
8.9	Quantum Machine Learning: Principles and Algorithms	235
8.10	Quantum Machine Learning Paradigms	236
8.11	Hybrid Quantum-Classical Approaches	239
8.12	Examples of Hybrid Quantum-Classical Algorithms for Specific Tasks	240
8.13	Applications and Opportunities in Quantum Machine Learning	241
8.14	Conclusion	243
8.15	The Future of Quantum Machine Learning: Challenges and Opportunities	244
	References	245
9	Quantum Computing AI for Climate Modeling	247
	<i>K. Deeba, S.R. Ramya, B.G. Geetha and K. Shantha Kumari</i>	
9.1	Introduction	248
9.2	Climate Modeling	249
9.3	Quantum AI for Climate Modeling	249
9.4	Literature Survey	250
9.5	Traditional Computers Over Quantum AI for Climate Modeling	251

9.6	The Potential Applications of Quantum AI in Climate Modeling	255
9.7	Ethical Considerations and Societal Implications	256
9.8	Conclusion	257
9.9	Future Directions and Challenges	257
	References	258
10	An Outlook on Universal Quantum Computers	261
	<i>M. Jaithoon Bibi, V. Kavitha, V. Krishnapriya, K. Gowri and S. Manoj</i>	
	Introduction	261
	History	262
	Quantum Information Theory	263
	Chances	264
	Quantum Computing in Cryptography	265
	Entanglement	265
	Ethical and Societal Implications	267
	Privacy and Security	267
	Job Displacement and Workforce Transition	268
	Equity in Access to Quantum Technologies	269
	Environmental Impact	270
	Dual-Use Dilemmas	270
	Data Bias and Fairness	271
	Regulatory and Governance Challenges	271
	Impact of Cybersecurity	271
	Cultural and Social Changes	272
	Advantages of Quantum Computers	272
	Faster Computations	272
	Best for Simulation	273
	Medicine Creation	274
	Google Search	274
	High Privacy	275
	Used in Radar Making	275
	Used in Artificial Intelligence	276
	Machine Learning	276
	Algorithm Creation	277
	The Low Temperature Needed	278
	Not Open for Public	278
	Internet Security	278
	Error Correction	279
	Scalability	280

Hardware Development	280
Software Development	281
Classical Computer Interfaces	281
Standards and Protocols	282
Trained Talent	283
Overall Expense	283
Future of Quantum Computing	283
Quantum Circuits	283
Quantum Cognition	285
Quantum Cryptography	285
Quantum Neural Networks (QNNs)	286
Optimization	287
ML/Big Data	287
Simulation	288
Materials Science	289
Conclusion	289
References	290
Part 2: Quantum Computing and Security	291
11 Establishment of Secure Quantum Network Communication with Cryptography Algorithm	293
<i>S. Padmanayaki, K. Geetha, S. Sophia, P. Jayasuriya, Khan Mohammad Jarina Begum and M. Balasaraswathi</i>	
11.1 Introduction	294
11.2 Literature Review	295
11.3 Proposed Methodology	298
11.3.1 Improved Shor Algorithm	299
11.4 Results	300
11.4.1 Comparison Results	301
11.5 Conclusion	302
References	302
12 Quantum Computing in Industry: Unveiling Applications and Opportunities	305
<i>N.A. Natraj, B. Sundaravadivazhagan, R. Sarathkumar, Harishchander Anandaram and Sarala Patchala</i>	
12.1 Introduction	306
12.1.1 Brief Overview of Quantum Computing	306
12.1.2 The Importance of Quantum Computing in the Industrial Sector	308

12.1.3	Unveiling the Strategic Analysis of Quantum Computing in the Industry	310
12.1.3.1	The Industry Potential Transformed by Quantum Computing	310
12.1.3.2	Instructions for Industry Participants	310
12.2	Quantum Fundamentals and Algorithms: Pioneering the Quantum Frontier	311
12.2.1	Quantum Computing: Superposition, Entanglement, and Quantum Bits	311
12.2.2	Delving into Quantum Algorithms: Unraveling the Potential Impact	312
12.2.3	Navigating the Quantum Frontier: A Strategic Insight	313
12.2.4	The Quantum Odyssey Continues: A Thousand Words and Beyond	313
12.3	Industries Poised for Transformation Through Quantum Computing	314
12.3.1	Quantum Computing in Finance and Cryptography: Pioneering a Quantum Revolution	314
12.3.1.1	Quantum Computing in Finance	314
12.3.1.2	Quantum-Safe Cryptography: Navigating the Quantum Threat	315
12.3.1.3	Optimization of Financial Portfolios: Quantum's Strategic Advantage	315
12.3.1.4	Managing Quantum in Finance and Cryptography	316
12.3.2	Quantum Computing in Supply Chain and Logistics: Revolutionizing Routes and Enhancing Inventories	316
12.3.2.1	Quantum Computing in Supply Chain: A Paradigm Shift	316
12.3.2.2	Route Optimization Using Quantum Algorithms: A Quantum Symphony of Possibilities	317
12.3.2.3	Inventory Management Enhancements: Quantum's Strategic Advantage	317
12.3.2.4	Navigating the Quantum Landscape in Logistics	318
12.3.3	Quantum Computing in Drug Discovery and Healthcare: A Quantum Frontier Unveiled	318
12.3.3.1	Quantum Computing in Healthcare: A Transformative Paradigm	318

12.3.3.2	Molecular Simulation and Drug Discovery Acceleration: A Quantum Symphony	319
12.3.3.3	Quantum Precision Touch to Improve Personalized Medicines	319
12.3.3.4	The Quantum Revolution in Healthcare: A Glimpse into the Future	320
12.3.3.5	Navigating the Quantum Landscape in Healthcare	320
12.3.4	Quantum Computing in Energy and Materials Science: A Revolution	321
12.3.4.1	Energy and Materials Science Quantum Computing: A Partnership	321
12.3.4.2	Quantum's Sustainable Energy Production and Consumption Optimization	322
12.3.4.3	Navigating Quantum in Energy and Materials Science	322
12.4	Quantum Computing Challenges and Future: Navigating the Quantum Frontier	323
12.4.1	Quantum Hardware Limits	323
12.4.2	Quantum Computing Considerations	324
12.4.3	Future Quantum Computing Impact	325
12.4.4	Quantum Frontier Navigation	326
12.5	Conclusion	327
	References	328
13	A Secure Transition Perspective on the Expectations and Benefits of Quantum Networks Over Classical Networks	331
	<i>S. Mayukha and R. Vadivel</i>	
13.1	Introduction	332
13.2	Brief Overview of Classical Networks and Its Limitations	333
13.2.1	Introduction to the Concept of Quantum Networks	333
13.2.2	Importance of Secure Transition from Classical to Quantum Networks	334
13.3	Objectives of the Chapter	334
13.4	Fundamentals of Quantum Communication	335
13.4.1	Basic Principles of Quantum Mechanics Relevant to Quantum Communication	335
13.4.2	Quantum Superposition and Entanglement	335
13.4.3	Quantum Bits (Qubits) and Its Properties	337
13.4.4	Quantum Key Distribution (QKD) as a Foundation for Secure Communication	338

13.4.5	Quantum Networking's Emergence	339
13.4.6	Detailed Explanation of Various QKD Protocols (BB84, E91, etc.)	341
13.4.7	Comparison of QKD with Classical Key Distribution Methods	341
13.4.8	Illustration of How QKD Ensures Secure Communication	342
13.4.9	Real-World Examples of Successful QKD Implementations	343
13.5	Overview of Common Security Threats in Classical Networks	343
13.5.1	Limitations of Classical Cryptography	344
13.5.2	Examples of Successful Attacks on Classical Networks	345
13.6	Secure Communication in the Quantum Era	345
13.7	Paradoxes of Quantum Functionalities	347
13.7.1	Introduction to the Fundamental Paradoxes	347
13.7.2	Exploration of Superposition and Entanglement	347
13.7.3	Examination of How These Paradoxes Form the Foundation of Quantum Computing's Transformative Potential	347
13.7.4	Illustration of How Quantum Functionalities Differ Fundamentally from Classical Computation	348
13.7.5	Motivation for Transitioning to Quantum Networks for Enhanced Security	348
13.8	Security Risks in Post-Quantum Computing	349
13.8.1	In-Depth Analysis of Vulnerabilities Faced by Classical Networks	349
13.8.2	Discussion on the Accelerated Threat Landscape	349
13.8.3	Examination of Potential Risks to Classical Cryptographic Methods	350
13.8.4	Exploration of the Need for Enhanced Security Measures	350
13.9	Lessons from the Y2K Problem	351
13.9.1	Overview of the Y2K Problem and Its Impact on Classical Computing	351
13.9.2	Analysis of the Importance of Foresight and Proactive Measures	351
13.9.3	Identification of Key Lessons Learned from Past Challenges in Technology Transitions	352
13.10	Quantum-Proofing Measures for a Secure Transition	352

13.10.1	In-Depth Exploration of Quantum-Proofing Strategies	352
13.10.2	Examination of Quantum Key Distribution (QKD) as a Game-Changer	353
13.10.3	Discussion on the Development of Quantum-Resistant Encryption Methods	353
13.10.4	Emphasis on Collaboration within a Proactive, User-Centric Community	354
13.11	Quantum Network Architecture	354
13.11.1	Components of a Quantum Network	354
13.11.2	Quantum Entanglement-Based Network Communication	355
13.11.3	Hybrid Quantum–Classical Network Models	356
13.11.4	Scalability and Feasibility Considerations	357
13.12	Quantum Network Security Advantages	357
13.12.1	Inherent Security Features of Quantum Communication	357
13.12.2	Unbreakable Quantum Key Distribution and Secure Communication Channels	358
13.12.3	Quantum-Resistant Algorithms for Enhanced Post-Quantum Security	359
13.12.4	Quantum-Resistant Data Integrity and Authentication	359
13.13	Challenges in Implementing Quantum Networks	360
13.13.1	Technical Challenges in Building and Maintaining Quantum Networks	360
13.13.2	Infrastructure Requirements for Quantum Communication	361
13.13.3	Quantum Error Correction and Fault Tolerance	361
13.13.4	Current Limitations and Ongoing Research Efforts	362
13.14	Case Studies and Success Stories	362
13.14.1	Real-World Examples of Successful Transitions from Classical to Quantum Networks	362
13.14.2	Experiences of Organizations in Enhancing Security through Quantum Technologies	363
13.14.3	Lessons Learned and Best Practices for a Smooth Transition	364
13.15	Regulatory and Ethical Considerations	364
13.15.1	Overview of Current Regulations and Standards for Quantum Communication	364

13.15.2	Ethical Considerations in the Deployment of Quantum Networks	365
13.15.3	International Collaboration and Standardization Efforts	366
13.16	Future Outlook and Emerging Technologies	366
13.16.1	Predictions for the Future of Quantum Networks	366
13.16.2	Emerging Technologies That Could Further Enhance Quantum Network Security	367
13.16.3	Potential Applications Beyond Secure Communication	368
13.17	Conclusion	368
	References	369
14	Beyond Classical Limits: Exploring the Promise of Post-Quantum Cryptography	373
	<i>M. G. Divyajyothi, Rachappa Jopate and B. Sundaravadivazhagan</i>	
14.1	Introduction	374
14.2	Quantum Computing	375
14.3	Post-Quantum Cryptographic Techniques	377
14.4	Quantum Computing and AI Synergy	381
14.5	Industry 5.0 and Security Concerns	384
14.6	Use Cases of Post-Quantum Cryptography in Industry 5.0	386
14.7	Conclusion	387
	References	388
15	Quantum Computing's Implications for Cybersecurity	395
	<i>Gowri K., S. Jawahar, V. Kavitha, B. L. Shivakumar and M. Jaithoon Bibi</i>	
15.1	Introduction	396
15.1.1	Quantum Computing	396
15.1.2	Quantum Computing—History and Background	396
15.1.3	Quantum Theory	396
15.1.3.1	A Comprehensive Overview of Quantum Theory	397
15.1.4	Classical Bits	397
15.1.4.1	Qubits: How Do They Vary from Conventional Bits?	397
15.1.4.2	A Contrast Between Classical and Quantum Computing	397
15.1.5	Qubit	398

	15.1.5.1 Physical vs. Logical Qubits	398
	15.1.5.2 Atomic Attachment with Superposition	399
	15.1.6 Quantum Computer's Speed	400
15.2	Quantum Cybersecurity	401
	15.2.1 Cybersecurity	401
	15.2.2 Quantum Cybersecurity	402
	15.2.2.1 Quantum Risks to Cybersecurity	402
	15.2.2.2 Importance of Cybersecurity	403
	15.2.3 Cybersecurity with Quantum Computers	410
	15.2.4 Impact of Quantum Computing on Cybersecurity	410
	15.2.5 Create Currently, Decode Later	411
15.3	Peter Shor Developed a Quantum Algorithm	411
	15.3.1 Adjusting Cybersecurity to Address the Threat	413
15.4	Conclusion	413
	References	413

Part 3: Quantum Computing Innovations and Future Perspectives 415

16	Quantum Machine Learning for Industry 4.0	417
	<i>Indu Bala, Kiran Ahuja and Maad M. Mijwil</i>	
16.1	Introduction	418
16.2	Industry 4.0	420
16.3	Role of Quantum Machine Learning in Industry 4.0	422
16.4	Use Cases of Quantum Machine Learning in Industry 4.0	424
16.5	Challenges in the Implementation of Quantum Machine Learning in Industry 4.0	426
16.6	Procedure to Implement Quantum Machine Learning in Industry	427
16.7	Recommendations and Future Scope	429
	References	431
17	Quantum Computing and AI Applications in Industry 5.0	
	Use Cases	435
	<i>Jihane Gharib and Youssef Gahi</i>	
17.1	Introduction	436
17.2	Background: Current Landscape and Drivers for a 5th Revolution	438
17.3	Understanding Industry 5.0: A Human-Centric Approach	440
17.4	Quantum Computing and Artificial Intelligence as a Critical Driver for Industry 5.0	449

17.5	Conclusion and Future Perspective	461
	References	462
18	Quantum Artificial Intelligence (QAI) Paradigm for Voice-Controlled Devices	465
	<i>Aswani S. and E. Chandra</i>	
18.1	Quantum Artificial Intelligence (QAI) for Voice-Controlled Devices	466
18.1.1	Introduction	466
18.1.2	Relevance of QAI in Industry 5.0 and Voice-Controlled Devices	467
18.1.3	Evolution from Industry 4.0 to Industry 5.0	468
18.1.4	Challenges and Limitations in Traditional AI Faces Industry 5.0	469
18.2	AI Applications in Industry 5.0	471
18.2.1	AI in Supply Chain Optimization	471
18.2.2	AI in Voice-Controlled Device Transformation	472
18.2.3	Challenges and Opportunities in Industry 5.0	473
18.2.4	Evolution of Voice-Controlled Devices	474
18.2.5	Voice Assistant Performance Boost	474
18.2.6	Quantum-Enhanced Voice Recognition	476
	18.2.6.1 Use Cases in Voice-Controlled Devices	476
18.2.7	Security and Privacy Considerations	477
18.3	Quantum Artificial Intelligence for Industry 5.0: Challenges and Considerations	477
18.3.1	Technical Hurdles and Quantum Hardware	478
18.3.2	Quantum Error Detection	479
18.3.3	Integration with Classical AI Systems	480
	18.3.3.1 Significance of Integration	480
	18.3.3.2 Challenges and Opportunities	480
	18.3.3.3 Potential Applications	481
18.3.4	Quantum AI Bias and Fairness	481
18.3.5	Quantum Ethical Frameworking	482
18.4	Quantum Computing Potential Impacts	483
18.4.1	Algorithms for Natural Language Understanding	484
18.4.2	Quantum Neural Networks	485
18.4.3	Quantum Language Models	486
18.4.4	Quantum-Powered Future	486
18.4.5	Ethical Consideration for the Quantum Artificial Intelligence Paradigm	488

18.5	A Symbiotic Relationship Between Voice Recognition and Quantum Computing	489
18.5.1	Limitations of Classical Artificial Intelligence for Voice Commands	489
18.5.2	Quantum Computing Improves Voice Recognition	491
18.5.3	QAI Algorithms for NLP	492
18.5.4	Enhancing User Experience with Quantum Voice Interface	492
	References	493
19	Exploring the Entrepreneurial Opportunities Arising from AI-Driven Quantum Computing Advancements	497
	<i>M. Ashok Kumar, Aliyu Mohammed, M. Marimuthu and B. Sundaravadivazhagan</i>	
19.1	Introduction	498
19.2	Objective of the Study	499
19.2.1	Clarification of the Primary Research Goal	499
19.2.2	Specific Objectives and Their Relation to Quantum Computing and Entrepreneurship	500
19.2.2.1	To Investigate the Status of Quantum Computing and Its Future Development with Artificial Intelligence	500
19.2.2.2	Identification of the Main Entrepreneurial Opportunities Made Possible by AI-Driven Quantum Computing	500
19.2.2.3	To Examine the Problems and Dangers That Entrepreneurs Encounter in AI-Based Quantum Computing	500
19.2.2.4	Examine Market Trends and Projections for AI-Driven Quantum Computing	500
19.2.2.5	Examining Financing Choices, Business Ideas, and Startup Methodologies	500
19.2.2.6	Concerns about Intellectual Property and the Job of Partnerships	501
19.3	Statement of the Problem	501
19.3.1	Identification of Key Challenges and Gaps in the Field of AI-Driven Quantum Computing	501
19.3.1.1	Scalability of Quantum Hardware	501
19.3.1.2	Quantum Error Correction	501

	19.3.1.3	Quantum Algorithm Complexity	501
	19.3.1.4	AI Algorithm Integration	501
	19.3.1.5	Access to Quantum Resources	502
19.3.2		Discussion of Implications for Entrepreneurship	502
	19.3.2.1	Risk and Uncertainty	502
	19.3.2.2	Competitive Landscape	502
	19.3.2.3	Investment and Funding Complexities	502
	19.3.2.4	Intellectual Property Issues	502
	19.3.2.5	Partnerships and Collaborations	502
19.3.3		Quantum-Related Challenges	503
19.3.4		Entrepreneurial Challenges and Opportunities	503
19.4		Literature Review	503
	19.4.1	Conceptual Framework	503
	19.4.1.1	Overview of Quantum Computing Concepts	503
	19.4.1.2	Role of Artificial Intelligence in Enhancing Quantum Computing	504
	19.4.1.3	Theoretical Foundations of Quantum Algorithms	505
19.4.2		The Budding Ecosystem: Cultivating AI-Driven Quantum Entrepreneurs	506
	19.4.2.1	Incubators and Accelerators	506
	19.4.2.2	Funding Sources	506
	19.4.2.3	Collaborative Initiatives	507
	19.4.2.4	Challenges and Opportunities	507
19.4.3		Entrepreneurial Success Stories	507
	19.4.3.1	Xanadu (Canada): Quantum Drug Discovery	507
	19.4.3.2	Zapata Computing (US): Finance and Optimization	508
	19.4.3.3	QuTech Delft (Netherlands): Quantum Hardware and Software	508
	19.4.3.4	QuTech Delft (Netherlands): Quantum Cybersecurity	508
	19.4.3.5	Cambridge Quantum Computing (UK): Materials Science and Quantum Chemistry	509
19.4.4		Current Market Trends and Entrepreneurial Opportunities in AI-Driven Quantum Computing	509
	19.4.4.1	Market Trends	509
	19.4.4.2	Entrepreneurial Opportunities	510

	19.4.4.3 Additional Considerations	510
19.5	Theoretical Framework	511
	19.5.1 An Introduction to Some Key Theoretical Frameworks (e.g., Quantum Information Theory)	511
	19.5.2 The Relevance to the Research Study	511
	19.5.3 Navigating the Quantum Frontier: Theoretical Frameworks for Entrepreneurial Exploration	511
	19.5.3.1 Technology Adoption Frameworks	512
	19.5.3.2 Frameworks for Business Model Innovation	512
	19.5.3.3 Risk Management Frameworks	512
	19.5.3.4 Additional Considerations	513
19.6	Empirical Study	513
	19.6.1 Examination of Real-World Applications and Advancements in AI-Driven Quantum Computing	513
	19.6.2 Two Case Studies of the Practical Implementation of AI in Quantum Computing	513
	19.6.3 The Quantum Startup Landscape: An Empirical Analysis	514
	19.6.3.1 Key Players and Innovations	514
	19.6.3.2 Challenges and Overcoming Strategies	515
	19.6.3.3 Future Trends and Opportunities	515
19.7	Gap in the Literature	516
	19.7.1 Identification of Areas Where Existing Research Falls Short	516
	19.7.1.1 Interdisciplinary Insights	516
	19.7.1.2 Practical Entrepreneurial Guidance	516
	19.7.1.3 Policy and Regulation	516
	19.7.1.4 Global and Regional Variations	516
	19.7.2 Rationale for the Need to Fill These Gaps	516
	19.7.2.1 Interdisciplinary Understanding	517
	19.7.2.2 Practical Entrepreneurial Guidance	517
	19.7.2.3 Policy and Regulation Compliance	517
	19.7.2.4 Regional Insights	517
	19.7.3 Entrepreneurial Research Gaps	517
19.8	Findings	518
	19.8.1 Presentation and Discussion of Findings in the Context of AI-Driven Quantum Computing	518
	19.8.2 Highlighting the Principal Entrepreneurial Opportunities Discovered During the Study	518
	19.8.2.1 Quantum-Enhanced Machine Learning	518

19.8.2.2	Quantum Simulation in Chemistry and Materials Science	519
19.8.2.3	Quantum-Secure Cryptography	519
19.8.2.4	Quantum Hardware and Software Development	519
19.8.2.5	Consulting and Education	519
19.9	Conclusion	519
19.9.1	Key Findings and Their Implications	519
19.9.2	Concluding Remarks on the Combination of Quantum Computing and Enterprise	520
	References	521
	Index	523

Preface

Welcome to *Quantum Computing and Artificial Intelligence: The Industry Use Cases*. In this groundbreaking volume, we explore the exciting intersection of quantum computing and artificial intelligence (AI) and their transformative potential across various industries.

Part 1 of this book explores the fundamentals of quantum computing and its practical applications. We begin with an overview of quantum computers, examining their real-world applications and challenges. From there, we explore the emerging field of post-quantum cryptography, investigating methods to ensure data privacy and security in the quantum computing era. We also delve into the synergies between quantum computing and blockchain technology, uncovering revolutionary use cases and innovative data privacy controls.

As we delve deeper, we investigate how quantum computing can revolutionize weather forecasting, leveraging optimization algorithms for long-term accuracy. Furthermore, we explore the symbiotic relationship between AI and quantum computing, uncovering how AI empowers quantum computing to achieve new heights of performance. Additionally, we discuss quantum random number generation and the establishment of quantum networks, laying the foundations for future advancements in the field.

Part 2 focuses on the critical intersection of quantum computing and security. We examine the establishment of secure quantum network communication using advanced cryptography algorithms. Furthermore, we explore the myriad applications and opportunities that quantum computing offers to various industries. We also take a comprehensive look at the transition from classical to quantum networks, highlighting the benefits and expectations associated with this paradigm shift. Additionally, we explore the promise of post-quantum cryptography and its implications for cybersecurity in the quantum computing era.

In Part 3, we turn our attention to quantum computing innovations and future perspectives. We explore the exciting potential of quantum machine learning for Industry 4.0, as well as the applications of quantum computing and AI in the emerging Industry 5.0 landscape. Furthermore, we delve into the paradigm of Quantum Artificial Intelligence (QAI) and its implications for voice-controlled devices. Lastly, we examine the entrepreneurial opportunities that arise from advancements in AI-driven quantum computing, paving the way for future innovation and growth.

We thank everyone who contributed to this volume and, finally, Martin Scrivener and the Scrivener Publishing team for its publication. Throughout this book, we aim to provide readers with a comprehensive understanding of the synergistic relationship between quantum computing and artificial intelligence, as well as their profound implications for various industries. Whether you are a seasoned professional, a researcher, or an entrepreneur, we hope this book inspires you to explore the limitless possibilities at the intersection of quantum computing and artificial intelligence. Enjoy the journey!

December 2024