

NETWORKED SENSING SYSTEMS



Edited By

Rajesh Kumar Dhanaraj, Malathy Sathyamoorthy,
Balasubramaniam S. and Seifedine Kadry

 Scrivener
Publishing

WILEY

Networked Sensing Systems

Scrivener Publishing

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

Publishers at Scrivener

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

Networked Sensing Systems

Edited by

Rajesh Kumar Dhanaraj

Malathy Sathyamoorthy

Balasubramaniam S

and

Seifedine Kadry



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 9781394310869

Front cover images supplied by Pixabay.com

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	xvii
1 Introduction to Network Sensing Systems in Society 5.0: Issues and Challenges	1
<i>Ankit Kumar, Anurag Kumar Kanojiya and Subitha D.</i>	
1.1 What is Society 5.0?	2
1.1.1 Advancements in Society 5.0 Over Society 4.0	3
1.1.2 Integration and Interconnectivity	3
1.1.3 Data Utilization and Analysis	4
1.1.4 Personalization and Customization	4
1.1.5 Sustainability and Ethical Considerations	4
1.1.6 Human-Centric Design and Empowerment	4
1.2 Network Sensing Systems in Society 5.0	5
1.3 Issues and Challenges	6
1.3.1 Data Privacy and Security	6
1.3.2 Importance of Privacy and Security	7
1.4 Encryption and Decryption Techniques: Safeguarding Data Integrity	8
1.4.1 Decryption Technology	9
1.4.2 Challenges and Decisions	10
1.4.3 Interoperability Challenges in Society 5.0: A Tripping Block on the Road to a Hyperconnected Future	10
1.5 Understanding Interoperability on Society 5.0	10
1.5.1 The Smart City Dilemma: A Case Study in Interoperability Woes	11
1.5.2 Ensuring Integration and Data Exchange	11
1.5.3 Standardization Challenges and Solutions	12
1.5.4 Heterogeneity Challenges and Solutions	12
1.6 Importance of Robust Communication and Power Plans	12
1.6.1 The Requirement and Imperative of Flexible and Dependable Infrastructure	13

1.6.2	Infrastructure Resilience	14
1.6.3	Key Characteristics of Sturdy Infrastructure	14
1.6.4	Infrastructure Resilience's Importance in Society 5.0	15
1.6.5	Infrastructure Resilience Techniques	16
1.6.6	Reduced Operational Costs	16
1.6.7	Safeguarding the Digital Age: Security and Privacy in Infrastructure	17
1.7	Environmental Effects and Energy Efficiency	17
1.7.1	Supporting Sustainability through Energy-Efficient Approach	18
1.7.2	Building Automation Systems: Transforming Buildings into Energy-Conscious Entities	19
1.7.3	Connected Appliances: Transforming Everyday Devices into Energy-Conscious Partners	20
1.7.4	Benefits of Connected Appliances	20
1.7.5	Challenges and Considerations	21
1.7.6	Energy-Efficient Manufacturing: Optimizing Industries for a Sustainable Future in Society 5.0	21
1.7.7	Benefits of Energy-Efficient Manufacturing	22
1.8	Utilizing Renewable Energy Sources	22
1.8.1	Methods of Harnessing Cleaner Energy in Society 5.0	23
1.9	Conclusion	24
1.9.1	Future Directions	24
	References	26
2	Remote and Urban Environmental Area Sensing, Connectivity Issues, and Solutions Based on Emerging Technologies	31
	<i>Abinaya M., Vadivu G., Balasubramaniam S and Sundaravadivazhagan B.</i>	
2.1	Introduction	32
2.1.1	Urban Environment Remote Sensing Overview	32
2.1.2	Smart Factory	32
2.1.3	Benefits of Remote Sensing in Cities	33
2.2	Connectivity Challenges in Urban Remote Sensing	33
2.2.1	Conventional Remote Sensing Systems' Technological Limitations	33
2.2.2	Logistical Obstacles in the Integration and Transmission of Data	34
2.2.3	Problems Affect Data Analysis and Quality	34
2.2.4	Cutting Edge Technologies to Handle Connectivity Issues	35

2.3	Artificial Intelligence for Enhancing Data Processing and Analysis	35
2.3.1	Artificial Intelligence for Data Insights	35
2.3.2	Real-Time Monitoring With IoT Sensors	36
2.3.3	Advanced Imagery and Data Acquisition	36
2.3.4	Secure Data Management With Blockchain	36
2.3.5	Immersive Data Visualization With AR/VR	37
2.4	Case Study	37
2.4.1	Monitoring Urban Air Quality With IoT Sensors	37
2.4.2	Analyzing Satellite Images for Urban Development and Planning	38
2.4.3	Drone Aerial Vehicle-Based Monitoring for Environmental Control	40
2.4.4	Augmented and Virtual Reality Uses in Planning and Monitoring Urban Environments	41
2.4.5	Combining Emerging Technologies and Remote Sensing	43
2.5	Frameworks for Integrating Multiple Data Sources	45
2.5.1	Platforms for Collaborative Work and Data Sharing	45
2.5.2	Regulatory Aspects and Policy Implications	48
2.5.3	Prospective Pathways and Difficulties	50
2.6	The Possible Effects of Next-Generation Connectivity and 5G	52
2.6.1	Privacy and Ethical Issues With Urban Remote Sensing	52
2.6.2	New Technologies' Scalability and Affordability	54
2.6.3	AR and VR's Place in the Future of Urban Environment Management	56
2.7	Conclusion	57
2.7.1	Future Gap	58
	References	58
3	Efficient Network and Communication Technologies for Smart and Sustainable Society 5.0	63
	<i>P. Kanaga Priya, R. Sivaranjani, Malathy Sathyamoorthy and Rajesh Kumar Dhanaraj</i>	
3.1	Introduction	64
3.1.1	Evolution of Societal Paradigms	64
3.1.2	Transition from Industry 4.0 to Society 5.0	68
3.1.3	Definition and Key Characteristics of Society 5.0	70
3.1.4	Importance of Efficient Network and Communication Technologies	72
3.1.5	Critical Technologies Shaping Smart and Sustainable Society 5.0	72

3.2	Literature Survey	73
3.3	Internet of Things for Smart Connectivity	76
3.3.1	IoT Applications in Smart Cities, Agriculture, Healthcare, and Industry	76
3.3.2	Challenges in IoT Implementation	79
3.3.3	Opportunities in IoT Implementation	79
3.4	Next-Generation Cutting Edge Communication Technologies: 5G and Beyond	80
3.4.1	Evolution of Cellular Communication Standards	80
3.4.2	5G Networks' Features and Capabilities	81
3.4.3	Emerging Trends and Technologies Beyond—5G (B5G) and 6G	82
3.5	Edge Computing: Decentralized Processing for Low Latency	83
3.5.1	Understanding Edge Computing Architecture	84
3.5.2	Edge Computing's Benefits for Analytics and Data Processing	85
3.5.3	Use Case and Deployment Scenario	86
3.6	Blockchain Technology: Securing Data Integrity and Trust	87
3.6.1	Fundamentals of Blockchain Technology	87
3.6.2	Applications in Secure Data Sharing, Supply Chain Management, and Decentralized Finance	89
3.6.3	Challenges and Potential Solutions	89
3.7	Artificial Intelligence in Network Optimization	90
3.7.1	Role of AI and Machine Learning in Network Management	91
3.7.2	AI-Driven Approaches for Resource Allocation and Optimization	91
3.8	Energy-Efficient Networking for Sustainability in Society 5.0	92
3.8.1	Strategies for Reducing Energy Consumption in Communication Networks	94
3.8.2	Green Networking Technologies and Practices in Society 5.0	94
3.9	Challenges and Opportunities in Implementing Efficient Network Technologies	95
3.10	Future Directions and Recommendations	96
3.10.1	Research Priorities for Advancing Network and Communication Technologies	97
3.10.2	Policy Recommendations for Fostering Sustainable Development in Society 5.0	97
3.10.3	Collaborative Efforts Toward Achieving a Smart and Sustainable Society 5.0	98

3.11	Conclusion	98
	References	99
4	Advanced Techniques for Human-Centric Sensing in Environmental Monitoring	101
	<i>S. Aathilakshmi, Visali C., T. Manikandan and Seifedine Kadry</i>	
4.1	Introduction	102
4.2	A Basic Human-Centric Sensing Mechanism	106
4.3	Types of Advanced HCS Environmental Monitoring System	110
4.3.1	Multispectral Sensors	110
4.3.2	Thermal Sensors	111
4.3.3	LiDAR	111
4.3.4	Hyperspectral Sensors	111
4.3.5	Photogrammetry Sensors	112
4.4	Applications in Environmental Monitoring	113
4.4.1	Smart Sensor	113
4.4.2	Wireless Network Technology	114
4.4.3	Passive Sensing Technology	115
4.4.4	Activity Recognition Technology	116
4.4.5	Gesture Recognition Technology	116
4.5	Conclusion and Future Prospects	117
	References	118
5	Energy-Aware System for Dynamic Workflow Scheduling in Cloud Data Centers: A Genetic Algorithm with DQN Approach	121
	<i>Hariharan B., Anupama C.G., Ratna Kumari Neerukonda and Rajesh Kumar Dhanaraj</i>	
5.1	Introduction	122
5.2	Related Works	124
5.3	Dynamic Workflow Scheduling System	127
5.3.1	System Architecture	127
5.3.2	Genetic Algorithm for Dynamic Workflow Scheduling	128
5.3.3	Deep Q-Learning for Dynamic Workflow Scheduling	130
5.3.4	Energy Consumption for Dynamic Workflow Scheduling	132
5.4	Problem Formulation and Proposed System Architecture	133
5.4.1	Hybrid Approach	133
5.4.2	Implementation of GA	135
5.5	Simulation Set-Up and Experimental Results	136

5.5.1	Makespan Computation	137
5.5.2	Energy Consumption Calculation	141
5.6	Conclusion	142
	References	142
6	Efficient Load Balancing and Resource Allocation in Networked Sensing Systems—An Algorithmic Study	145
	<i>Lalitha Krishnasamy, Divya Vetriveeran, Rakoth Kandan Sambandam and Jeneffa J.</i>	
6.1	Introduction to the Networked Sensing Systems	146
6.2	Understanding the Load Balancing Challenges	147
6.2.1	Types of Load Balancing	148
6.2.2	Load Balancing Technologies	149
6.3	Importance of Efficient Resource Allocation	150
6.4	Overview of Existing Approaches	151
6.4.1	Probabilistic Clustering	151
6.4.2	Non-Probability Clustering	152
6.5	Artificial Intelligence for Resource Handling	155
6.5.1	Naïve Bayes	157
6.5.2	Multi-Class SVM	157
6.5.3	AdaBoost	158
6.5.4	Clustering	159
6.5.5	Learning-Based Resource Allocation (LB-RA)	159
6.5.6	Neural Networks for Load Balancing and Resource Allocation	160
6.5.7	Reinforcement Learning	162
6.6	Real-World Applications	163
6.7	Performance Metrics	165
6.7.1	Throughput	165
6.7.2	Reaction Time	165
6.7.3	Latency	165
6.7.4	Versatility	165
6.7.5	Asset Use	165
6.7.6	Optimization	166
6.7.7	Fairness	166
6.7.8	MTTF	166
6.7.9	Cost Effectiveness	166
6.7.10	Adaptability	166
6.8	Research Directions	166
6.8.1	Edge Computing	167
6.8.2	ML and AI	167

6.8.3	Autonomous Resource Management	167
6.8.4	Containerization and Orchestration	167
6.8.5	Hybrid and Multi-Cloud Environments	167
6.8.6	Energy-Efficient Computing	168
6.8.7	Quantum Figuring	168
6.8.8	Asset the Executives	168
6.8.9	Security and Protection Contemplations	168
6.8.10	Cross-Domain Resource Allocation	168
6.9	Conclusion and Future Work	169
	Acknowledgments	169
	References	170
7	Sustainable Cities and Communities: Role of Network Sensing System in Action	173
	<i>Hitesh Mohapatra, Soumya Ranjan Mishra, Amiya Kumar Rath and Manjur Kolhar</i>	
7.1	Introduction	174
7.2	Literature Review	177
7.3	Proposed Study	181
7.3.1	Star Topology	181
7.3.2	Mesh Topology	182
7.3.3	Tree Topology	183
7.3.4	Clustered Topology	183
7.4	Performance Analysis	185
7.5	Mapping of Topology with Smart City's Applications	189
7.5.1	Mapping of Star Topology with Smart Parking Application	189
7.5.2	Mapping of Mesh Topology with Smart Grid Application	191
7.5.3	Mapping of Tree Topology with Smart Education Model	192
7.5.4	Mapping of Cluster Topology with Smart Health Care Model	194
7.6	Conclusion	195
	References	196
8	Air Pollution Monitoring and Control Via Network Sensing Systems in Smart Cities	199
	<i>S. Sharmila Devi</i>	
8.1	Introduction	199
8.2	Related Works	201
8.3	Air Quality System	203

8.4	Air Quality Monitoring Techniques	204
8.5	Conventional Air Pollution Monitoring	205
8.5.1	Manual Measurement and Evaluation of Air Quality	205
8.5.2	Automated Continuous Monitoring Devices	206
8.5.3	Monitoring Air Quality with Sensing Technology	207
8.6	Wireless Sensor Network for Air Monitoring	209
8.6.1	Wireless Sensor Networks	209
8.6.2	WSN Network Topologies	209
8.6.3	Zigbee Standard	211
8.7	Architecture of Wireless Sensor Networks	212
8.7.1	Fire and Flood Detection	214
8.7.2	Biocomplexity	214
8.7.3	Habitat Monitoring	215
8.7.4	Factors Influencing the Efficacy of Inexpensive Sensors in the Monitoring of Air Pollution	215
8.8	WSN-Based Air Pollution Monitoring in Smart Cities	216
8.9	Conclusion	221
	References	221
9	Interconnected Healthcare 5.0 Ecosystems: Enhancing Patient Care Using Sensor Networks	225
	<i>Ashwini A., Kavitha V. and Balasubramaniam S</i>	
9.1	Introduction to Healthcare 5.0	226
9.1.1	Evolution from Healthcare 4.0 to Healthcare 5.0	227
9.2	Real-Time Monitoring Using Sensor Networks	229
9.3	Advancements in Remote Patient Monitoring	231
9.3.1	Challenges in Healthcare 4.0	233
9.4	Early Disease Detection Through Sensor Networks	235
9.5	Leveraging Multisensor Data for Comprehensive Health Insights	237
9.6	Security Measures for Protected Health Information	240
9.7	Overcoming Infrastructure and Connectivity Barriers	241
9.8	Improving Treatment Plans Through Sensor-Generated Insights	242
9.9	Conclusion	243
	References	244

10 Farming 4.0: Cultivating the Future with Internet of Things Empowered on Smart Agriculture Solutions	247
<i>Ashwini A., S.R. Sriram, J. Manoj Prabhakar and Seifedine Kadry</i>	
10.1 Introduction to Smart Agriculture and IoT Integration	248
10.1.1 Evolution of Agriculture: From Traditional to Smart Farming	249
10.2 IoT Sensor Networks in Farming	250
10.2.1 IoT Sensors and Their Applications	251
10.3 Smart Pest and Disease Control in Crop Production	253
10.3.1 Meticulous Fertilization and Nutrition Control	253
10.3.2 Accurate Irrigation Techniques and Water Administration	255
10.4 Automation and Robotics in Agriculture	257
10.4.1 Agricultural Operations Using Automatic Systems	259
10.4.2 AI in Farm Automation	260
10.5 Cloud Computing for Agricultural Data Management	262
10.6 Big Data Analytics for Predictive Farming	264
10.7 Sustainable Practices with IoT in Agriculture	266
10.8 The Future Landscape of Farming 4.0	267
10.9 Conclusion	268
References	268
11 Public Safety Management in Smart Society 5.0: A Blockchain-Based Approach	273
<i>P.N. Senthil Prakash, S. Karthic and M. Saravanan</i>	
11.1 Introduction	274
11.2 Security Challenges in Society 5.0	278
11.3 Blockchain in Society 5.0	279
11.3.1 Blockchain for Refinery Industry	281
11.3.2 Blockchain in Identity Management	281
11.3.3 Blockchain and Its Impact in Healthcare	283
11.3.4 Blockchain for Supply Chain Management	285
11.3.5 Blockchain in Asset Management	285
11.3.6 Blockchain in Copyright Management	287
11.4 Conclusion	289
References	290

12 Virtualization of Smart Society 5.0 Using Artificial Intelligence and Virtual Reality	297
<i>Sakthivel Sankaran, M. Arun and R. Kottaimalai</i>	
12.1 Introduction to Smart Society 5.0	298
12.1.1 Smart Society 5.0 and Its Key Characteristics	298
12.1.2 Evolution from Previous Smart Society Models	299
12.2 Foundations of Virtual Reality	301
12.2.1 Brief History and Development of Virtual Reality	301
12.2.2 Key Components and Technologies in VR	302
12.2.3 VR Hardware and Software Ecosystems	303
12.3 Artificial Intelligence in Smart Societies	304
12.3.1 Overview of AI Technologies Shaping Smart Societies	304
12.3.2 Role of AI in Data Analytics, Automation, and Decision Making	306
12.3.3 AI-Driven Applications in Healthcare, Transportation, and Education	307
12.4 Integration of AI and VR	311
12.4.1 How AI and VR Technologies Complement Each Other	311
12.4.2 Examples of AI-Enhanced Virtual Reality Applications	312
12.4.3 Possibilities and Obstacles When Fusing AI with VR	312
12.5 AI and VR in Education	314
12.5.1 Virtual Classrooms and Immersive Learning Experiences	314
12.5.2 AI-Enabled Adaptive Learning Systems	314
12.5.3 Skill Development and Training Using VR and AI	315
12.6 Smart Society 5.0 Healthcare Innovations	315
12.6.1 Virtual Healthcare Consultations and Simulations	315
12.6.2 AI-Driven Diagnostics and Treatment Planning	316
12.6.3 VR and AI-Based Treatments and Rehab	316
12.7 Challenges and Future Directions	316
12.7.1 Current Obstacles to Integrate VR and AI in Smart Communities	316
12.7.2 Prospective Developments and Emerging Patterns in AI and VR in Smart Societies	317
12.7.3 Consider the Role of Emerging Technologies	317
12.8 Conclusion	318

12.8.1	Summary of AI and VR Technologies in Smart Societies	318
12.8.2	Vision for the Future of Smart Societies with AI and VR	318
	References	319
13	Battery Power Management Schemes Integrated with Industrial IoT for Sustainable Industry Development	323
	<i>D. Karthikeyan, A. Geetha, K. Deepa and Malathy Sathyamoorthy</i>	
13.1	Introduction	324
13.2	Current Battery Technologies	325
13.2.1	Metal–Air Battery	326
13.2.2	Lithium–Sulfur Battery	327
13.2.3	Batteries Beyond Lithium	328
13.3	Battery Energy Storage and Management	328
13.4	IoT and Cloud Computing Technology in BMS	334
13.5	Sustainable Developments via BMS	337
13.5.1	SDG8	337
13.5.2	SDG9	346
13.5.3	SDG12	346
13.5.4	SDG13	348
13.6	Conclusion	348
	References	349
14	Trends, Advances, and Applications of Network Sensing Systems	351
	<i>Ashwini A., Shamini G.I. and Balasubramaniam S</i>	
14.1	Introduction to Network Sensing Systems	352
14.1.1	Relevance in Different Sectors	353
14.2	Real-Time Trends in Sensor Technology	355
14.2.1	Advanced Sensing Modalities	355
14.2.2	Power-Efficient Designs	356
14.3	Advancements in Data Analytics	357
14.3.1	Big Data Analytics for Sensor-Generated Data	359
14.4	Applications in Healthcare	361
14.4.1	Remote Patient Monitoring	361
14.4.2	Smart Healthcare and Medical Establishments	362
14.4.3	Fall Detection and Old Care	362
14.5	Natural Disaster Detection with Response	363
14.5.1	Early Detection Systems	363

14.5.2	Satellite Imagery and Tracking	363
14.5.3	Resilient Communications Networks	363
14.5.4	Predictive Analysis and Modeling	364
14.6	Agricultural Sensing Systems	365
14.6.1	Crop Monitoring and Management	365
14.6.2	Soil Sensing and Precision Agriculture	365
14.6.3	Weather Monitoring and Forecasting	366
14.6.4	Livestock Monitoring and Management	366
14.6.5	Data Analytics and Decision Support System	366
14.6.6	Remote Monitoring and Automation	366
14.7	Intelligent Transportation Systems	367
14.8	Smart City Applications	368
14.9	Challenges	369
14.10	Conclusion	370
	References	370
	About the Editors	375
	Index	377

Preface

With today's improvements in wireless and mobile connectivity, Internet of Things (IoT) sensor technologies, and digital innovation, sustainability principles have started to reinforce one another. To switch to more resource-efficient solutions, use resources responsibly, and streamline operations, businesses must embrace digital transformation. Energy management, air pollution monitoring, fleet management, water management, and agriculture are a few examples of potential actuation sectors. Simultaneously, the expansion of IoT deployments and their integration into the contexts of 5G and upcoming 6G mobile networking necessitate that the solutions themselves be green and sustainable, incorporating, for instance, the use of energy- and environmentally-aware technical solutions for communications.

By offering previously unattainable solutions, networking can contribute to a more sustainable society by enabling the collection of data from new and heterogeneous sources in unique ways and from novel sources using novel technology. In addition, the networking-based solution itself needs to be sustainable or environmentally friendly. For instance, changing the network architecture and moving network equipment to key locations can reduce wasteful energy use. These goals drive the search for solutions, which range from "better" and novel sensing objects that need to be energy-efficient using mobile sensing devices.

The goal of "Networked Sensing Systems" is to present and highlight the most recent developments in sustainable networked sensing systems in a variety of contexts with the common goal of enhancing human well-being and halting climate change. Regardless of their area of expertise, the objective is to offer workable solutions that meet the major problems and difficulties in building a sustainable smart society 5.0. This book will serve as a potential platform to discuss networked sensing systems for a sustainable society, namely systems and applications based on mobile computers and wireless networks, while taking into account multidisciplinary approaches that emphasise the human element in resolving these difficulties.

Introduction to Network Sensing Systems in Society 5.0: Issues and Challenges

Ankit Kumar, Anurag Kumar Kanojiya and Subitha D.*

*School of Computer Science and Engineering, Vellore Institute of Technology,
Chennai, India*

Abstract

Network Sensing System in Society 5.0 provides unprecedented connectivity and data-driven solutions to numerous societal problems. But they also raise many questions and problems that need to be resolved to ensure they are used effectively and fairly. This content explores the key issues and challenges of the Society 5.0 community. Since sensors collect and transmit a lot of data continuously, data privacy and security become an important issue. Strong protection and encryption are required to prevent data from leakage, unauthorized access, and misuse. The integration and data sharing of many sensors and protocols depend on the interoperability and standardization of the sensor. So, the systems can be made more scalable and efficient using different structures and procedures. Transparency, impartiality, and fairness are among some of the ethical concerns under data analysis and algorithmic decision making. So, it is necessary to take necessary actions to ensure fair results and get rid of biases to maintain trust and prevent bad outcomes. Network Detection System 5.0 focuses on reliable power plans and strong communication methods; therefore, infrastructure flexibility and dependability are very important. Such vulnerabilities in the systems might have the potential to cause disturbances and may interfere with vital activities. Hence, it is necessary to invest in redundancy and resilience in infrastructure. Energy and safety are important issues due to the environmental impact of sensors and data processing. Energy-efficient solutions and renewable energy sources can reduce these impacts and promote sustainability. The development of technology, policy, and business management creates uncertainty about responsibility and control. Guidelines and policies should be developed to address legal, ethical, and social issues while promoting innovation and community service. Public

*Corresponding author: subitha.d@vit.ac.in

trust and acceptance are key to implementing Network Detection System 5.0. Transparent communication, community engagement, and meaningful feedback are critical to solving privacy, security, and consequence issues.

Keywords: Interoperability, standardization, transparency, energy efficiency, renewable smart grid, robust communication

1.1 What is Society 5.0?

Society 5.0 represents an enormous evolution in how data are accumulated, processed, and implemented to enhance various components of human existence [1–3]. While the idea of making use of statistics to improve efficiency and comfort is not always new, Society 5.0 distinguishes itself by means of expanding the scope of application throughout society in an incorporated manner. Unlike previous iterations, wherein computerized structures operated within specific domain names, like temperature control or transportation, Society 5.0 envisions a complete technique to optimizing all aspects of lifestyles.

The key distinction lies in the basic integration of structures to ensure happiness and safety in various sectors as well as strength, transportation, healthcare, buying, training, employment, amusement, and so forth. In Society 5.0, the focus shifts from isolated solutions to interconnected structures that work together seamlessly. This community allows the gathering of numerous certain real-world facts that are then processed by means of AI and other state-of-the-art IT structures. What sets Society 5.0 apart is the ability to use these vast amounts of data to directly shape human behavior and actions resulting in a more fulfilling and richer lifestyle. Unlike previous models where data guide only individual policies, Society 5.0 influences social behavior at a broad scale. Essentially, Society 5.0 creates an iterative cycle of constantly collecting, analyzing, and transforming data into meaningful insights that improve tangible real-world results. This cycle works across society and ensures that the benefits of data-driven decision making extend to all aspects of human life. As we dive deeper into the discussion, it is clear that Citizenship 5.0 represents a significant step forward in social improvement and embodies a future where data-driven insights pave the way for a happier, more comfortable society promising sustainability.

1.1.1 Advancements in Society 5.0 Over Society 4.0

Society 5.0 represents a significant advancement over Society 4.0 addressing various issues and challenges while offering significant improvements in several key areas. Let us see how Society 5.0 is superior to its predecessor and overcomes the limitations faced in Society 4.0 depicted in Figure 1.1.

1.1.2 Integration and Interconnectivity

Using Cyber-Physical Systems and the Internet of Things, Society 4.0 introduced the idea of connection between machines. However, those systems were mostly functioning in isolation, which resulted in dispersed data and ineffective system-to-device connection. Also, it had a vast communication gap between the interconnected devices. Society 5.0, forces integration and relationships between different entities. It made it easier for systems and domains to work jointly and communicate with one another promoting complete optimization and combined interactions.

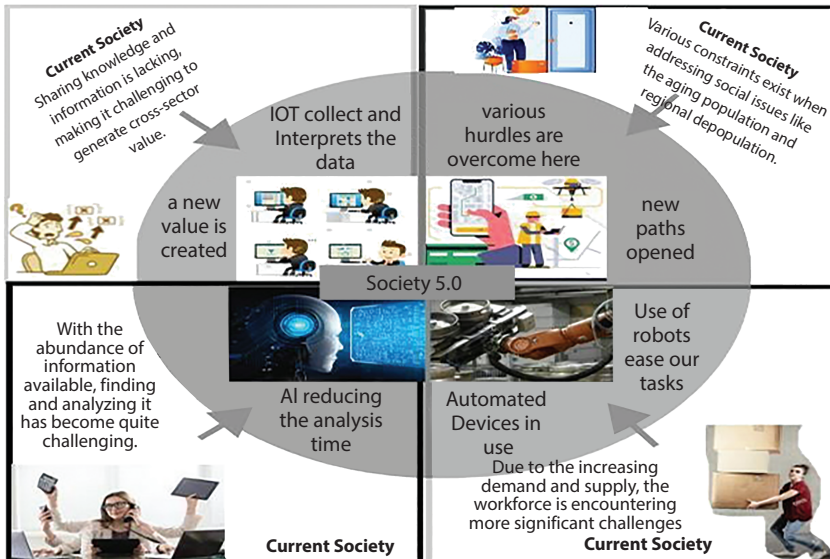


Figure 1.1 Interaction of society 5.0 and the current society.

1.1.3 Data Utilization and Analysis

Although Society 4.0 placed a force or intensity of expression that gives impressiveness or importance to something on connection and data collecting, it had created some trouble with the in-efficient use and analysis of the large volumes of data. The extraction of significant insights was hampered by no longer used or useful analytical methodologies and limited processing capabilities. Society 5.0 leverages advanced technologies like Artificial Intelligence (AI) and Big Data analytics to unlock the full potential of data. It employs sophisticated algorithms to analyze complex datasets in real time extracting actionable insights to drive decision making and innovation.

1.1.4 Personalization and Customization

Based on the user's preferences and actions, Society 4.0 introduced customized experiences and services. However, these efforts have largely failed due to a lack of awareness of unique needs and preferences. By exploiting complicated AI algorithms to analyze a wealth of information about unique interests, behaviors and situations, Society 5.0 elevates personalization to a new level. This can provide highly customized and flexible experiences in various sectors such as retail, healthcare, and education.

1.1.5 Sustainability and Ethical Considerations

Society 4.0 [4] largely ignores the problem of sustainability and ethics by prioritizing economic expansion and technological development. Rapid technological progress has worsened social inequality and destroyed the environment. Society 5.0 involves a balanced and holistic policy approach, with a strong emphasis on social responsibility, ethics, and the environment. It seeks to use technology for the greater good in addition to promoting equity, environmental protection, and ethical decision making at all levels of life with greater integration, improved data management, customized experiences, navigation, ethical considerations, and human-centered design. Society 5.0 has a huge step up from Society 4.0.

1.1.6 Human-Centric Design and Empowerment

Automation and digitization [5, 6] were brought about by Society 4.0 [4], while it was criticized for putting efficiency and productivity above the empowerment and welfare of people. Workers often believed that

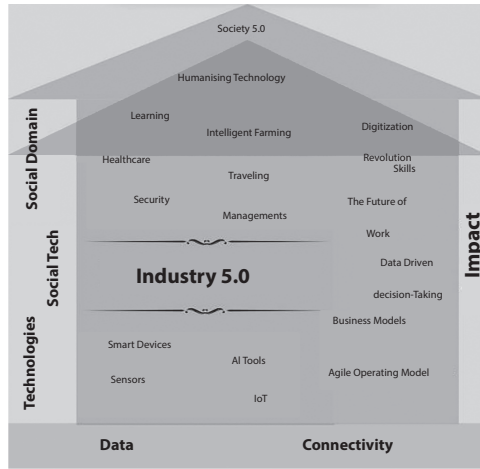


Figure 1.2 Industry 5.0—pyramid with human-centric technique.

methods pushed by technology were forcing them out or excluding them. Humanizing design and empowerment are given the most importance in Society 5.0 in Figure 1.2 ensuring that technology advances, rather than eclipses, mankind. To increase creativity, productivity, and well-being, it promotes the growth of human potential using technology and promotes cooperation between people and machines.

1.2 Network Sensing Systems in Society 5.0

Society 5.0 is characterized by extensive integration, advanced data testing, reputation stability, and the concept of web sentiment processing as the core represents a well-designed basic system, and it is a real analysis of high sensitivity and elevation analysis. Monitoring world events, analytics, trends and in real time, networked sensing systems play a key role in enabling seamless and streamlined integration of various social services from transportation and healthcare to energy management and urban planning through community development.

Data-driven decision-making principle [7] is a foundation of sensing systems based on networks, where data from IoT devices, sensors, and social media platforms are collected in real time from diverse sources. This information stream offers invaluable insights into the complex nature of the dynamics of the society and allows the stakeholders to make smart decisions about how to prevent the emerging problems and take advantage

of the opportunities. Through application of advanced data analytics methods, including machine learning and predictive modeling, network sensing systems can obtain actionable information from the data, and this information can then be applied to activities such as predictive maintenance, resource optimization, and risk management.

In addition to that, network sensing system in Society 5.0 also promotes creative and user-friendly design and public participation resulting in technological developments that serve people's needs and goals. Because of increase in openness, involvement, and democratic governing bodies, these systems have encouraged civilians to be the designers of their urban environments, health services, and transportation systems. Citizen feedback mechanisms and mutually beneficial decision-making platforms in network sensing systems increase stakeholder participation promoting citizen contact and giving them chance to participate in decision-making processes. Moreover, network sensing system in Society 5.0 do follow some ethical and sustainable principles by trying to protect privacy and data security to promote social fairness and reduce negative effect on the environment. These systems use smart meters, sensors for monitoring the environment, and renewable energy technologies to make it simpler to use resources more efficiently, reduce carbon production, and promote environment-friendly behavior. Furthermore, moral standards, encryption technologies, and data privacy rules assure private data security while maintaining public trust in the digital economy.

1.3 Issues and Challenges

1.3.1 Data Privacy and Security

Modeled upon a data-driven society [8], Society 5.0 stresses the concept of data-driven decision making and its capacity to impact growth in society. This viewpoint deviates from the traditional comprehension of the media by prioritizing data in the advancement of societal development. In the context of Society 5.0, data are more than just processed information; it also serves as a catalyst for practical findings that inspire transformative change in a wide range of sectors. The core data-driven society in Society 5.0 is enshrined in the Japanese government's "Development Plan 2018," where two terms explicitly reflect the data-driven society, as described in official documents in the field of computer physical systems (CPS) [9] and the Internet of Things (IoT) [10], which harnesses the power to digitize networks in various industrial sectors. This digitization facilitates the

collection of vast amounts of data, which is then transformed into actionable intelligence and applied to real-world situations into, thereby increasing the efficiency and effectiveness of decision-making processes.

The evolution of how data affects the real world of Society 5.0 is multifaceted. First, data indirectly influence social outcomes through human decision-making processes. For example, traditional approaches to urban planning have limited data sources which prevents the accuracy of the decision making process, but in a data-driven society [26], real-time data from multiple sources resides that smartphones, CCTV cameras, and transport cards provide a comprehensive understanding of cities dynamics empower stakeholders to make informed decisions, and thus the public fabric. Second, the public use of data in Society 5.0 is characterized by the direct impact of data through automated processes. For example, the complexity of adapting traffic signals to different needs for traffic management is beyond human capacity. In response, AI-controlled systems [11] use continuous input data to iteratively adjust control algorithms independently adapting to changing conditions and traffic. This paradigm shift from human- to AI-controlled systems model data as the primary driver of social work in Society 5.0.

More specifically, Society 5.0 indicates an evolution of paradigms toward a data-driven society in which data go beyond its usual use as information to become an essential part of social progress. By using data, Society 5.0 aims to improve efficiency, encourage innovation across a range of industries, and affect decision-making processes, for example. Data have a crucial role in deciding the future of society, as shown by the revolutionary potential of data-driven techniques, which use innovations in traffic management and urban planning as examples.

1.3.2 Importance of Privacy and Security

Operational approach of Society 5.0 revolves around the use of data to drive out societal progress; a huge responsibility is devolved to data privacy and security [12–14]. These two fundamental elements are very indispensable for sustaining data management integrity and for ethical application of the data. With the data increasingly decisive in the making decisions and also transforming societies, a major concern that should be taken care of is the confidentiality of the data and the privacy of an individuals' information.

Surveillance of the information is the basis for the reliability and credibility of the stakeholders, which should be based on data privacy and also security. Through the application of well-defined regulations

and protocols, organizations not only mitigate many legal risks but also create a platform that allows them to publicize the data and innovate. Obedience with the legal frameworks as GDPR and also CCPA is very critical reflecting the accountable control of the ethical data and also responsibility.

Strong security mechanisms [24], including encryption and access control, ensure the checking on the possible threats, such as data breaches and also unauthorized access. This preventive approach reduces the chance of misuse and enhances the secure handling of the data across the whole digital territory. Ethical considerations assume the first place in the directing of the data use in proper ways. Maintaining the privacy rights of the individuals and ensuring equality of the access to data are ethically very important components of the stewardship, which both promote openness and accountability within the data-driven environment.

Furthermore, the safeguard of data confidentiality and privacy will provide a secure platform for the development of innovation in the social structure of Society 5.0. Through such way of confining research and experiments on the data, organizations, in turn, will be able to continue innovating, and the technology will keep on being improved while protecting their intellectual property rights, and also assuring data integrity. In fact, data privacy and also security are not luxury building blocks of humanization in Society 5.0. At every stage of use, there is integration of these living organisms into data-driven decision-making processes, which guarantees just and responsible utilization of data to promote innovation and drive social change.

1.4 Encryption and Decryption Techniques: Safeguarding Data Integrity

Encryption and decryption methods are essential for guaranteeing the security, confidentiality, and integrity of sensitive data in the era of Society 5.0, when data are the essential resource for society. By making data illegible for unauthorized users and reducing the likelihood of unlawful access and exploitation, these techniques serve as the cornerstone of data protection initiatives. Let us explore the complexities of encryption and how it is decrypted in the context of Society 5.0. In Society 5.0 ecosystems, encryption is the first line of defense for data security [12]. Different encryption techniques are used to convert plaintext data into cipher text. Symmetric

Encryption is the method that encrypts and decrypts data using the same key. One of the most straightforward symmetric encryption [15] methods is the Caesar Cipher [16], which is also one of the simplest to break. Many additional symmetric encryption [15] methods have since been developed by cryptologists, including some that are currently in use to encrypt data like passwords. Asymmetric Encryption [17], also referred to as public-key cryptography, is a type of data encryption in which the matching decryption key, also known as the private key, and the encryption key, also known as the public key, are distinct. Only the matching private key can be used to decrypt an exchange that has been encrypted using the public key. In Society 5.0 contexts, key exchange techniques and secure communication channels are made available by algorithms like Elliptic Curve Cryptography [18] (ECC) and Rivest–Shamir–Adleman (RSA) [19]. Homomorphic Encryption [20] is an enhanced technique for encryption that preserves data privacy and encourages data analysis and interaction by enabling computations to be done on encrypted data without the need for decryption.

1.4.1 Decryption Technology

Decryption is the process of restoring encrypted text information to its original text allowing users to securely access encrypted information. Key technical points include the following:

Key Management: Effective management of encryption keys is crucial for a secure decryption process. Key management systems, including key identification, storage, rotation and destruction, ensure the confidentiality and integrity of encryption keys [19] in a community 5.0 environment.

Authentication: Verifying the user's identity and providing appropriate decryption authority are crucial to ensuring data security. Multi-factor authentication (MFA) [21] and biometric authentication [21] methods increase the security of the decryption process and reduce the risk of unauthorized access.

Decryption Algorithm: Using an industry-standard decryption algorithm corresponding to the encryption method used is crucial for successful data decryption. The organization uses advanced decryption algorithms to ensure data integrity and confidentiality throughout the decryption process.

1.4.2 Challenges and Decisions

While encryption and decryption technologies provide significant benefits in data protection in Society 5.0, some challenges and decisions need to be addressed as follows:

Performance: Strong Encryption algorithm will increase performance And affects system latency and response capacity. Security measures along with performance considerations are necessary for the integration of communication and decryption technologies.

Key Management Complexity: Managing encryption keys across multiple systems and platforms can be complex. Implementing a strong key management and encryption key management solution is critical to managing key lifecycles.

Compliance: When using encryption and decryption technologies, data protection laws and regulations (such as GDPR and CCPA) [22] must be followed. For staying within the law and fulfill regulatory requirements, it is really important to make sure that encryption solutions follow the rules set by regulators. Encryption and decryption strategies are vital for retaining data integrity and secrecy in Society 5.0. Organizations can shield sensitive records in information-pushed ecosystems by way of using robust encryption algorithms, effective key management techniques, and solid decryption techniques.

1.4.3 Interoperability Challenges in Society 5.0: A Tripping Block on the Road to a Hyperconnected Future

Society 5.0, which promises us of a hyper-connected and intelligent society, promises a future in which technology smoothly integrates into all aspects of our life. Consider a scenario in which smart cities optimize traffic flow, linked homes anticipate our wants, and intelligent healthcare systems deliver individualized treatment. However, this utopian vision is dependent on a critical factor: compatibility.

1.5 Understanding Interoperability on Society 5.0

Interoperability refers to the capability of various systems and gadgets to communicate and trade facts seamlessly. In the context of Society 5.0, this interprets to make that fact from diverse sources, including clever sensors, wearables, and infrastructure structures, may be simply incorporated and