PROSPECTS IN SMART TECHNOLOGIES

WSN and IoT

An Integrated Approach for Smart Applications

Edited by SHALLI RANI
and ASHU TANEJA

CRC Press
Taylor & Francis Group

WSN and IoT

Nowadays, all of us are connected through a large number of sensor nodes, smart devices, and wireless terminals. For these Internet of Things (IoT) devices to operate seamlessly, the Wireless Sensor Network (WSN) needs to be robust to support huge volumes of data for information exchange, resource optimization, and energy efficiency. This book provides in-depth information about the emerging paradigms of IoT and WSN in new communication scenarios for energy-efficient and reliable information exchange between a large number of sensor nodes and applications.

WSN and IoT: An Integrated Approach for Smart Applications discusses how the integration of IoT and WSN enables an efficient communication flow between sensor nodes and wireless terminals and covers the role of machine learning (ML), artificial intelligence (AI), deep learning (DL), and blockchain technologies which give way to intelligent networks. This book presents how technological advancement is beneficial for real-time applications involving a massive number of devices and discusses how the network carries huge amounts of data allowing information to be communicated over the Internet. Intelligent transportation involving connected vehicles and roadside units is highlighted to show how a reality created through the intelligent integration of IoT and WSN is possible. Convergence is discussed and its use in smart healthcare, where only through the intelligent connection of devices can patients be treated or monitored remotely for telemedicine or telesurgery applications. This book also looks at how sustainable development is achieved by the resource control mechanism enabling energy-efficient communication.

A wide range of communication paradigms related to smart cities, which includes smart healthcare, smart transportation, smart homes, and intelligent data processing, are covered in the book. It is aimed at academicians, researchers, advanced-level students, and engineers who are interested in the advancements of IoT and WSN for various applications in smart cities.

Prospects in Smart Technologies

Series Editor
Mohammad M. Banat
Mohammad M. Banat, Jordan University of Science and Technology, Irbid, Jordan
banat@just.edu.jo
Sara Paiva, Instituto Politécnico de Viana do Castelo, Viana do Castelo, Portugal
sara.paiva@estg.ipvc.pt

Published Titles

Emerging Technologies for Sustainable and Smart Energy
Edited by
Anirbid Sircar, Gautami Tripathi, Namrata Bist, Kashish Ara Shakil, and Mithileysh Sathiyanarayanan

CYBORG
Human and Machine Communication Paradigm
Kuldeep Singh Kaswan, Jagjit Singh Dhatterwal, Anupam Baliyan, and Shalli Rani

Emerging Technologies and the Application of WSN and IoT
Smart Surveillance, Public Security, and Safety Challenges
Edited by
Shalli Rani and Himanshi Babbar

WSN and IoT
An Integrated Approach for Smart Applications
Edited by
Shalli Rani and Ashu Taneja

For more information on this series, please visit: https://www.routledge.com/Prospects-in-Smart-Technologies/book-series/CRCPST

WSN and IoT

An Integrated Approach for Smart Applications

Edited by
Shalli Rani and Ashu Taneja

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

Designed cover image: Shutterstock

First edition published 2024
by CRC Press
2385 NW Executive Center Drive, Suite 320, Boca Raton FL 33431

and by CRC Press
4 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN

CRC Press is an imprint of Taylor & Francis Group, LLC

ISBN: 978-1-032-56689-4 (hbk)
ISBN: 978-1-032-56771-6 (pbk)
ISBN: 978-1-003-43707-9 (ebk)

DOI: 10.1201/9781003437079

Typeset in Times
by KnowledgeWorks Global Ltd.

Contents

List of Figures and Tables vii
Preface xv
Acknowledgments xvii
Editors xix
Contributors xxi

Chapter 1 Introduction to IoT and WSN 1

Jyoti Maini and Shalli Rani

Chapter 2 The Role of Sustainable IoT in Present-Day Life 35

Parul Saini, Lipika Gupta, Shivani Malhotra, and Imali Dias

Chapter 3 Designing an Integrated IoT-WSN Framework for Smart City Applications 64

Sanjivani Hemant Kulkarni, Namrata Gawande, Ashwin S. Chatpalliwar, Namita Parati, Kishor S. Wagh, Deepak T. Mane, and Basant Tiwari

Chapter 4 Principles of Artificial Intelligence in the Internet of Things 88

Ankita Sharma and Shalli Rani

Chapter 5 Blockchain-Based Communication Frameworks for Smart Vehicles 109

Rakhi Mutha, Neeraj, and Ashu Taneja

Chapter 6 A Sustainable IoT-Based Smart Transportation System for Urban Mobility 144

Mahendra Balkrishna Salunke, Shailesh V. Kulkarni, Shraddha Ovale, Bhushan M. Manjre, Suresh Limkar, Farhadeeba Shaikh, and Vyasa Sai

Chapter 7 Optimizing Content Delivery in ICN-Based VANET Using Machine Learning Techniques 165

Rais Allauddin Mulla, Mahendra Eknath Pawar, Anup Bhange, Krishan Kumar Goyal, Sashikanta Prusty, Samir N. Ajani, and Ali Kashif Bashir

Chapter 8 The Role of IoMT Technologies in Revolutionizing Healthcare: A Comprehensive Overview 187

Sushmita Sunil Jain, Saurabh Manoj Kothari, and Satyam Kumar Agrawal

Chapter 9 Deep Learning and Its Applications in Healthcare.......................... 203

Shubham Gupta, Pooja Sharma, and Thippa Reddy

Chapter 10 An Explainable Deep Learning Model for Clinical Decision Support in Healthcare.. 225

Shrinivas T. Shirkande, Sarika T. Deokate, Sulakshana Sagar Malwade, Raju M. Sairise, Ashwin S. Chatpalliwar, Rashmi Ashtagi, Vinit Khetani, and Syed Hassan Ahmed

Chapter 11 Deep Learning Models for Automated Diagnosis of Brain Tumor Disorder in Smart Healthcare 243

Kamini Lamba and Shalli Rani

Chapter 12 6G and Distributed Computing for IoT: A Survey 264

Abhishek Hazra, Mainak Adhikari, and Lalit Kumar Awasthi

Chapter 13 Designing a Decentralized IoT-WSN Architecture Using Blockchain Technology 291

Vaibhav V. Gijare, Satpalsing D. Rajput, Srinivas Ambala, Mrunal Swapnil Aware, Wankhede Vishal Ashok, Yatin Gandhi, and Imran Memon

Chapter 14 Privacy-Preserving Machine Learning on Non-Co-Located Datasets Using Federated Learning: Challenges and Opportunities.. 314

Jyoti L. Bangare, Nilesh P. Sable, Parikshit N. Mahalle, and Gitanjali Shinde

Chapter 15 Deep Learning Method for Hyperspectral Image Classification 336

Parul Bhanarkar and Salim Y. Amdani

Chapter 16 Toward Smarter Industries: Security Framework Using Attribute-Based Encryption and Systematic Solutions 355

Shruti and Shalli Rani

Index.. 379

List of Figures and Tables

Figure 1.1	Internet of Things.	2
Figure 1.2	Layers of IoT architecture.	4
Figure 1.3	IoT architecture.	5
Figure 1.4	Underground WSNs.	7
Figure 1.5	Multimedia WSNs.	8
Figure 1.6	Underwater WSNs.	9
Figure 1.7	Wireless sensor network.	10
Figure 1.8	Wireless sensor network topologies.	11
Figure 1.9	Point-to-point network.	11
Figure 1.10	Star network.	12
Figure 1.11	Tree network.	13
Figure 1.12	Smart city.	17
Figure 1.13	IoT in healthcare.	17
Figure 1.14	Smart farming.	18
Figure 1.15	Smart homes.	19
Figure 1.16	Applications of IoT and WSN.	20
Figure 1.17	Edge computing.	21
Figure 1.18	AI and ML.	24
Figure 2.1	Basic architecture of an IoT system.	36
Figure 2.2	Benefits of IoT in every field.	38
Figure 2.3	An illustration of sustainable IoT using solar energy to power IoT nodes.	39
Figure 2.4	Major contributing factors of sustainable IoT devices.	40
Figure 2.5	Reducing the carbon footprint using sustainable approaches.	44
Figure 2.6	Key strategies for increasing energy efficiency.	45
Figure 2.7	Contribution of 5G technology to lowering the carbon footprint.	47
Figure 2.8	Two contributing factors for sustainable development.	52

Figure 2.9 Application areas of IoT. 53
Figure 2.10 Benefits of IoT in agriculture with SDGs. 55
Figure 2.11 Benefits of IoT in healthcare with SDGs. 56
Figure 2.12 Some of the latest developments of IoT-enabled healthcare products. 57
Figure 2.13 IoT in the smart city with the sustainable development goals (SDGs) of the United Nations. 58
Figure 2.14 IoT-based manufacturing industries with SDGs of the United Nations. 59
Figure 3.1 IoT-WSN integrated framework. 67
Figure 3.2 IoT-WSN framework with cloud infrastructure. 78
Figure 4.1 Relationship between AI, ML, and DL. 89
Figure 4.2 The working of AI. 90
Figure 4.3 AI principles. 90
Figure 4.4 Use of AI data mining. 92
Figure 4.5 Techniques of AI. 93
Figure 4.6 ML classification algorithms. 94
Figure 4.7 Comparison of the accuracy of ML classification algorithms. 94
Figure 4.8 DL classification algorithms. 95
Figure 4.9 Comparison of DL classification algorithms. 95
Figure 4.10 Computer vision. 96
Figure 4.11 AI-powered IoT. 98
Figure 4.12 Steps for AI-IoT. 99
Figure 4.13 Applications of AI-IoT. 105
Figure 5.1 Smart vehicles for clean mobility. 110
Figure 5.2 Vehicle-to-vehicle (V2V) communication. 110
Figure 5.3 Vehicle-to-infrastructure (V2I) communication. 111
Figure 5.4 Vehicle-to-cloud (V2C) communication. 111
Figure 5.5 Vehicle-to-pedestrian (V2P) communication. 112
Figure 5.6 Vehicle-to-grid (V2G) communication. 112
Figure 5.7 Role of blockchain technology in addressing these challenges. 115

Figure 5.8 Core principles of blockchain. 116
Figure 5.9 Components of blockchain. 118
Figure 5.10 Blocks, headers, and transactions in a blockchain. 119
Figure 5.11 Consensus algorithms. 120
Figure 5.12 Types of blockchain. 120
Figure 5.13 Cryptographic techniques used in blockchain. 122
Figure 5.14 Merkle tree. 123
Figure 5.15 Secure vehicle-to-vehicle (V2V) communication. 124
Figure 5.16 Trusted vehicle-to-infrastructure (V2I) communication. 126
Figure 5.17 Immutable data logging and tamperproof records. 128
Figure 5.18 Smart contract. 130
Figure 5.19 Blockchain and IoT integration. 135
Figure 5.20 Blockchain, smart contracts and AI integration. 136
Figure 6.1 IoT-based smart transportation system. 145
Figure 6.2 Smart transportation system. 147
Figure 6.3 Design for a smart transportation system. 149
Figure 6.4 Traffic optimization. 151
Figure 6.5 Flowchart for traffic flow prediction. 152
Figure 6.6 IoT-based smart transportation system. 155
Figure 6.7 Outcome. 158
Figure 6.8 Autonomous vehicles and traffic integration framework. 159
Figure 6.9 Integration of mobility-as-a-service (MaaS) with a smart transportation system. 161
Figure 7.1 Architecture for zone-based congestion control in VANET. 169
Figure 7.2 Basic ICN architecture in VANET. 171
Figure 7.3 Communication model in information-centric networking (ICN). 172
Figure 7.4 ICN-based content delivery. 173
Figure 7.5 VANET machine learning model. 177
Figure 7.6 NDN using deep learning. 180
Figure 7.7 Collaborative filtering powered by AI in the edge cloud. 180

Figure 7.8 CCN architecture. 182

Figure 8.1 Development of IoMT. 191

Figure 8.2 Architecture of IoMT. 192

Figure 8.3 Types of IoMT devices. 193

Figure 8.4 Different applications of IoMT. 196

Figure 9.1 General structure of a healthcare network. 205

Figure 9.2 Healthcare monitoring system (using both in-building and mobile antennas). 206

Figure 9.3 Patient monitoring and tracking in a hospital ward. 208

Figure 9.4 Applications of a Recommender System. 209

Figure 9.5 Overall structure of the Health Recommendation System (HRS). 210

Figure 9.6 The flow of information in MHealth. 211

Figure 9.7 Artificial neural network (ANN) and deep learning (DL) topologies are compared. 212

Figure 9.8 Deep learning applications in healthcare. 216

Figure 9.9 The machine learning (ML) process. 216

Figure 9.10 Categorization of machine learning (ML) algorithms. 217

Figure 9.11 Hierarchical representation of deep learning. 218

Figure 9.12 The architecture of a convolutional neural network. 219

Figure 9.13 The deep belief network (DBN) framework. 221

Figure 9.14 A representation of an autoencoder. 221

Figure 10.1 Clinical decision support system. 226

Figure 10.2 Explainable deep learning models. 229

Figure 10.3 Communication model in the CDS system. 230

Figure 10.4 Explainable deep learning model for clinical decision support. 233

Figure 10.5 Integration of EDL methods into WSN and IoT. 235

Figure 10.6 Precision. 236

Figure 10.7 Recall. 236

Figure 10.8 F1-Score. 237

Figure 10.9 Accuracy. 237

Figure 10.10 Comparative evaluation of explainable deep learning models. 238
Figure 11.1 Basic architecture of a traditional artificial neural network. 244
Figure 11.2 Basic architecture of a deep neural network. 244
Figure 11.3 Basic architecture of an effective hybrid model with style-transfer learning. 248
Figure 11.4 Basic architecture of federated learning. 249
Figure 11.5 Basic architecture of convolutional neural networks. 250
Figure 11.6 Basic architecture of recurrent neural networks. 251
Figure 11.7 Basic architecture of long short-term memory model. 251
Figure 11.8 Basic architecture of a convolutional-based autoencoder (AE). 252
Figure 11.9 Basic architecture of generative adversarial network. 253
Figure 11.10 Opportunities in smart healthcare. 256
Figure 11.11 Current challenges in IoT-based smart healthcare. 257
Figure 12.1 IoT and fog–cloud architecture. 266
Figure 12.2 Requirements of 6G in IoT technology. 275
Figure 12.3 IoT–cloud layered model. 279
Figure 12.4 Standard fog computing architecture. 280
Figure 12.5 Components and functionalities of serverless computing. 281
Figure 12.6 Components and functionalities of container-based scheduling. 282
Figure 13.1 Overview of IoT-WSN architecture. 292
Figure 13.2 Working flow diagram of IoT-WSN architecture using blockchain technology. 293
Figure 13.3 Basic block diagram of IoT-WSN architecture. 297
Figure 13.4 Overview of blockchain technology. 302
Figure 13.5 Block overview of proposed IoT-WSN architecture. 303
Figure 13.6 Basic diagram of blockchain-based IoT-WSN architecture. 305
Figure 13.7 Block diagram of decentralization in IoT-WSN architecture compared to centralized architecture. 305
Figure 14.1 Machine learning approaches for privacy preservation in IoT. 315

Figure 14.2 Federated learning approach. 316

Figure 14.3 Horizontal federated learning. 318

Figure 14.4 Vertical federated learning. 319

Figure 14.5 Federated learning on non-co-located datasets. 325

Figure 14.6 Flow diagram for federated learning with secure aggregation. 327

Figure 15.1 Hyperspectral image classification. 337

Figure 15.2 Integration of hyperspectral imaging (HSI) with IoT and WSN. 340

Figure 15.3 Convolutional neural network (CNN) architecture for hyperspectral image classification. 343

Figure 15.4 Recurrent neural network (RNN) architecture for hyperspectral image classification. 344

Figure 15.5 Deep belief network (DBN) architecture for hyperspectral image classification. 345

Figure 15.6 Precision. 349

Figure 15.7 Recall. 349

Figure 15.8 F1-Score. 349

Figure 15.9 Accuracy. 349

Figure 15.10 Comparative analysis. 350

Figure 15.11 Object detection on hyperspectral images in wireless networks. 351

Figure 16.1 Industry 4.0's various manufacturing sectors. 356

Figure 16.2 Architecture of the attribute-based encryption (ABE) scheme. 358

Figure 16.3 Characteristics of Industry 5.0. 361

Figure 16.4 Opportunities of Industry 5.0. 362

Figure 16.5 Various applications of Industry 5.0. 363

Figure 16.6 Architecture of the Industrial Internet of Things (IIoT). 369

Figure 16.7 Outline of the proposed IIoT framework using the ABE model. 371

Figure 16.8 Steps for obtaining a sustainable model in Industry 5.0. 373

Table 1.1 Differences between WSN and IoT 13

Table 1.2 Edge Computing in IoT and WSN 23

Table 1.3 Tools for Blockchain 28

Table 2.1 Different Factors and Technologies Used for Making Sustainable IoT Systems 49

Table 3.1 Comparison of Sensor Types Utilized in Smart City Applications 70

Table 3.2 Protocols Used in Smart City Applications for Communication 76

Table 3.3 Comparative Study of Various Machine Learning Algorithms Used in an IoT-WSN Framework for Smart City Applications 81

Table 4.1 Comparison Table Based on AI Principles, Techniques and Applications 106

Table 6.1 Outcomes of the IoT-based smart transport system 157

Table 6.2 Integration of Autonomous Vehicles 160

Table 6.3 Integration of Mobility-as-a-Service (MaaS) 161

Table 7.1 Summary of Different Methods and Common Pitfalls 170

Table 7.2 Comparison Emphasizing the Key Traits of Machine Learning Methods 178

Table 7.3 Deep Learning/Machine Learning Analysis in Detail 181

Table 8.1 Differences between IoT and IoMT 189

Table 9.1 Summary of Deep Learning Algorithm Models 219

Table 10.1 Publically Available Datasets 232

Table 10.2 Analysis of Explainable Methods 235

Table 11.1 Comparison of DNN Approaches in Healthcare 245

Table 11.2 Parameter-Based DL and IoT Approaches 246

Table 11.3 State-of-the-Art Techniques for Diagnosing Brain Tumors 254

Table 11.4 State-of-the-Art Techniques for Diagnosing Brain Tumors 255

Table 11.5 State-of-the-Art Techniques for Diagnosing Brain Tumors 255

Table 12.1 Comparison between 6G and the Existing Communication Technologies 267

Table 12.2 Performance Analysis among the Existing Research 283

Table 13.1 Comparative Study of the Components of a Decentralized IoT-WSN System 296

Table 15.1 Publically Available Hyperspectral Image Datasets 342

Table 15.2 Comparison of Deep Learning Techniques for Hyperspectral Image Classification 346

Table 15.3 Pavia University Hyperspectral Dataset 347

Table 15.4 Experimental Results 348

Table 16.1 Differences between Industry 4.0 and Industry 5.0 360

Table 16.2 Differences between the use of ABE in Industry 4.0 and Industry 5.0 367

Preface

This book presents the integration of the Internet of Things (IoT) and Wireless Sensor Networks (WSNs) for smart applications. It includes the emerging technologies of IoT and WSN, the latest innovations, trends, and concerns, as well as practical challenges encountered, and solutions adopted.

At present, all of us are connected through a large number of sensor nodes, smart devices, and wireless terminals. For these IoT devices to operate seamlessly, the WSNs need to be robust. To support huge volumes of data for information exchange, resource optimization and energy efficiency play an important role. The role of machine learning (ML), artificial intelligence (AI), blockchain, caching, deep learning (DL) in optimum network performance will lead to smarter applications of the future. A wide range of communication paradigms pertaining to smart applications, which includes smart cities, smart healthcare, smart transportation, and intelligent data processing, are also discussed.

This book also covers a thorough convergence of IoT and WSN for different use case scenarios. It is revealed that how a set of key enabling technologies (KET) related to network management, resource control, data sensing, decision-making, and automation can be efficiently integrated in one system. The technological advancement is beneficial for real-time applications involving a massive number of devices. The technology can be extremely useful for Industrial IoT (IIoT) and Industry 5.0. The vision of intelligent transportation which involves connected vehicles and the road side units can be made a reality through the intelligent integration of IoT and WSN. This convergence finds usage in smart healthcare where through the intelligent connection of the devices, the patients can be treated or monitored remotely for telemedicine or telesurgery applications. The resource control mechanism enables energy efficient communication for sustainable development. This book provides step-by-step guidance to readers, starting from the technological background to real-time implementation involving different use-case scenarios.

MATLAB® is a registered trademark of The Math Works, Inc.
For product information, please contact:

The Math Works, Inc.
3 Apple Hill Drive
Natick, MA 01760-2098
Tel: 508-647-7000
Fax: 508-647-7001
E-mail: info@mathworks.com
Web: http://www.mathworks.com

Acknowledgments

First and foremost, I would like to thank my husband, **Shvet Jain**, for standing beside me throughout my research career so far. He has been my motivation for continuing to improve my knowledge and move forward in my career. I dedicate this book of mine to him.

Moreover, without the prayers and best wishes of my parents, my sister, and both of my sons, none of my achievements would have been possible.

I am also thankful to the editorial team and my co-editor, **Dr. Ashu Taneja**, who really helped me in every aspect of the preparation of this book. Her prompt response and care of the literature and contributions was remarkable. She is indeed a great and responsible researcher.

I would also like to thank each and every one behind the completion of this book, who were a great help, and without their efforts, it wouldn't have been possible to publish this book.

Last, but not least, my gratitude is due to my inspiration **Dr. Archana Mantri**, Vice Chancellor, Chitkara University, Punjab, for her trust in me and for giving me the confidence to make my efforts successful in each and every field.

Editors

Shalli Rani, PhD, has been pursuing a postdoctoral fellowship from Manchester Metropolitan University, UK, since July 2022. She is a professor at Chitkara University Institute of Engineering and Technology, Chitkara University, Rajpura, Punjab, India. She has more than 18 years of teaching experience. She received an MCA degree from Maharishi Dyanand University, Rohtak in 2004, the M.Tech degree in Computer Science from Janardan Rai Nagar Vidyapeeth University, Udaipur in 2007, and a PhD degree in Computer Applications from Punjab Technical University, Jalandhar in 2017. Her main areas of interest and research are Wireless Sensor Networks, Underwater Sensor Networks, Machine Learning, and Internet of Things. She has published/accepted/presented more than 100 papers in international journals/conferences (SCI & Scopus) and edited/authored five books with international publishers. She is serving as the associate editor of *IEEE Future Directions Letters*. She served as a guest editor in *IEEE Transaction on Industrial Informatics*, Hindawi WCMC, and Elsevier IoT Journals. She has also served as reviewer in many repudiated journals of IEEE, Springer, Elsevier, IET, Hindawi, and Wiley. She has worked on Big Data, Underwater Acoustic Sensors, and IoT to show the importance of WSN in IoT applications. She received a young scientist award in February 2014 from Punjab Science Congress, Lifetime Achievement Award and Supervisor of the Year Award from Global Innovation and Excellence, 2021.

Ashu Taneja, PhD, is an associate professor at Chitkara University Research and Innovation Network (CURIN), Chitkara University, Punjab, India. She has a PhD in Electronics and Communication Engineering with 12 years of experience serving industry, teaching, education, and research. She received her Master of Engineering (M.E.) degree from Thapar University, Patiala, Punjab in 2011 and Bachelor of Technology (B.Tech) degree from Kurukshetra University, Haryana, in 2008. She has authored more than 50 publications in international journals/conferences (SCI & SCOPUS) and she has filed more than 20 patents. Dr. Taneja has also served as a reviewer in many reputable journals from IEEE, Springer, Elsevier, IET, Hindawi, and Wiley. Her research interests include Next Generation Wireless Networks, IoT, 5G, 6G, Energy Harvesting, User Selection, Antenna Selection, Intelligent Reflecting Surfaces, and Vehicular Communication.

Contributors

Mainak Adhikari
Indian Institute of Information Technology
Lucknow, India

Satyam Kumar Agrawal
Centre for In Vitro Studies and Translational Research
Chitkara School of Health Sciences, Chitkara University
Rajpura, India

Syed Hassan Ahmed
California State University
Long Beach, USA

Samir N. Ajani
Department of Computer Engineering
St. Vincent Pallotti College of Engineering and Technology
Nagpur, India

Srinivas Ambala
Pimpri Chinchwad College of Engineering
Pune, India

Salim Y. Amdani
Babasaheb Naik College of Engineering
Pusad, India

Ankita Sharma
Chitkara University Institute of Engineering and Technology
Chitkara University
Rajpura, India

Wankhede Vishal Ashok
Department of Electronics and Telecommunication Engineering
S.H.H.J.B. Polytechnic
Nashik, India

Rashmi Ashtagi
Department of Computer Engineering
Vishwakarma Institute of Technology
Pune, India

Mrunal Swapnil Aware
Computer Science and Engineering
MIT World Peace University
Pune, India

Lalit Kumar Awasthi
National Institute of Technology
Uttarakhand, India

Jyoti L. Bangare
Department of Computer Engineering
Vishwakarma Institute of Information Technology
Pune, India

Ali Kashif Bashir
Manchester Metropolitan University
Manchester, UK

Parul Bhanarkar
Babasaheb Naik College of Engineering
Pusad, India

Anup Bhange
Department of Computer Science and Engineering
KDK College of Engineering
Nagpur, India

Ashwin S. Chatpalliwar
Department of Industrial Engineering
Shri Ramdeobaba College of Engineering and Management
Nagpur, India

Sarika T. Deokate
Department of Computer Engineering
Pimpri Chinchwad College of Engineering
Pune, India

Imali Dias
Faculty of Science, Engineering, and Built Environment
Deakin University, Burwood Campus
Melbourne, Australia

Yatin Gandhi
Competent Softwares
Pune, India

Namrata Gawande
Department of Computer Engineering
Pimpri Chinchwad College of Engineering
Pune, India

Vaibhav V. Gijare
Department of Electronics and Telecommunication
School of Electrical Engineering
MIT Academy of Engineering, Alandi (D)
Pune, India

Krishan Kumar Goyal
Faculty of Computer Application
R.B.S. Management Technical Campus
Agra, India

Lipika Gupta
Department of Electronics and Communication Engineering
Chitkara University Institute of Engineering and Technology
Rajpura, India

Shubham Gupta
Rayat-Bahra University
Mohali, India

Abhishek Hazra
National University of Singapore
Singapore

Sushmita Sunil Jain
Centre for In Vitro Studies and Translational Research
Chitkara School of Health Sciences
Rajpura, India

Vinit Khetani
Cybrix Technologies
Nagpur, India

Saurabh Manoj Kothari
College of Engineering Design and Physical Sciences
Brunel University
Uxbridge, UK

Sanjivani Hemant Kulkarni
Computer Science and Engineering
MIT World Peace University
Pune, India

Shailesh V. Kulkarni
Department of Electronics and Telecommunication Engineering
Vishwakarma Institute of Information Technology
Pune, India

Kamini Lamba
Chitkara University Institute of Engineering and Technology
Rajpura, India

Suresh Limkar
Department of Artificial Intelligence and Data Science
AISSMS Institute of Information Technology
Pune, India

Parikshit N. Mahalle
Department of Artificial Intelligence and Data Science
Vishwakarma Institute of Information Technology
Pune, India

Jyoti Maini
Chitkara University Institute of Engineering and Technology
Rajpura, India

Shivani Malhotra
Department of Electronics and Communication Engineering
Chitkara University Institute of Engineering and Technology
Rajpura, India

Sulakshana Sagar Malwade
Department of Computer Science and Engineering
School of Polytechnic and Skill Development
MIT World Peace University
Pune, India

Deepak T. Mane
Department of Computer Engineering
Vishwakarma Institute of Technology
Pune, India

Bhushan M. Manjre
Department of Computer Science and Engineering
G. H. Raisoni Institute of Engineering and Technology
Nagpur, India

Imran Memon
Bahria University
Islamabad, Pakistan

Rais Allauddin Mulla
Department of Computer Engineering
Vasantdada Patil Pratishthan College of Engineering and Visual Arts
Mumbai, India

Rakhi Mutha
Amity University
Jaipur, India

Neeraj
Chitkara University School of Engineering and Technology
Solan, India

Shraddha Ovale
Department of Computer Engineering
Pimpri Chinchwad College of Engineering
Pune, India

Namita Parati
Department of Computer Science and Engineering,
Maturi Venkata Subba Rao (MVSR) Engineering College
Hyderabad, India

Mahendra Eknath Pawar
Department of Computer Engineering
Vasantdada Patil Pratishthan College of Engineering and Visual Arts
Mumbai, India

Sashikanta Prusty
Department of Computer Science and Engineering
Siksha 'O' Anusandhan (Deemed to be University)
Bhubaneshwar, India

Satpalsing D. Rajput
Pimpri Chinchwad College of Engineering
Pune, India

Shalli Rani
Chitkara University Institute of Engineering and Technology
Rajpura, India

Thippa Reddy
College of Information Science and Engineering
Jiaxing University
Jiaxing, China

Nilesh P. Sable
Vishwakarma Institute of Information Technology
Pune, India

Vyasa Sai
Intel Corporation
Santa Clara, USA

Parul Saini
Department of Electronics and Communication Engineering
Chitkara University Institute of Engineering and Technology
Rajpura, India

Raju M. Sairise
Yadavrao Tasgaonkar College of Engineering and Management
Pune, India

Mahendra Balkrishna Salunke
Department of Computer Engineering
Pimpri Chinchwad College of Engineering and Research
Pune, India

Farhadeeba Shaikh
Department of Computer Science and Engineering
School of Polytechnic and Skill Development
MIT World Peace University
Pune, India

Pooja Sharma
Rayat-Bahra University
Mohali, India

Gitanjali Shinde
Vishwakarma Institute of Information Technology
Pune, India

Shrinivas T. Shirkande
Department of Computer Engineering
S.B. Patil College of Engineering
Pune, India

Ashu Taneja
Chitkara University Institute of Engineering and Technology
Rajpura, India

Basant Tiwari
Hawassa University
Hawassa, Ethiopia

Kishor S. Wagh
Department of Computer Engineering
AISSMS Institute of Information Technology
Pune, India

1 Introduction to IoT and WSN

Jyoti Maini and Shalli Rani

1.1 INTRODUCTION

Internet of Things (IoT) and Wireless Sensor Networks (WSNs) are two closely related technologies that are transforming the way we collect and analyze data in a wide range of industries. IoT is a connected arrangement of various devices, vehicles, and other objects installed with different sensors and software that empower data collection and data interchange with other systems. These data can then be used to inform decision-making, enhance processes, and improve efficiency across a wide range of applications.

WSN, on the other hand, is a specific type of IoT network that is designed to collect data from a large number of small sensors spread over a wide area. These can be used to analyze a variety of environmental factors, such as temperature, humidity, and pressure, and can transmit these data wirelessly to a central hub or data collection system.

The main distinction between IoT and WSN is that IoT is a more general term that encompasses a large count of devices and applications, while WSN is a specific type of IoT network that is focused on collecting data from sensors in a wireless, distributed manner. WSNs are often used in many areas such as monitoring environmental factors, industrial automation, and smart cities, where it is important to collect data from many sensors over a wide area.

Together, IoT and WSN are revolutionizing industries such as agriculture, transportation, manufacturing, and healthcare by enabling real-time operational insights, enabling predictive maintenance, and optimizing resource utilization. The potential benefits of these technologies are vast, and as they are progressive, they will have an increasingly crucial role in developing the future of the global economy.

1.1.1 Internet of Things

IoT is described as the interconnection of physical objects, home appliances, vehicles, and other products that incorporate electronics, software, sensors, and connectivity that allow these items to connect and exchange data through the Internet (Figure 1.1). IoT devices encompass everything from smartwatches and fitness trackers to home security systems, thermostats, and even cars. IoT allows these devices to communicate with each other and with other systems, providing new ways to monitor and control various aspects of daily life [1].

The potential benefits of IoT include increased efficiency, improved safety, and reduced costs across various industries, from manufacturing and agriculture

DOI: 10.1201/9781003437079-1

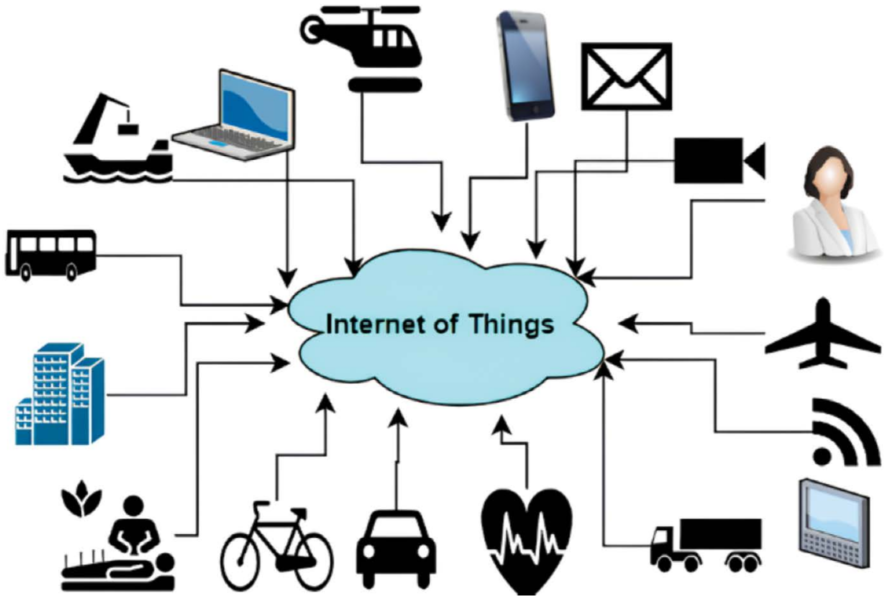

FIGURE 1.1 Internet of Things.

to healthcare, transportation, and smart homes. However, IoT also raises concerns about potential abuse and unintended consequences, as well as privacy and data security.

The adoption rate of IoT devices has increased rapidly over the last few years and is expected to continue to succeed remarkably. According to Statista's report, the number of IoT devices worldwide will reach to approx. 76 billion by 2025, from 27 billion in 2019 [2]. This growth can be attributed to several factors, including:

1. *Advancements in technology:* The rapid development of new technologies such as low-power wireless networks, miniaturized sensors, and cloud computing have made it easier and more affordable to deploy IoT devices.
2. *Cost reduction:* The cost of IoT devices has decreased significantly over the years, making them more approachable to an ample range of industries and applications.
3. *Increased connectivity:* The widespread availability of high-speed Internet and the increasing adoption of 5G technology have made it easier for IoT devices to communicate and share data.
4. *Business benefits:* IoT devices offer numerous benefits to businesses, including improved efficiency, productivity, and cost savings, which have encouraged their adoption.
5. *Consumer demand:* The growing demand for connected devices and smart home technologies has also contributed to the increased adoption of IoT devices.

It will become increasingly important to address concerns such as security, privacy, and interoperability to ensure that these devices are used safely and responsibly, as the number of IoT devices continues to grow.

1.1.1.1 Key Features of IoT

Here are few of the features of IoT [3, 4]:

- *Connectivity*: IoT devices are often connected to the Internet to be able to exchange data and interact with other devices.
- *Sensors and actuators*: These devices often are embedded with sensors that collect data about various factors such as temperature, environment, etc. as well as actuators that can control and respond to that environment.
- *Data analytics*: IoT devices generate large amounts of data that can be analyzed to generate insights and improve decision-making, optimize processes, automate tasks, and enhance overall productivity and efficiency.
- *Machine learning* (*ML*) *and artificial intelligence* (*AI*): IoT can incorporate ML and AI algorithms to automate tasks and improve efficiency.
- *Interoperability*: IoT devices are designed to work together and with other systems, allowing for seamless integration and interoperability, which means you can connect anything to your communications infrastructure and global information.
- *Inconsistent or non-uniformity*: IoT system is based on various networks and hardware platforms. These can communicate with other devices or service platforms with varying sizes and functionality over various networks, meaning IoT devices are inconsistent.
- *Dynamic and self-adapting*: IoT devices need to adapt dynamically depending on the situation. For example, a camera can capture data depending on the lighting conditions. It automatically switches to night mode or day mode. It is a self-adaptive technique.
- *Security*: IoT devices must be secure to protect against cyberattacks and ensure the privacy of user data.
- *Scalability*: IoT systems can be scaled up or down to accommodate changes in demand and the addition of new devices and applications.

1.1.1.2 Layers of IoT Architecture

The IoT architecture typically consists of several layers that work together to enable the connectivity and functionalities of IoT devices and systems [5]. Here is a brief overview of each layer:

- *Perception layer*: This layer consists of the sensors and various physical devices that collect data about the environmental parameters, such as temperature, light, sound, or motion.
- *Network layer*: This layer connects devices and sensors to each other and to the Internet, typically using wireless protocols such as Wi-Fi, Bluetooth, or Zigbee.

- *Middleware layer*: This layer handles the interaction between the devices and the applications that use the data they generate. It also provides services such as data storage, messaging, and security.
- *Application layer*: This layer consists of the software applications and services that analyze and use the data generated by the devices. Examples of applications include smart home systems, healthcare monitoring tools, or industrial control systems.
- *Business layer*: Under this layer, the business models and processes are included that drive the development and deployment of IoT solutions. It also includes the governance and management of the data generated by IoT systems.

The architecture of IoT is designed for collecting, processing, and analyzing data which has been generated by various physical devices and sensors, enabling the development of applications and services that improve efficiency, security, and quality of life across various industries and applications.

Here is a simplified diagram of the architecture of IoT (Figure 1.2), showing the different layers and their interconnections:

1.1.1.3 Building Blocks of IoT Architecture

IoT architecture, shown in Figure 1.3, consists of four building blocks. These are (1) Sensors, (2) IoT gateways and frameworks, (3) Cloud server system, and (4) Mobile applications.

1. *Sensors*: Sensors obtain information from the environment or specific locations and are ubiquitous. For example, an IoT gateway allows a temperature sensor to send room temperature. Sensors can collect a wide range of data, including location, weather and environmental conditions, machinery in operation, engine maintenance information, human body information, and vehicle vital signs.
2. *IoT Gateways and frameworks*: The network of sensor nodes is linked to the Internet through gateways. It is an entrance or a path to the Internet

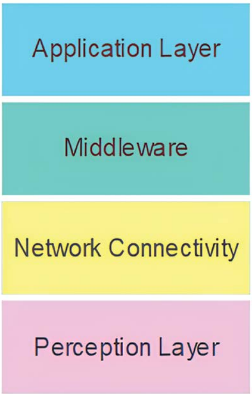

FIGURE 1.2 Layers of IoT architecture.

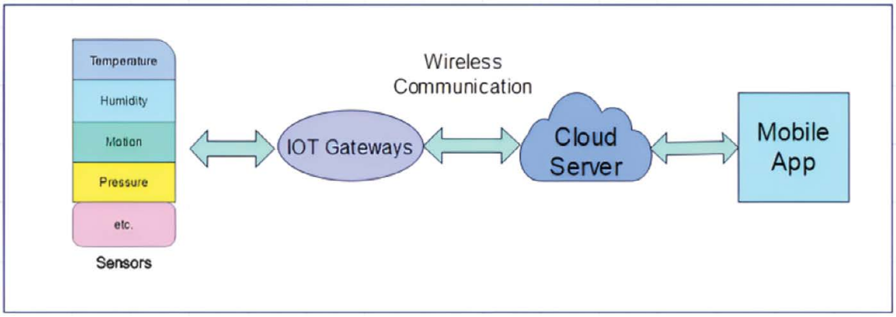

FIGURE 1.3 IoT architecture.

for all the things and devices that we want to interact with. It collects data from sensors and sends it to the Internet infrastructure to establish connectivity.

3. *Cloud server system*: The data transmitted over the gateway is securely processed and stored in cloud servers, i.e. in data centers. The processed data is then utilized to execute intelligent actions that make all of our gadgets intelligent. In the cloud, all analysis and decision-making are done by keeping the user's convenience in mind.
4. *Mobile applications*: Thanks to an easy-to-use smartphone application, customers can remotely manage and monitor devices such as interior thermostats and car engines. These applications deliver critical information directly from the cloud on your smartphone or tablet. Utilizing the following analytics, the information is displayed to the customer in the form of graphs, bar charts, and pie charts, so that users can easily understand the scenario. We may pass the signals to guide the sensors to change their default settings via our mobile application. For example, adjust the default temperature of AC and many other default values.

1.1.2 WSN – Introduction

WSN is a special kind of network consisting of a large number of tiny, low-power, inexpensive, and autonomous sensor nodes that are connected to each other with wireless facilities. These sensor nodes are equipped with various capabilities such as acquisition, processing, and communication that allow them to collect and transmit data from the physical environment to a central location [6].

WSNs are typically used for monitoring and controlling physical environments, such as temperature, humidity, pressure, light, sound, speed, direction and motion, pollutant levels, chemical concentration, vibrations, and many more such conditions. They are mostly used in different applications areas, such as environmental monitoring, industrial automation, home automation, healthcare monitoring, and military surveillance.

WSNs are characterized by their ability to function in harsh and remote environments, low power consumption, self-organization, and self-healing capabilities.

However, WSNs also face several challenges, such as limited bandwidth, limited energy, and limited processing capabilities, as well as security and privacy concerns [7].

Therefore, WSNs provide an economical and flexible solution for collecting and transmitting data from physical environments, enabling real-time tracking and control of various applications.

1.1.2.1 Features of WSN

WSNs are designed to have several features that enable them to perform their intended functions [8]. Here are some of the key features of WSNs:

1. *Low-power consumption*: WSNs are designed to consume minimal power, allowing the nodes to operate for extended periods of time on limited energy resources such as batteries.
2. *Small size*: The nodes in a WSN are typically small, allowing them to be deployed in large numbers and in tight spaces.
3. *Wireless communication*: The nodes in a WSN communicate with each other using wireless communication protocols, allowing them to be deployed in areas where wired communication is not practical or feasible.
4. *Self-organization*: WSNs are designed to self-organize, allowing the nodes to automatically establish and reconfigure their network connections.
5. *Autonomous operation*: The nodes in a WSN are typically autonomous and can operate independently of human intervention.
6. *Low cost*: The nodes in a WSN are typically low cost, allowing them to be deployed in large numbers and over a wide area.
7. *Fault tolerance*: WSN is designed to be fault tolerant and can continue to function even if some nodes fail or are damaged.
8. *Data processing and analysis*: WSNs are designed to perform data processing and analysis locally on the nodes, allowing them to filter and compress the data before transmitting it to the central location.

These features of WSNs enable them to be used in a large variety of applications, from environmental monitoring to industrial automation, and from healthcare to military surveillance.

1.1.2.2 Types of WSN

There are several types of WSNs that can be classified based on their applications, communication protocols, power source, and topology [6, 9]. Here are some common types of WSNs:

1. *Environmental sensor networks*: An environmental sensor network is a system of interconnected sensors designed to monitor and collect data about various aspects of the environment. These sensors are typically deployed in different locations to gather information on parameters such as temperature, humidity, air quality, noise levels, pollution levels, and other environmental factors. The sensors in the network continuously measure and record data, which is then transmitted wirelessly or through a wired connection to a

central server or data repository for analysis. The collected data can be used to monitor and assess environmental conditions in real-time, detect patterns, identify trends, and make informed decisions regarding environmental management and resource allocation. Environmental sensor networks find applications in various fields, including climate monitoring, urban planning, agriculture, industrial monitoring, and disaster management. They play a crucial role in improving environmental sustainability, enhancing public health and safety, and supporting evidence-based decision-making to address environmental challenges.

2. *Terrestrial WSNs* (*TWSNs*): These include many wireless sensor nodes, which can be used as unstructured or structured. Nodes are randomly distributed in unstructured mode staying within the allocated destination area [6, 9]. In pre-planned or structured mode, optimized placement, grid placement, 2D and 3D placement models are considered [6]. These networks are above ground and can get activated through solar cells. Energy can be saved by minimizing latency, optimizing routing, and using low duty cycle operation. TWSNs find applications in diverse fields, including environmental monitoring, agriculture, infrastructure monitoring, wildlife tracking, and disaster management. They provide real-time or near real-time data about the monitored parameters, allowing for better understanding, analysis, and decision-making.
3. *Underground WSNs* (*UWSNs*): The entire network is underground, as they are effectively used to monitor conditions underground. However, a terrestrial sink node is used to transfer information to the base station. Challenges in UWSNs include limited power supply, harsh underground conditions, network topology planning, and communication reliability (Figure 1.4). Researchers

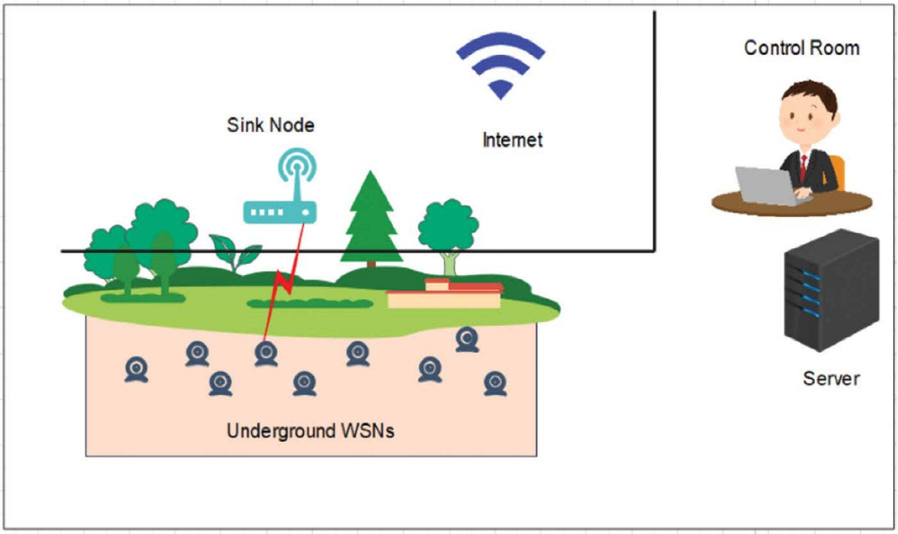

FIGURE 1.4 Underground WSNs.

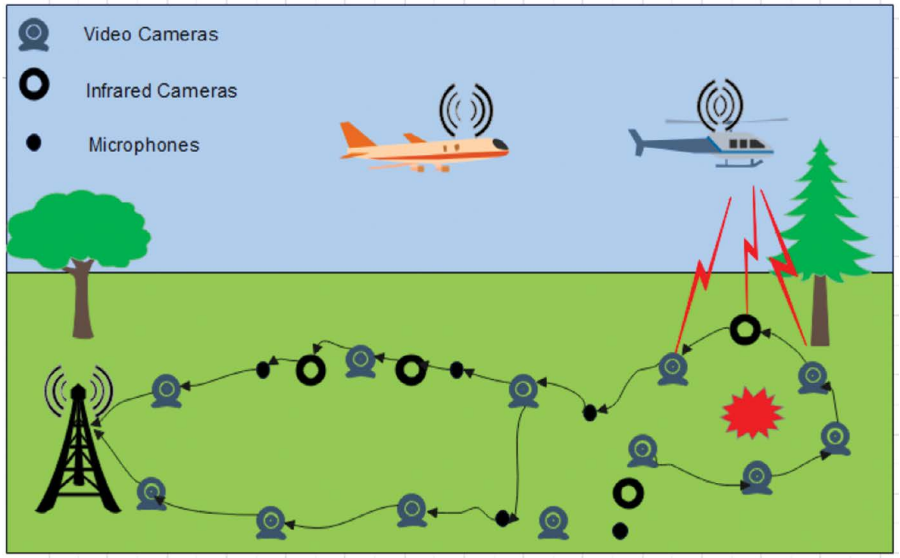

FIGURE 1.5 Multimedia WSNs.

and engineers continue to explore innovative solutions to improve the efficiency, range, and resilience of communication in these networks. These sensor networks are more expensive. The devices and machines used require proper maintenance.

4. *Multimedia WSNs* (*MWSNs*): The nodes in these networks collect information in the form of pictures, audio, and video by connecting to cameras and microphones. They can keep a check on various actions as they occur and display the events visually (Figure 1.5). These nodes are interconnected via wireless links for the purposes of data retrieval and data compression. The latest techniques of data processing and compressing are used to compress the data. The compressed audio and video data can also be sent over these sensor networks, to reduce the power consumption and high bandwidth. Research and development in MWSNs focus on improving multimedia data processing algorithms, developing energy-efficient communication protocols, and enhancing the overall network performance to enable reliable and real-time multimedia data collection and transmission.
5. *Mobile sensor networks* (*MSNs*): Mobile networks are not settled at one location but can shift from one place to another. These are networks consisting of mobile nodes equipped with sensors that can move autonomously or be controlled remotely. Unlike traditional sensor networks where the sensors are stationary, MSNs allow for dynamic data collection and monitoring capabilities in various environments. They can easily connect with your surroundings. Their main benefit is to provide better area coverage, and better channel capacity. These MSNs are more adaptable when compared to other static sensor network systems. These WSNs are used in applications

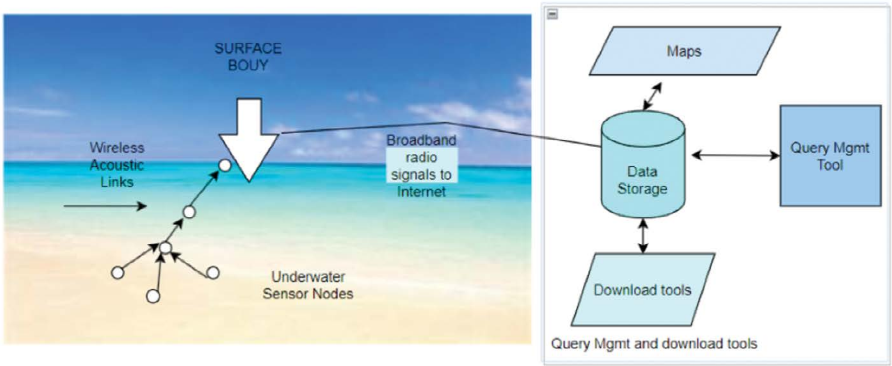

FIGURE 1.6 Underwater WSNs.

where the sensors are mobile, such as in vehicle tracking, animal tracking, and search and rescue operations.

6. *Underwater sensor networks* (*UWSNs*): The wireless underwater system consists of devices or sensor nodes installed underwater. These WSNs are used to monitor and collect data in underwater or aquatic environments such as oceans, lakes, and rivers (Figure 1.6). These vehicles are mostly used to collect information from sensor nodes. These consist of small, battery-powered sensor nodes to measure parameters such as water temperature, salinity, pressure, pH levels, dissolved oxygen, or the presence of pollutants. These nodes communicate with each other and with a surface-based sink node or base station to transmit the collected data. Long propagation delays and sensor failures are major challenges for these communication systems, and the batteries in these WSNs are limited and cannot be recharged. Therefore, various technologies have been evolved to solve this problem of energy utilization and conservation. Underwater communication in UWSNs faces challenges due to the features of the underwater medium, including high attenuation, limited bandwidth, multipath fading, and the requirement for specialized communication techniques. Acoustic waves are commonly used for long-range communication in UWSNs, although optical and electromagnetic methods can be employed for short-range communication in clear water.

1.1.2.3 How It Works

A WSN is a set of special devices called sensors that are used to monitor and record various environmental conditions and store this data in a central location.

A WSN has multiple nodes. These nodes are portable, small-sized detection stations. Each sensor node consists of a transducer or sensor, transceiver, microcontroller, and power supply. The transducer detects changes in your physical condition and produces an electrical signal. These signals are sent to a microcomputer for further processing. The microcomputer transmits signal to the receiving node and data is then sent to the computer over the Internet (Figure 1.7).

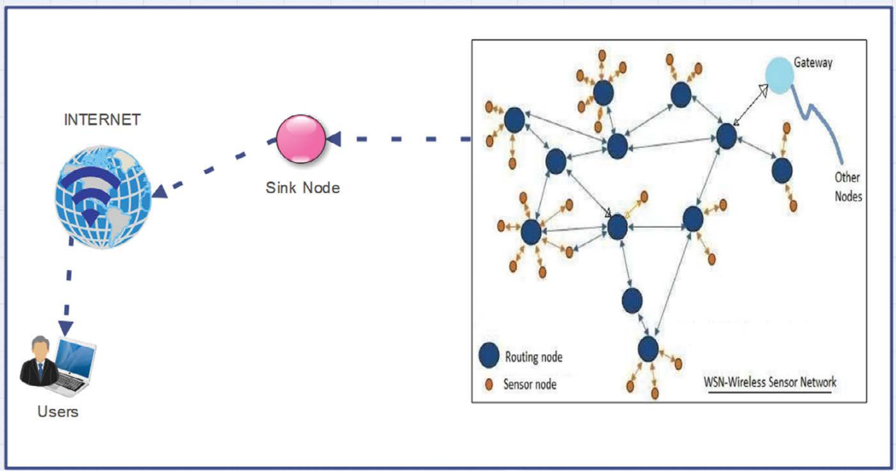

FIGURE 1.7 Wireless sensor network.

1.1.2.4 WSN Topologies

The nodes in WSN are arranged in geometric representations, called topologies [6, 9, 10]. The most common sensor network topologies are as follows (Figure 1.8):

1. Point-to-point (dedicated) network
2. Star network
3. Tree network
4. Mesh network

1. *Point-to-point (dedicated) network topology*: In dedicated topology, the nodes can communicate directly with each other. There is only one data communication path, realizing highly secure communication. Since there is no central hub, each node acts as both client and server (Figure 1.9).
2. *Star network topology*: In a star topology, communication takes place through a central hub and in contrast to point-to-point topology, direct communication between sensor nodes is not possible. Hubs act as servers and nodes act as clients (Figure 1.10).
3. *Tree network topology*: In tree topology, the central hub performs as a root node or parent node. Each node is connected to the previous higher node, and finally connects to the root node (Figure 1.11). The leading advantages of this topology are that the network is easy to expand, and errors can be easily detected. However, it has the drawback of being heavily dependent on the base cable. If the base cable cracks or breaks, the entire network collapses. The data is moved back from the leaf node to the parent node and finally to the root node.
4. *Mesh network topology*: A mesh network allows all nodes to interact directly with each other without relying on a central hub. Data can be moved from one node to another. This is the most reliable network communication

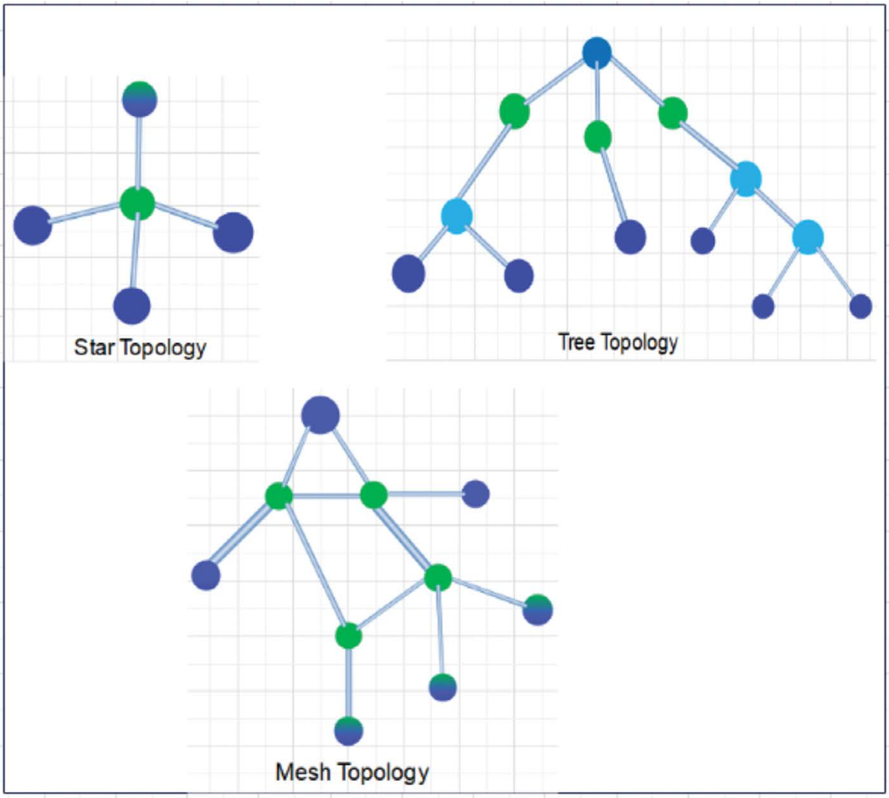

FIGURE 1.8 Wireless sensor network topologies.

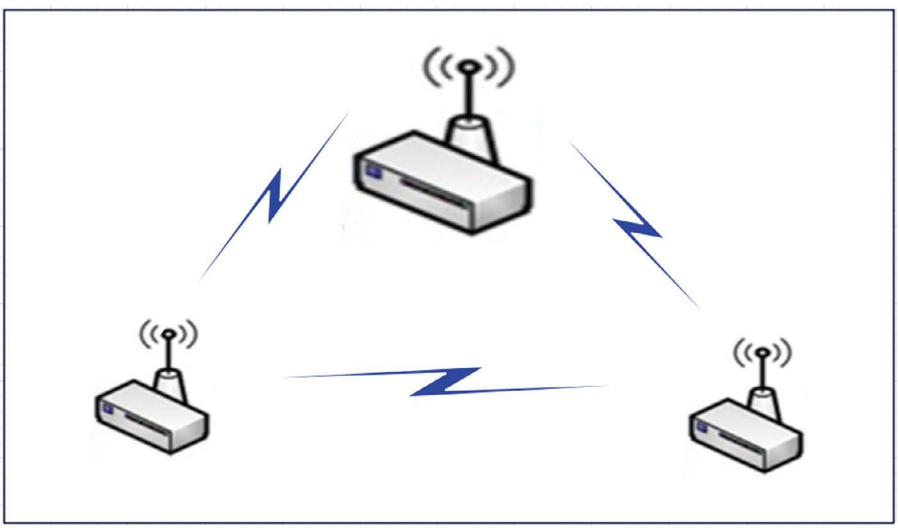

FIGURE 1.9 Point-to-point network.

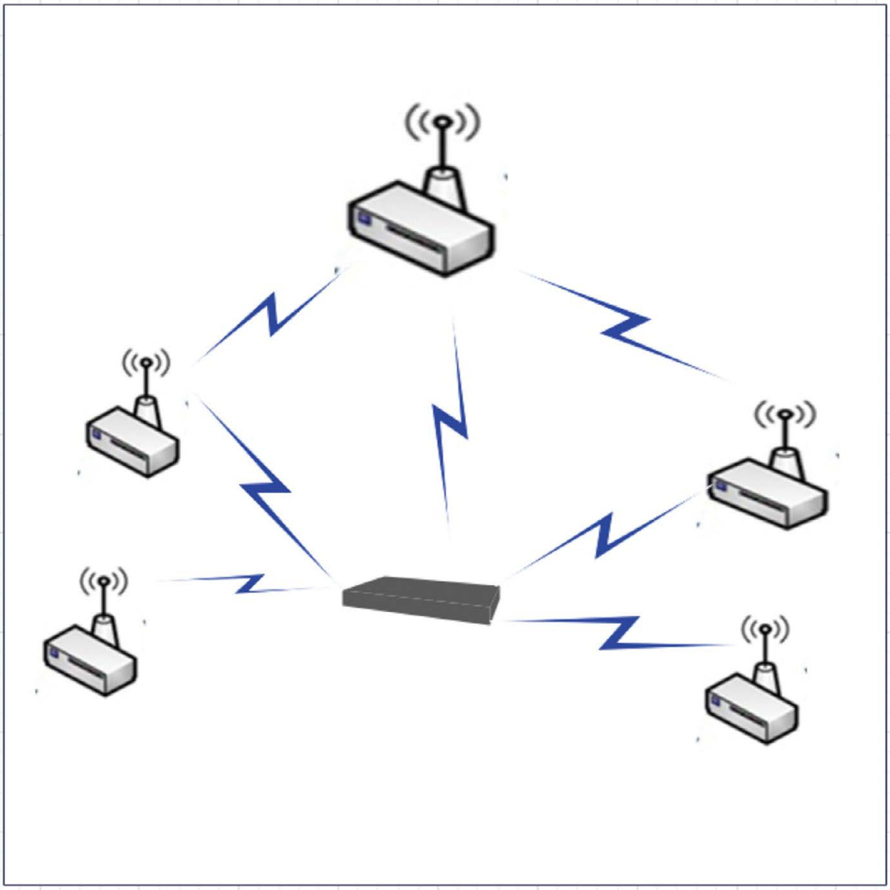

FIGURE 1.10 Star network.

structure as it has no single failure point. However, this complicated structure consumes a lot of power.

1.1.2.5 Differences between Wireless Sensor Network and Internet of Things

Table 1.1 shows the differences between WSN and IoT.

1.1.3 Convergence of IoT and WSN

The convergence of the IoT and WSNs is becoming increasingly common and important. This convergence involves combining the data collection capabilities of WSNs with the communication and data processing capabilities of IoT systems [12, 13].

Combining WSNs and IoT can enable more efficient, intelligent, and scalable data collection and analysis in a variety of applications. For example, WSNs can be used

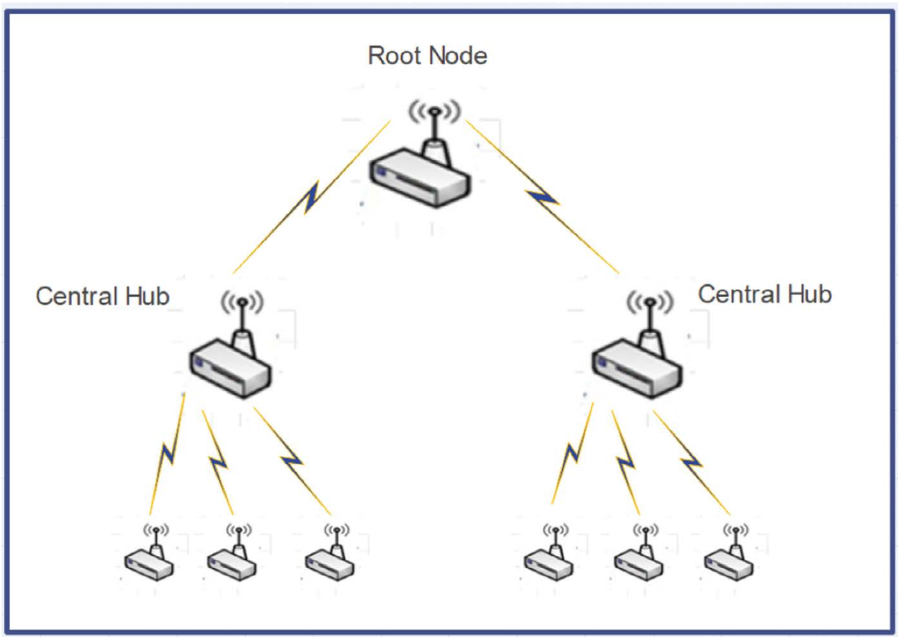

FIGURE 1.11 Tree network.

to collect data from remote or harsh environmental conditions, while IoT can provide cloud-based processing and storage capabilities for the collected data.

It is a natural evolution of both technologies. The two technologies have many similarities, including the ability to collect and transmit data from the physical environment, low power consumption, and wireless communication. The convergence of

TABLE 1.1
Differences between WSN and IoT

Wireless Sensor Network	Internet of Things
WSN is anything that connects to a wireless network to collect data or monitor the environment.	IoT means WSN + Internet + Cloud Storage + Mobile/Web Applications.
WSN consists of a network of a large number of tiny low-power devices called nodes that communicate through wireless channels for information sharing.	IoT consists of a gateway that is used to connect the devices to internetworks (using switches, routers, Access Points, etc.).
WSN follows IPv4 and it has a sink node but no gateway.	IoT follows IPv6 on the sensor network (802.15.4 MAC/PHY) and IPv4 on the internetwork part [11].
Routing protocols in WSN include, DSR, CTP, PEGASIS, LEACH, SEP, AODV, OLSR, SPIN, and TEEN.	Routing protocols in IoT include, RPL, 6LoWPAN, MQTT-SN, CoAP, AODV, BLE Mesh, and Zigbee.

these technologies has led to the creation of new applications and opportunities in various domains, including industrial automation, healthcare, environmental monitoring, and smart cities.

One of the major advantages of the convergence of IoT and WSN is the capability to integrate large-scale networks with local sensor networks. This integration enables the collection and analysis of data from multiple sources, providing a better and improved view of the physical environment. For example, a smart city network can use IoT devices and WSNs to monitor traffic flow, air quality, and noise pollution, providing a better understanding of the city's environmental conditions.

Another benefit of this combination is the ability to reduce power consumption and increase the lifespan of the network. By using WSNs for local sensing and IoT devices for data aggregation and communication, the network can be optimized for low power consumption, reducing the need for frequent battery replacements.

It also poses several challenges, such as interoperability, security, and power management. In order to fully realize the potential of this convergence, there needs to be standardization and coordination among different technologies and protocols. Additionally, security measures need to be implemented to protect the sensitive data collected and transmitted by WSNs and IoT devices. Finally, efficient power management strategies need to be developed to extend the lifespan of WSN nodes and IoT devices.

Therefore, the convergence of IoT and WSN is expected to drive innovation and create new opportunities for businesses and individuals alike. The ability to collect and analyze data from the physical environment in real-time has the potential to revolutionize or transform many different industries and domains, improving efficiency, safety, and quality of life, but it also requires careful planning, coordination, and implementation to ensure its success.

1.1.4 Sustainable Integration of IoT and WSN for Smart Applications

The integration of the IoT and WSN can enable the development of smart applications that enhance sustainability in various domains. This integration enables seamless data exchange between IoT devices and sensors, enabling real-time monitoring, control, and analysis of physical systems. Sustainable IoT is an approach to designing and implementing IoT systems in a way that prioritizes sustainability and environmental responsibility. Smart applications that use sustainable IoT technology aim to reduce energy consumption, minimize waste and environmental impact, and promote social well-being [14, 15].

Here are some key considerations for designing sustainable IoT systems for smart applications: [16]

1. *Energy efficiency*: One of the crucial considerations for sustainable integration is optimizing the energy consumption of IoT devices and sensors. WSNs typically operate on limited battery power, so energy-efficient protocols and algorithms should be employed to minimize energy consumption. Sustainable IoT systems should be designed to consume minimal power, using energy-efficient components and power management techniques and

to explore energy harvesting techniques to minimize energy consumption. This includes using low-power sensors, such as sleep modes and wake-on-demand, duty cycling, adaptive sampling, and data aggregation that can help prolong the network's lifetime, and leveraging renewable energy sources for power generation, including solar or kinetic energy, that can also be used to power IoT devices.

2. *Recycling and waste reduction*: Sustainable IoT systems should be designed to minimize waste and promote recycling. This includes using recyclable materials in IoT devices, implementing take-back programs, and designing systems that can be easily upgraded or repurposed.
3. *Data management and analytics*: Efficient data management and analytics play a vital role in sustainable IoT. IoT generates a massive amount of data from various connected devices. Sustainable IoT systems should prioritize efficient data management, minimizing the amount of data transmitted and processed to reduce energy consumption, and implement data compression techniques, edge computing, and intelligent analytics to reduce data transmission and processing. Data compression and filtering techniques can be used to minimize data transfer, and edge computing enables data processing locally to the source node, reducing the need to transfer data to the cloud, thereby conserving energy and network bandwidth. WSNs can also employ data fusion techniques to combine data from multiple sensors and eliminate redundant information.
4. *Lifecycle analysis and circular economy*: Sustainable IoT systems should be designed with a lifecycle analysis approach and to support circular economy principles, taking into account the environmental impact of the system throughout its entire lifecycle, from manufacturing to disposal. Consider factors like manufacturing, deployment, operation, and end-of-life management. Promote circular economy principles by designing devices for ease of repair, upgradeability, and recycling to minimize waste and resource depletion.
5. *Smart resource management*: Use IoT for smart resource management to optimize resource consumption and reduce waste. Monitor and control energy usage, water consumption, and other resources in real-time, enabling efficient allocation and conservation. Therefore, by leveraging IoT and WSN, real-time data can be collected, analyzed, and used to make intelligent decisions that minimize waste, improve resource allocation, and reduce environmental impact.
6. *Social impact and inclusion*: Ensure that IoT solutions contribute to social well-being and inclusivity. Consider accessibility, privacy, and security aspects to protect user data and maintain trust. Develop solutions that address social challenges and provide equitable access to smart services for all.
7. *Collaboration and partnerships*: Foster collaboration among stakeholders, including governments, industry, academia, and communities, to promote sustainable IoT initiatives. Encourage knowledge sharing, research, and development of sustainable practices and technologies.

8. *Interoperability and standardization*: IoT and WSN integration should adhere to interoperability standards to facilitate seamless communication between devices and systems from different vendors. Standardization efforts promote compatibility, reduce implementation complexity, and foster innovation within the IoT ecosystem.
9. *Connectivity and communication*: Seamless connectivity and reliable communication between IoT devices and WSN sensors are essential. Robust wireless communication protocols and networking architectures should be used to ensure efficient and uninterrupted data transmission. This enables the integration of diverse sensors and devices into a unified smart system.
10. *Standards and certification*: Adhere to industry standards and certifications that promote sustainable practices in IoT. Certification programs, such as Energy Star, EPEAT, or LEED, can provide guidelines and benchmarks for sustainable IoT design, operation, and disposal.

Therefore, sustainable IoT for smart applications has the potential to create more efficient and environmentally responsible systems that can reduce energy consumption, minimize waste, and improve the sustainability of our society. By prioritizing sustainability in IoT design and implementation, we can create a more resilient and environmentally conscious future.

1.1.4.1 Applications Areas of IoT and WSN

IoT and WSN have a wide range of applications areas across various industries. These applications cover different domains, including the industrial sector, medical sector, agriculture, smart cities, security, and emergencies, etc. A few of application areas shown in Figure 1.16 have been discussed here:

a. *Smart cities*: Building smart cities includes intelligent transportation systems [17], smart buildings, traffic jams [17, 18], waste management [19], intelligent lighting, smart parking, and city maps (Figure 1.12). This may incorporate a variety of functionalities such as AI-enabled IoT devices that can be used to track, control, and mitigate traffic congestion in smart cities [20]. Moreover, IoT will also enable the installation of intelligent street lighting that adapts to the weather. To realize an IoT smart city, it is necessary to utilize RFID and sensors. IoT for most systems such as parking meters, streetlights, sprinkler systems, etc. Many countries have plans to implement the IoT facilities.
b. *Healthcare*: As [21] explains, enhanced and automated IoT devices are assisting in the transformation of healthcare systems. Other technologies that improve a range of activities, such as communicating reports with different persons and places, maintaining records, and administering medications. It significantly improves the transformation of the healthcare industry [21]. IoT applications offer benefits to health sector as it may be broadly classified as automated data gathering and analysis, person identity and authentication, and patient, employee, and asset monitoring (Figure 1.13). Moreover, authentication and identification reduce the requirement for