



Intelligent Mobile and IoT Ecosystems

Bridging Cloud, Fog, Edge, and AI

Edited by M. K. Kavitha Devi, Thangavel Murugan,
K. Indira, Raja Lavanya and S. Abinaya

A **Chapman & Hall** Book

 **CRC Press**
Taylor & Francis Group

Intelligent Mobile and IoT Ecosystems

How are cloud computing, fog computing, edge computing, and artificial intelligence (AI) working together to create intelligent mobile and IoT ecosystems? The fundamental concepts and practical uses of these technologies, showing their transformative effects across different industries, are covered in *Intelligent Mobile and IoT Ecosystems*. The book starts with an overview of the core principles of cloud, fog, and edge computing, along with AI, giving a clear understanding of their roles in today's digital world. It explains how these technologies collaborate to improve real-time data processing, security, and user experiences in mobile and IoT settings.

- Theoretical foundations and practical applications of intelligent mobile and IoT systems, focusing on the interaction among cloud, fog, and edge computing and AI.
- Detailed case studies and applications showing successful implementations across different industries.
- Insights into how deep learning models are adapted and applied for IoT environments to improve system intelligence and efficiency.
- A dedicated focus on mobile edge intelligence and its role in enabling smart decision-making at the network's edge.
- Addressing key aspects of security, including secure communication protocols and privacy-preserving methods.

With a strong emphasis on real-world applications and case studies, this book is intended for researchers, engineers, and practitioners who have a comprehensive understanding of integrating cloud, fog, edge, and AI technologies within mobile and IoT ecosystems.



Taylor & Francis

Taylor & Francis Group
<http://taylorandfrancis.com>

Intelligent Mobile and IoT Ecosystems

Bridging Cloud, Fog, Edge, and AI

Edited by
M. K. Kavitha Devi, Thangavel Murugan,
K. Indira, Raja Lavanya and S. Abinaya



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business
A CHAPMAN & HALL BOOK

Front cover image: ArtemisDiana/Shutterstock

First edition published 2026

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

© 2026 selection and editorial matter, M. K. Kavitha Devi, Thangavel Murugan, K. Indira, Raja Lavanya and S. Abinaya; individual chapters, the contributors

Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, access www.copyright.com or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. For works that are not available on CCC please contact mpkbookspermissions@tandf.co.uk

Trademark notice: Product or corporate names may be trademarks or registered trademarks and are used only for identification and explanation without intent to infringe.

ISBN: 978-1-041-00194-2 (hbk)

ISBN: 978-1-041-00199-7 (pbk)

ISBN: 978-1-003-60865-3 (ebk)

DOI: 10.1201/9781003608653

Typeset in Times

by Apex CoVantage, LLC

Contents

Preface.....	vii
About the Editors	xi
List of Contributors	xiii
Chapter 1 Introduction to Mobile and IoT Ecosystems	1
<i>S. Gokilapriya, K. Sakthivel, Ramani Kannan, and K. Karthikeyan</i>	
Chapter 2 Understanding Cloud Computing in the Mobile and IoT Context	17
<i>M. Kavitha, P. Sangeetha, M. Satthiyaraju, B. Vivekanandam, S. Aarathi, and D. Suseela</i>	
Chapter 3 Fog Computing: Extending Cloud to the Edge	36
<i>R. Muthuselvi, V. Gayathri, and X. Ignatius Selvarani</i>	
Chapter 4 Edge Computing: Empowering Real-Time Decision-Making	53
<i>K. Ulagapriya, Cynthia Jayapal, K. V. M. Shree, A. Poonguzhali, Jad Gergi Matta, and Divya Bairavi</i>	
Chapter 5 The Role of Artificial Intelligence in Mobile and IoT Applications	69
<i>Astangini Selvaraj, Rama Abirami, Ponvizhy Swathy, S. Thanga Tamil Selvi, and M. Anitha</i>	
Chapter 6 Machine Learning for Mobile and IoT Applications	89
<i>R. Saranya and R. Elakkiya</i>	
Chapter 7 Machine Learning for IoT and Mobile: Trends and Future Directions.....	110
<i>Isaivani Mariyappan, S. Kayalvizhi, Josep M. Guerrero, R. Aravinda Raj, C. Sonia, and N. Sundaraperumal</i>	
Chapter 8 Deep Learning Models for Intelligent IoT Ecosystems	131
<i>K. Vijayakumari, Jasmine Gnanadurai, S. Usharani, and K. Velusamy</i>	
Chapter 9 Integration of Mobile Edge Computing and Artificial Intelligence for Distributed Learning Approaches.....	150
<i>M. Nirmala Devi, B. Subbulakshmi, G. Ananthi, A. R. Abdul Rajak, and K. S. Sendhil Kumar</i>	

Chapter 10	Collaborative Intelligence in IoT Ecosystems.....	170
	<i>Vishal, Komal, Anjana Sharma, and Md. Mortuza Ahmmed</i>	
Chapter 11	Security and Privacy in Intelligent Mobile and IoT Systems.....	193
	<i>V. Kalaichelvi, P. Vimala Devi, K. Manjula, S. Hemamalini, and S. Arobana</i>	
Chapter 12	AI and IoT Innovations Transforming Industries and Enhancing Urban Sustainability.....	217
	<i>Ann Baby, Oluwagbemiga Paul Agboola, Ann Rija Paul, and Shoby Sunny</i>	
Chapter 13	Energy-Efficient Edge AI for Smarter Mobile and IoT Systems.....	236
	<i>V. Aanandaram, P. Deepalakshmi, and Sathiyandrakumar Srinivasan</i>	
Chapter 14	Fostering Ethical Leadership and Sustainable Innovation in Intelligent Mobile and IoT Ecosystems	259
	<i>R. Purushothaman, R. Alamelu, M. Sudha, and Mariofanna Milanova</i>	
Chapter 15	Future Aspects of BC-IoT: Integrating Blockchain with Mobile and IoT Ecosystem.....	281
	<i>S. Sorna Lakshmi, S. Sabena, L. Sai Ramesh, and A. Razia Sulthana</i>	
Index		297

Preface

The rapid growth of mobile devices and the Internet of Things (IoT) has revolutionized how we live, work, and interact with one another. This interconnected network of devices, sensors, and systems has created remarkable opportunities for innovation across various industries, including health care, transportation, smart cities, agriculture, and manufacturing. To unlock the full potential of these technologies, it is essential to seamlessly integrate cloud computing, fog computing, edge computing, and artificial intelligence (AI). This book, *Intelligent Mobile and IoT Ecosystems: Bridging Cloud, Fog, Edge, and AI*, aims to provide a comprehensive understanding of how these technologies work together to form intelligent, adaptive, and efficient ecosystems.

In today's digital landscape, effectively managing and utilizing the data generated at the edge of networks is crucial. The convergence of cloud, fog, and edge computing with AI facilitates real-time decision-making, enhances security, preserves privacy, and increases scalability. This integration addresses the growing demands for low latency, high reliability, and energy efficiency required by modern applications. As a result, our topic occupies a key position in the current technological trajectory, serving as a fundamental resource for researchers, practitioners, industry professionals, policymakers, and students who are eager to understand and implement these integrated systems.

Chapter 1: "Introduction to Mobile and IoT Ecosystems" provides an overview of the evolution of mobile and IoT ecosystems, tracing advancements from 1G to the anticipated 6G. It highlights key technologies, the architecture of IoT ecosystems, and applications across sectors, while addressing challenges and future trends related to interoperability and security in technology integration.

Chapter 2: "Understanding Cloud Computing in the Mobile and IoT Context" provides an in-depth analysis of the integration of cloud, edge, and fog computing with AI, highlighting their significance in mobile and IoT environments. It covers the evolution of cloud service models, highlights operational efficiency, discusses data privacy security strategies, and addresses future trends and challenges in the technological landscape.

Chapter 3: "Fog Computing: Extending Cloud to the Edge" explores the transformative impact of fog computing in health care, emphasizing its ability to connect cloud computing with IoT devices. It highlights real-time data collection from wearables, addressing traditional cloud limitations like latency and security. Through case studies, the chapter demonstrates the significant potential of fog computing to enhance patient care.

Chapter 4: "Edge Computing Empowering Real-Time Decision-Making" highlights edge computing as a transformative approach to data processing, bringing tasks closer to data sources. It emphasizes benefits such as reduced latency, enhanced security, and improved efficiency in real-time applications, including health care and autonomous vehicles, while addressing challenges like resource limitations and interoperability, underscoring the role of emerging technologies.

Chapter 5: "The Role of Artificial Intelligence in Mobile and IoT Ecosystem" offers an in-depth exploration of machine learning algorithms and their applications in mobile and IoT environments. It showcases the synergy between mobile devices and IoT systems, emphasizing AI's role in enhancing security and solving complex challenges while providing insights into recent advancements, benefits, and potential drawbacks.

Chapter 6: "Machine Learning for Mobile and IoT Applications" emphasizes the importance of deploying machine learning models on resource-constrained devices, such as mobile phones and IoT systems. It discusses innovative techniques for ensuring privacy and security while optimizing efficiency. The chapter also explores preprocessing strategies, tools, and frameworks to overcome deployment challenges and enhance automation across various fields.

Chapter 7: "Machine Learning for IoT and Mobile: Trends and Future Directions" highlights the impactful integration of machine learning (ML) in IoT and mobile environments. It explores diverse ML techniques and their real-time applications in fields like health care and agriculture

while addressing challenges such as data privacy and computational limits, providing actionable solutions for developing secure and efficient ML-driven IoT applications.

Chapter 8: “Deep Learning Models for Intelligent IoT Ecosystems” highlights the essential role of deep learning (DL) within intelligent Internet of Things (IoT) ecosystems, enhancing system intelligence and autonomy. It examines various DL architectures and strategies in edge, fog, and cloud environments, focusing on real-time analytics and predictive maintenance, with case studies in innovative health care and industrial automation.

Chapter 9: “Integration of Mobile Edge Computing and Artificial Intelligence for Distributed Learning Approaches” is crucial as it delves into the integration of edge computing and AI, emphasizing their role in enhancing low-latency and privacy-preserving data processing. By examining diverse applications across health care, autonomous vehicles, and smart cities, the chapter highlights innovative solutions to current technological challenges and envisions future advancements, such as 5G and quantum AI.

Chapter 10: “Collaborative Intelligence in IoT Ecosystems” emphasizes the significance of collaborative intelligence in enhancing IoT ecosystems by integrating humans, devices, and AI. It explores advanced frameworks and algorithms that facilitate real-time decision-making and resource efficiency while addressing critical challenges like interoperability and security, ultimately paving the way for future technological innovations.

Chapter 11: “Security and Privacy in Intelligent Mobile and IoT Systems” emphasizes the critical framework for the IMIS system architecture, highlighting the necessity of device-level security through lightweight encryption. It addresses the essential protocols for secure data exchange, aiming to protect information during storage and transmission. Additionally, the chapter introduces AI-based decision systems that enhance security through real-time assessments and intelligent corrective actions.

Chapter 12: “AI and IoT Innovations in Transforming Industries and Enhancing Urban Sustainability” highlights the pivotal role of AI and IoT in transforming urban and industrial landscapes. By showcasing real-world applications and case studies, it highlights their potential in enhancing efficiency, sustainability, and public welfare. The chapter calls for collaborative efforts and strategic policies to foster a resilient and innovative AI-IoT ecosystem.

Chapter 13: “Energy-Efficient Edge AI for Smarter Mobile and IoT Systems” is pivotal in understanding how edge AI transforms various industries through real-time decision-making, energy-efficient models, and innovative learning methods. It highlights the significant impact on smart ecosystems and privacy concerns while exploring future technologies, such as green AI and quantum machine learning, paving the way for scalable and responsible AI solutions.

Chapter 14: “Fostering Ethical Leadership and Sustainable Innovation in Intelligent Mobile and IoT Ecosystems” emphasizes the integral role of sustainability within IoT ecosystems, intertwining environmental, economic, and social dimensions. It advocates for ethical leadership and governance, ensuring accountability in data practices. By employing a mixed-methods approach and focusing on practical innovations, the chapter provides valuable insights for developing resilient and responsible innovative applications.

Chapter 15: “Future Aspects of BC-IoT: Integrating Blockchain with Mobile and IoT Ecosystem” explores the integration of blockchain with the Internet of Things (IoT), emphasizing its importance in enhancing trust, transparency, and decentralization. It examines future advancements, such as lightweight consensus mechanisms, decentralized IDs, and automated smart contracts, while addressing vulnerabilities and risks, ultimately showcasing the potential for transformative impact in smart cities.

The target audience for this book is broad and diverse. It includes academic researchers seeking in-depth insights into the latest advancements, industry professionals and engineers involved in developing IoT solutions, solution providers looking to enhance their offerings, as well as students and educators in computer science, electrical engineering, and related fields. Additionally, policy-makers aiming to understand the technological landscape for informed decision-making will find

this book valuable. Whether readers are pursuing theoretical knowledge or practical applications, this book offers valuable insights tailored to their interests.

In conclusion, this volume makes a significant contribution to the field by bridging the gap between various converging technologies and presenting them within a unified framework. Its comprehensive approach not only enhances academic understanding but also offers practical guidance for implementing intelligent IoT ecosystems. Through this work, we aim to inspire further innovation, encourage interdisciplinary collaboration, and support the ongoing evolution of intelligent networked environments that will shape our future.



Taylor & Francis

Taylor & Francis Group
<http://taylorandfrancis.com>

About the Editors

M. K. Kavitha Devi received her BE and ME in computer science and engineering and her PhD in information and communication engineering in 1994, 2004, and 2011, respectively. Her research focuses on recommender systems, cloud computing, theoretical computation, image analytics, information security, and steganalysis. She has published more than 50 papers in reputed international journals and conferences. She has authored books and chapters in renowned publications. She is the proud recipient of the “Best Computer Science Faculty Award” of the ASDF Global Award. She has organized many funded workshops, seminars, and conference in her institution. Under her guidance, nine PhD scholars have completed, and one PhD scholar is pursuing, their research work. Currently, she is a Professor and Head of the Department at the Department of Computer Science and Business Systems, Thiagarajar College of Engineering, Madurai.

Thangavel Murugan is a senior IEEE member serving as an assistant professor in the Department of Information Systems and Security, College of Information Technology, and as a faculty fellow in the Center for Excellence in Teaching and Learning, United Arab Emirates University, Abu Dhabi, United Arab Emirates. He received his doctorate from Madras Institute of Technology (MIT) Campus, Anna University–Chennai. He received his postgraduate degree of ME computer science and engineering from JJ College of Engineering and Technology, Trichy, under Anna University–Chennai (university first rank holder and gold medalist), and his bachelor’s degree of BE computer science and engineering from MAM College of Engineering, Trichy, under Anna University–Chennai (college first rank holder and gold medalist). He presently holds 12+ years of teaching and research experience from various academic institutions. He has published 24+ articles in international journals, 9+ edited books, 3+ authored books, 29+ book chapters in international publications, 5+ patents, 45+ in the proceedings of international conferences, and 3 in the proceedings of national conferences/seminars. He has been actively participating as reviewer in international journals and conferences. He has attended 100+ workshops/FDPs/conferences in various higher learning institutes, like IIT, Anna University. He has organized 50+ workshops/FDPs/contests/industry-based courses over his past years of experience. He has been a technical speaker in various workshops/FDPs/conferences. His research specialization is information security, cloud computing, ethical hacking, cyberforensics, blockchain, AI applications, and educational technology.

K. Indira is an assistant professor at Thiagarajar College of Engineering (TCE), Madurai, specializing in information technology since June 2012. She holds a PhD in information and communication engineering from Anna University–Chennai, focusing on an efficient machine learning model for multicloud recommender systems. Actively engaged in intellectual property rights through TCE-IPR cell, she spearheads the IT Department Association Community, IT-Alumni Club, and serves in the Siemens MoU Center for Excellence. Her expertise spans cloud computing, recommender systems, C#/NET, service-oriented computing, and software-defined networking. Her continuous learning includes workshops at IIT Delhi, MIT, and CDAC Chennai and Bangalore. She is a professional member of ACM and IIC, and she initiated and continues to lead TECHUTAV, a national-level technical forum, along with launching a mobile application on the Play Store.

Raja Lavanya is an assistant professor in the Department of Computer Science and Technology. She received her BE and ME in computer science and engineering and her PhD in information and communication engineering in 2009, 2012, and 2023, respectively. Her current areas of interest include IoT and security systems. She has published more than 20 papers in reputed international journals and conferences. She has authored book chapters in renowned publications.

S. Abinaya is an assistant professor in the Department of Computer Science and Engineering in VIT Chennai. She received her BE and ME in computer science and engineering and her PhD in information and communication engineering in 2009, 2012, and 2023, respectively. Her current areas of interest include recommender systems. She has published more than 20 papers in reputed international journals and conferences.

Contributors

V. Aanandaram was born in Paramakkudi, Tamil Nadu, India, in 1998. He received his BSc degree in computer science from the University of Madras, Chennai, India, in 2016 and his MSc in computer science from the Kalasalingam Academy of Research and Education, Virudhunagar Dt, Tamil Nadu, India, in 2022 and is pursuing his PhD in computer science. His research interests are network security, artificial intelligence and machine learning, routing algorithms, and quantum computing.

S. Aarthi is an Assistant Professor in the Department of Computer Science at Kathir College of Engineering and an emerging researcher in the field of cloud computing. She holds a B.Tech (Information Technology) and an M.E. degree in Computer Science. With a deep curiosity to view the world through a technical lens, she explores innovative solutions that address modern computing challenges. Her work focuses on harnessing advanced technologies to enhance efficiency, scalability, and security in cloud environments. Guided by a passion for continuous learning, she strives to make meaningful contributions to the ever-evolving digital landscape.

Dr. A. R. Abdul Rajak is an associate professor and the head of the Department of Electrical and Electronics Engineering at BITS Pilani, Dubai Campus. His research interests encompass communication systems, VLSI design, embedded systems, computer networks, machine learning, wireless and mobile networks, image processing, micro- and nanoelectronic circuits, software systems, robotics, and automation. He has contributed to various academic publications in these areas.

Dr. Rama Abirami is a lecturer in the Department of Electrical and Computer Engineering at Curtin University, Malaysia. She holds extensive academic and research experience in artificial intelligence, wireless communication systems, IoT architectures, and intelligent embedded systems. Her research focuses on integrating AI-driven solutions with next-generation communication technologies to improve system performance and reliability. She has published research articles and book chapters in reputed international venues and actively contributes to academic mentoring and curriculum development. Her work emphasizes practical and scalable AI applications in modern mobile and IoT ecosystems.

Dr. Oluwagbemiga Paul Agboola is a dedicated architect and accomplished educator whose work reflects a strong commitment to academic excellence and professional growth. He earned his PhD in architecture from Universiti Teknologi Malaysia (UTM), Johor-Bahru, where he was honored as the best graduating PhD researcher in the Department of Architecture in 2017. He holds a master's degree in architecture from Federal University of Technology, Akure, Nigeria. Dr. Agboola currently serves as an assistant professor in the Department of Architecture within the Faculty of Engineering and Architecture at Istanbul Gelisim University, Turkey. His research expertise spans sustainable architecture, landscape planning and design, smart environments, and environmental sustainability in rural and urban development. He has published extensively in international journals and conferences. He is also a research fellow at the Center for Research, Innovation, Development, and Entrepreneurship (CRIDE-UK) and a professional architectural educator with the Association of Architectural Educators in Nigeria (M-AARCHES).

Md. Mortuza Ahmmed is a faculty member in the Department of Computer Science and Engineering at American International University–Bangladesh (AIUB), Dhaka. His academic background and professional expertise are rooted in computer science and engineering, with a strong focus on emerging technologies and data-driven computing solutions. His research interests encompass advanced computing paradigms, data analytics, and innovative algorithmic approaches aimed at solving contemporary technological challenges. He is particularly interested in applying intelligent and data-centric methods to develop scalable and efficient computing systems. Mr. Ahmmed is actively engaged in higher education and academic development, contributing through effective teaching, student mentoring, and participation in research and academic collaborations. He is committed to fostering a research-oriented learning environment and promoting interdisciplinary work that leads to impactful and practical outcomes.

Dr. R. Alamelu, senior assistant professor at SASTRA University, has 25 years' teaching experience, 100+ SCOPUS-indexed publications, and a doctorate in quality management. An expert in supply chain management, HR analytics, and circular economy, she has authored a book, guided research, organized academic events, and consulted for industries in Tamil Nadu.

Mrs. M. Anitha is a research scholar at Thiagarajar College of Engineering, Madurai, India. Her research interests encompass artificial intelligence, IoT systems, data analytics, and intelligent networked applications. She focuses on developing AI-based methodologies for enhancing the performance and reliability of mobile and IoT ecosystems. She has participated in academic research activities and contributed to scholarly works in emerging computing domains. Her research aims to address challenges related to scalability, security, and intelligent data processing in next-generation smart systems.

Mr. Aravinda Raj Rajasekaran is currently working as an assistant professor in the Department of Electrical and Electronics Engineering at SRM MADURAI College for Engineering and Technology, TamilNadu, India. He is doing his PhD in the Faculty of Electrical Engineering from Anna University, Tamil Nadu. His research interests include renewable energy systems, smart grid, electric vehicles, and power systems.

Arobana Joseph Stanley is an educator and ICT professional with over two decades of experience in teaching, technology, and administration. She heads the ICT/Robotics/AI Department at Sunrise International School, Abu Dhabi, UAE. Her expertise spans programming, web applications, driving innovation, and excellence in academic and educational technologies.

Dr. Ann Baby is a distinguished academician and researcher at Rajagiri College of Social Sciences, Kalamassery. She holds a PhD in computer science from Bharathiar University, where she was also a university rank holder in her post-graduation. With expertise spanning artificial intelligence, data analytics, and management sciences, she has made significant contributions through high-quality research publications in Scopus-indexed journals and conferences. Her work focuses on applying emerging technologies to solve real-world challenges. She has presented papers at national and international conferences and actively collaborates on interdisciplinary research projects. She has provided consultancy in data analytics and digital transformation and has delivered numerous workshops and expert sessions in cybersecurity, machine learning, and emerging technologies. Committed to advancing knowledge, mentoring young scholars, and driving impactful research that bridges theory and practice, Dr. Baby is a lifetime member of the Computer Society of India and Soft Computing Research Society (SCRS).

Divya Bairavi is working as an assistant professor in the Department of Computer Science and Engineering, Artificial Intelligence and Machine Learning, at Vels Institute of Science, Technology, and Advanced Studies, Chennai. She graduated her master of engineering in the Department of Information Technology at Sri Sairam Engineering College, Chennai, Tamil Nadu. She is pursuing her PhD in computer science at Anna University, Chennai. She has been in the field of artificial intelligence and machine learning at VISTAS for more than two years and worked as Python and data science trainer at Whitehtjr Pvt. Ltd., Mumbai, for three years. She has been in the teaching profession for more than ten years and has various papers in national and international journals, conferences, and symposiums. Her main area of interest includes Python, artificial intelligence and machine learning, data science, and cognitive learning.

P. Deepalakshmi is working as a professor in computer science and engineering in Kalasalingam Academy of Research and Education (Kalasalingam University), Srivilliputhur, Tamil Nadu, India. Her enormous designations include as the director (accreditation and ranking) and dean of the School of Computing at Kalasalingam Academy of Research and Education, an assessor (NAAC), an ACM senior member, an IEEE senior member (CS, RAS, WIE), and a research fellow (INTI University, Malaysia). She has more than 100 papers in international journals and conference proceedings, as well as book chapters and lecture notes. Her research interest includes but is not limited to optimization techniques, network routing, distributed computing, network security, data analytics, and application of AI and ML techniques in health-care, legal, and cybersecurity domains.

Dr. R. Elakkiya is an accomplished researcher and assistant professor of computer science at BITS Pilani, Dubai. A gold medalist and university first rank holder from Anna University, she specializes in sign language recognition and has been listed among the top 2% world scientists (Stanford–Elsevier, 2024–2025). She has published 75+ papers, authored books, filed patents, and secured 14 funded projects from leading national and international agencies. A dynamic leader, she chairs ACM-W Dubai, serves in key roles at APPCAIR, and contributes widely as an AI/ML consultant, innovator, and invited speaker across global platforms.

Mrs. V. Gayathri is an assistant professor of information technology in Kamaraj College of Engineering and Technology, Virudhunagar. She is currently pursuing her PhD in data analytics in health care at Kalasalingam Academy of Research and Education, Krishnankovil. Her research interests include cybersecurity, health-care informatics, big data security, and predictive analytics, and she has published her work in reputed conferences and journals.

Jasmine Gnanadurai is currently associated with the Department of Electrical and Computer Engineering, George Fox University, Newberg, Oregon, USA. She is a researcher in the field of electrical and computer engineering, with a strong focus on emerging computing paradigms. Her academic interests span across advanced computational systems and intelligent technologies that address real-world engineering challenges. She has published various research papers in the areas of Internet of Things (IoT) and cloud computing, emphasizing efficient system architectures, scalability, security, and data-driven optimization.

Mrs. S. Gokilapriya is an assistant professor in the Department of Computer Science at K. S. R. College of Arts and Science for Women. She holds an MCA degree and is currently pursuing her PhD at Bharathidasan University. With strong expertise in machine learning, image processing, and computer networks, she has published research papers, presented her work at national and international conferences, and authored two academic books. She has completed several FDPs and MOOC courses in emerging technologies, including AI, cloud, blockchain, and digital productivity. Her professional experience includes roles in teaching and programming, with a deep commitment to academic excellence and innovation.

Dr. Josep M. Guerrero received his BS degree in telecommunications engineering, MS degree in electronics engineering, and PhD in power electronics from the Technical University of Catalonia, Barcelona, in 1997, 2000, and 2003, respectively. Prof. Guerrero is an associate editor for *IEEE Transactions on Power Electronics*, *IEEE Transactions on Industrial Electronics*, and *IEEE Industrial Electronics Magazine* and an editor for *IEEE Transactions on Smart Grid* and *IEEE Transactions on Energy Conversion*.

Hemamalini Siranjeevi is an assistant professor in the Department of Computer Science and Engineering, Srinivasa Ramanujan Centre, SASTRA Deemed University. Her area of research includes machine learning, natural language processing, large language models, and cryptography

Mrs. X. Ignatius Selvarani is an assistant professor of computer science and engineering with over 13 years of teaching experience in Kamaraj College of Engineering and Technology, Virudhunagar. She completed her ME and CSE in PSR Engineering College, Sivakasi. She is doing research in artificial intelligence and machine learning. Her expertise lies in IoT applications, machine learning, and deep learning. This book reflects her commitment to bridging academic research with practical industry applications.

Dr. Cynthia Jayapal is a professor in the School of Computer Science and Engineering, R. V. University, Bengaluru, India. She received her BE in computer science and engineering from Bharathidasan University, her ME in computer science and engineering from Bharathiar University, and her PhD in information and communication engineering from Anna University, Chennai. She has over 25 years of combined experience in academia and industry. Her research interests include data communication, wireless and vehicular ad hoc networks, and ad hoc and sensor networks. She has published more than 40 research papers in reputed international journals and conferences. Dr. Cynthia serves as a reviewer for Springer *Wireless Networks*, *KSII Transactions on Internet and Information Systems*, and *IET Intelligent Transport Systems*. She has undertaken consultancy projects for government agencies and industry and is actively involved in international academic collaborations with institutions in the USA, New Zealand, and Singapore.

Kalaichelvi, V., received her PhD in information and communication engineering from Anna University, Chennai, in 2013. She is working as an associate professor in the Department of Computer Science and Engineering, SRC, SASTRA Deemed University–Kumbakonam. Her research interests include cryptography, steganography, and security issues in various IT fields.

Dr. Ramani Kannan (senior member, IEEE) is a distinguished senior lecturer and postgraduate program leader at Universiti Teknologi PETRONAS, Malaysia. He formerly served as the chairperson of the IEEE Power Electronics Society, Malaysia Chapter (2022–2024), demonstrating strong leadership in professional and technical communities. In 2024, he joined the IEEE R10 Professional Activities Committee and the Ad hoc Committee on Industry Engagement and Round Table. A chartered engineer (UK) and professional technologist (MBOT), he has expertise spanning power electronics, renewable energy, battery management systems, electric vehicles, and machine learning. Dr. Ramani has received major recognitions, including the Career Award for Young Teacher from AICTE, Government of India, and the Outstanding Researcher Award from Universiti Teknologi PETRONAS, along with the Outstanding Contribution Award from IEEE PELS Malaysia in 2024. He serves as an associate editor for *IEEE Access* and the *IET Journal of Engineering* and has authored over 275 publications in reputed journals and conferences.

Mr. K. Karthikeyan is currently serving as an assistant professor in the Department of Computer Science and Business Systems at K. S. Rangasamy College of Technology, Tamil Nadu, India. He holds an ME degree and is presently pursuing his PhD at Anna University. With over 11 years of teaching experience, he has academic and research contributions that span the fields of network

security and machine learning. He has authored three papers in international refereed journals, presented ten papers in national and international conferences, and published three patents. In addition, he has contributed three book chapters to reputed publications.

Kavitha Manikandan is an Assistant Professor in the Department of Artificial Intelligence and Data Science at Kathir College of Engineering, with over 15 years of teaching experience. She is currently pursuing a Ph.D. at Anna University and holds B.E. and M.E. degrees in Computer Science. Her areas of expertise include artificial intelligence, machine learning, and cloud computing. She has published research articles, contributed to funded projects, delivered international presentations, and authored one book chapter in a reputed publication.

S. Kayalvizhi is designated as an assistant professor in the Department of Computer Science and Design in Sethu Institute of Technology, Madurai, India. She is pursuing her doctoral degree under Anna University, Chennai. Her research areas include wireless sensor network and blockchain technology and body area network with IoT application.

Ms. Komal is an assistant professor in the School of Computer Applications at Lovely Professional University, India. She is currently pursuing her PhD in digital image processing from Lovely Professional University, with a research focus on signal processing and advanced image processing techniques. Her academic and research interests include digital image analysis, signal processing algorithms, and their applications in emerging computing and intelligent systems. She actively integrates research insights into her teaching to foster analytical and practical understanding among students. Ms. Komal has substantial teaching experience at the postgraduate level, where she delivers courses such as database management systems, operating systems, and the Internet of Things (IoT). She is committed to innovative pedagogy, curriculum development, and mentoring students in both academic and applied projects. Her ongoing research work aims to contribute to the development of efficient, accurate, and scalable image processing solutions, addressing contemporary challenges in data-driven and sensor-based computing environments.

Manjula, K., professor of computer science at SASTRA Deemed University, has over two decades of teaching excellence. With a background in mathematics, MCA, and MPhil, she earned her PhD in welding defect classification using ultrasonic signals and images. Her interests include signal/image processing, data mining, machine learning, AI, etc.

Dr. Isaivani Mariyappan is currently working as an assistant professor in the Department of Electrical and Electronics Engineering at Vaigai College of Engineering, Madurai, India. She received her BE and ME in electronics and instrumentation engineering and embedded systems technologies in 2006 and 2014, respectively. She earned her PhD in 2022 from Anna University, Tamil Nadu, focusing on multi-processor system-on-chip in VLSI domain. She has published more than 13 papers in reputed international journals and conferences. She has authored book chapters in renowned publications. She has been serving as an active reviewer in international journals and reputed book chapter publications. Her research interests include embedded systems, VLSI system, IoT, and power system protection applications.

Jad Matta is a researcher and developer with a PhD in computer science and a PhD in applied mathematics from Bircham International University. His interests center on machine learning, particularly swarms intelligence, along with algorithms and compiler design. His work focuses on developing and implementing advanced compiler techniques, including symbol tables, register allocation, parse trees, semantic analysis, and context-free grammars. Alongside this, he conducts research on advanced swarm intelligence methods, such as ant colony optimization, neural networks, and genetic algorithms.

Dr. Mariofanna Milanova, professor of computer science at UA Little Rock since 2001, specializes in AI, machine learning, and visual computing. An IEEE senior member, Fulbright scholar, and NVIDIA DLI ambassador, she has 120+ publications, two patents, and research supported by NSF, NIH, DARPA, DoD, and industry partners.

Dr. R. Muthuselvi is working as a professor in the Department of Information Technology in Kamaraj College of Engineering and Technology, Virudhunagar. She has a solid academic background and is a highly competent technology expert. Her areas of expertise include the Internet of Things and high-performance computing. She possesses a wealth of professional expertise and has been an editorial board member and reviewer for a number of reputable journals. An active participant in the area, she has written and published more than 50 papers in journals, international conferences, books, and book chapters, with a particular emphasis on Internet of Things and artificial intelligence.

Ann Rija Paul is an assistant professor at Rajagiri College of Social Sciences (Autonomous) with 10 years of teaching experience. Her research interests include machine learning, deep learning, artificial intelligence, and computer vision. She has served as a resource person for numerous training programs and workshops, delivering over 200 hours of sessions across domains such as android development, full-stack web development (Python Django and PHP Laravel), data science, machine learning, data mining, and Python programming at various institutions. Her research contributions include publications in SCI and Scopus-indexed journals and conferences, covering areas such as real-time vehicle tracking, accident detection, IoT-based forecasting, video retrieval, text summarization, and cloud security. She continues to contribute actively to teaching, research, and skill development through academic engagement and expert training activities.

Dr. A. Poonguzhali is working as a professor and head in the Electronics and Communication Engineering Department at Sri Sairam College of Engineering, Bangalore, affiliated with Visvesvaraya Technological University. She graduated in engineering at Periyar Maniammai College of Technology for Women, Thanjavur, Tamil Nadu, India. She secured her master of engineering in information and communication in the College of Engineering (Guindy Campus), Chennai, Tamil Nadu, India. She secured her PhD in computer science at Pondicherry University, Pondicherry, India. She is in the field of electronics and communication engineering at Sri Sairam College of Engineering, Bangalore and Karnataka, India. She has been in the teaching profession for more than 30 years. She has presented 35 papers in national and international journals, conferences, and symposiums. Her main area of interest includes wireless sensor networks, Internet of Things, and digital image processing.

Purushothaman R., research assistant at SASTRA University's Srinivasa Ramanujan Centre, is a dedicated academic with interests in circular economy, supply chain, operations, general management, and HRM. Passionate about knowledge advancement, he actively engages in research and scholarly work, contributing to the academic community across multiple management disciplines.

S. Sabena is a PhD holder and assistant professor at Anna University Regional Campus, Tirunelveli, India. She has several years of academic and research experience in the areas of artificial intelligence, multi-agent systems, machine learning, and intelligent computing. Her research focuses on developing efficient computational models and intelligent solutions for real-world engineering problems. She has published scholarly articles in reputed national and international journals and conferences. Dr. Sabena is actively involved in undergraduate and postgraduate teaching, curriculum development, academic mentoring, and research guidance, and she contributes to advancing engineering education through innovative teaching and research practices.

L. Sai Ramesh is a PhD holder and serves as a faculty member in the Department of Computer Science and Engineering at St. Joseph's Institute of Technology, Chennai, India. His academic and research interests include artificial intelligence, machine learning, data analytics, and emerging computing technologies. He has published research papers in reputed journals and conferences and actively participates in research and academic activities. Dr. Sai Ramesh is dedicated to teaching, student mentoring, curriculum enrichment, and applying modern computing techniques to solve practical problems, contributing to both academic excellence and professional development in computer science and engineering.

Dr. K. Sakthivel received his ME (computer science and engineering) degree in 2005 and PhD degree in 2012. He is working as a professor in the Department of Computer Science and Engineering, K. S. Rangasamy College of Technology (Autonomous), Tiruchengode. He has 25 years of teaching experience and has published papers in several international journals and conferences. His areas of research interest include image retrieval using hierarchical agglomerative and K-means clustering algorithms. He is an active member of ISTE and IAENG, with interest that includes soft computing, image processing, network security, Internet of Things, etc.

Sangeetha, P. is an Assistant Professor in the Department of Artificial Intelligence and Data Science at Kathir College of Engineering. She has over 6 years of academic experience and 2 years of industry experience, enabling her to effectively integrate real-world applications with classroom teaching. She is currently pursuing a Ph.D. under Anna University, with a strong research focus on Artificial Intelligence, Machine Learning, and Data Science. Passionate about emerging technologies, she actively contributes to curriculum development and mentors students in innovative, project-based learning.

Dr. R. Saranya is an assistant professor in the Department of Computer Science with Data Analytics at PSG College of Arts and Science, Coimbatore. She has extensive experience in teaching and research, spanning areas such as artificial intelligence, data analytics, machine learning, the Internet of Things, and database systems. She actively contributes to academic research through publications in reputed journals and edited volumes and regularly presents her work at national and international conferences. Her academic interests encompass interdisciplinary research, with a particular focus on the application of AI and data-driven technologies in social, health-care, and entrepreneurial ecosystems. She is passionate about mentoring students, curriculum development, and promoting innovation-oriented learning.

M. Satthiyaraju is working as an Assistant Professor in the Department of Mechanical Engineering at SRM Institute of Science and Technology, Vadapalani Campus, Chennai. He received his PhD in Mechanical Engineering from the National Institute of Technology (NIT), Tiruchirappalli, India, and his Master's degree in Engineering Design from the College of Engineering, Guindy, Chennai. His current research interests focus on the design and development of piezoelectric polymers, nanofibers, and nanocomposites for energy harvesting, sensing, and actuator applications, as well as the testing of additively manufactured materials.

Mrs. Astangini Selvaraj is a research scholar in the Department of Computer Science and Business Systems at Thiagarajar College of Engineering, Madurai, India. Her research interests include artificial intelligence, intelligent mobile computing, Internet of Things (IoT), edge-cloud integration, and data-driven smart systems. She actively works on applying AI techniques to enhance mobile and IoT ecosystems, focusing on efficiency, scalability, and intelligent decision-making. She has contributed to scholarly publications and book chapters in emerging technologies and continues to engage in interdisciplinary research that bridges computer science, business systems, and intelligent applications.

Ms. Anjana Sharma is an assistant professor in the School of Computer Applications at Lovely Professional University, India. She is currently pursuing her PhD in artificial intelligence and machine learning at Lovely Professional University. Her research focuses on data analytics, with an emphasis on applying advanced algorithms to extract meaningful insights from complex and large-scale datasets. Her research interests include data analytics, advanced data mining techniques, machine learning algorithms, and intelligent data-driven decision-making systems. She actively integrates research with teaching to provide students with a strong balance of theoretical foundations and hands-on practical exposure to modern analytical tools and techniques. Ms. Sharma teaches postgraduate-level courses, such as data science, data visualization, big data, and database management systems. She is committed to outcome-based education, continuous curriculum enhancement, and mentoring students in research-oriented and industry-relevant projects. Her ongoing research aims to design efficient, scalable, and intelligent analytical models that can be effectively applied to real-world problems in data-intensive computing environments.

Dr. K. V. M. Shree has been working as a professor and dean (R&D) in the Department of Artificial Intelligence and Data Science in Dhanalakshmi Srinivasan Engineering College (Autonomous) since May 2023. With over 25 years of dynamic experience in academia, research, and administration, she possesses a robust foundation in wireless networks and computer communication. As a dedicated academician, she has successfully served as a principal and professor, enhancing student outcomes and fostering an engaging learning environment. Her publication record, including presentations at esteemed institutions, like IIT Kharagpur and Nanyang Technological University in Singapore, and 15 papers in reputed journals and authorship of the book *Digital Communication*, showcases her commitment to advancing knowledge.

S. Sorna Lakshmi is a researcher in the Department of Computer Science and Engineering at Anna University Regional Centre, Tirunelveli, India. She holds an ME degree in computer science and engineering from Thiagarajar College of Engineering. Her research interests include blockchain technologies, computer networks, the Internet of Things (IoT), and related emerging areas in distributed and intelligent systems. She is actively involved in research activities focused on designing secure, scalable, and efficient computing solutions for real-world applications. Her work also includes contributing to academic publications, supporting student research, and engaging in interdisciplinary studies that address current challenges in modern computing and networked systems.

Sathiyandrakumar Srinivasan received a bachelor's degree in science from Madurai Kamarajar University, India, in 1998. Then he obtained a master of computer application degree in Madras University, Chennai, India, in 2002; an MBA from Bharathidasan University, Trichy, India, in 2004; and a PhD in cybersecurity at Kalasalingam University, Srivilliputhur, India, in 2023. Currently, he is working as an associated vice president, software engineering, at V2 Technologies Inc., New Jersey, USA, which includes cybersecurity architecture. His research interest focuses on malware analysis, malware prediction and detection, and anomaly detection of user-level access. He is working as a director of technology in an honorable role for Project Management Institute (PMI) in Nashville, Tennessee, USA. He has seven patents, all with respect to cybersecurity, IoT, and machine learning. He is the author of two books related to cybersecurity, artificial intelligence, and machine learning. He serves on the editorial boards for several IEEE and SCI journals.

Dr. M. Sudha, assistant professor at SASTRA University's Srinivasa Ramanujan Centre since 2019, holds a PhD in information and communication engineering from Anna University. With 13 years of teaching experience, she has published research, guided 40+ projects, and earned awards, specializing in image processing, signal processing, communication, and AI.

Razia Sulthana Abdul Kareem is a PhD holder and senior lecturer at the University of Greenwich, London, UK. She has extensive experience in teaching, research, and curriculum development in higher education. Her research interests include artificial intelligence, data science, intelligent systems, and applied computing. She has published in reputed journals and conferences and is actively involved in supervising undergraduate and postgraduate research projects. Dr. Razia contributes to academic leadership through innovative teaching practices, interdisciplinary research, and continuous engagement with emerging technologies in computing and data-driven systems.

Dr. Shoby Sunny is an assistant professor at Rajagiri College of Social Sciences (Autonomous), Kochi, with over 20 years of experience in both industry and academia. Her research interests span digital image processing, data mining, and machine learning. She has published several research papers in reputed international journals and conferences, with contributions covering areas such as plant disease detection, image enhancement techniques, network scanning methodologies, and student engagement analytics. She remains committed to advancing research and fostering academic growth through teaching, mentorship, and scholarly work.

Mrs. C. Sonia is currently working as an assistant professor in the Department of Electrical and Electronics Engineering at Vaigai College of Engineering, Madurai, India. She is pursuing her PhD in electrical engineering from Anna University, Tamil Nadu. Her research interests include power electronics and drives, renewable energy, electric vehicle, and power systems.

Mr. N. Sundaraperumal is currently working as an assistant professor in the Department of Electrical and Electronics Engineering at Vaigai College of Engineering, Madurai, India. His research interests include electric vehicles, renewable energy systems, smart grid, power electronics and drives, and IoT.

Mrs. D. Suseela, assistant professor in AI and data science at Sri Krishna College of Engineering and Technology, Coimbatore, has ten years' teaching experience. Pursuing a PhD at Anna University, she holds MTech and BTech degrees in IT. Her research spans network security, cloud computing, machine learning, and deep learning.

Mrs. Ponvizhy Swathy is an assistant professor in the Department of Information Technology at SSM College of Engineering, Dindigul, Tamil Nadu, India. Her research interests include artificial intelligence, data analytics, IoT applications, and smart computing systems. She has teaching and research experience in emerging computing technologies and has contributed to academic publications in AI-enabled systems. Her work focuses on leveraging intelligent algorithms to enhance data processing and decision-making in mobile and IoT environments. She is actively involved in research-driven teaching and interdisciplinary academic activities.

Ms. S. Thanga Tamil Selvi is an assistant professor at Bannari Amman Institute of Technology, Sathya Mangalam, Tamil Nadu, India. Her areas of interest include artificial intelligence, machine learning, IoT systems, and intelligent software engineering. She has contributed to research publications focusing on smart and adaptive computing solutions. Her academic work emphasizes the application of AI techniques to real-world mobile and IoT-based systems, aiming to improve automation, efficiency, and system intelligence. She is actively involved in research, teaching, and mentoring in the field of emerging technologies.

- K. Ulagapriya** has got 11 years' IT industry experience and 12 years' academic experience and is currently working as an associate professor and the head in the Department of Computer Science and Engineering—Artificial Intelligence and Machine Learning, Vels Institute of Science, Technology, and Advanced Studies, Chennai. She worked in various IT companies, like Infosys and L&T Infotech and has rich experience in programming. She pursued research in machine learning and has published several journal papers in machine learning. Her research interests include machine learning, data analytics, artificial intelligence, and software engineering.
- Dr. S. Usharani** is a professor and the head of the Department of MCA, Viswam Engineering College, Madanapalle, with over 18 years of teaching experience. She holds a PhD in computer science and is TNSET-qualified, with expertise in AI, data mining, cloud computing, and big data analytics. She is an Indian patent holder in machine learning–based IoT security and is an active researcher, reviewer, and academic leader committed to quality education and innovation. She is certified in NPTEL Domain Scholar and Discipline Star.
- K. Velusamy**, MSc, MPhil (CS), received his degree from Periyar University, Salem. Presently, he is doing PhD in computer science, in the Department of Computer Science, Sri Vasavi College (Bharathiyar University), Erode, Tamil Nadu, India. He has published many research papers in referred journals and presented papers at various national/international conferences. His area of specialization includes data mining, artificial neural networks, and blockchain technology with IoT.
- Dr. K. Vijayakumari** is an assistant professor of computer science at Trinity College for Women, Namakkal. She holds a PhD from Bharathidasan University, specializing in fuzzy systems and optimization techniques. Her expertise includes artificial intelligence, machine learning, IoT, data mining, and smart health care. She is a recipient of the NPTEL Domain Scholar and Discipline Star recognitions. She has published several research papers, book chapters, and books in the areas of Internet of Things (IoT), artificial intelligence, and fuzzy optimization algorithms.
- Vimala Devi, P.**, received her PhD in computer science and engineering from SASTRA Deemed University. She is currently working as an assistant professor in the Department of Computer Science and Engineering, SRC, SASTRA Deemed University—Kumbakonam. Her research interests include cryptography, body area networks, and cloud computing.
- Dr. Vishal Choudhary** is an associate professor in the School of Computer Applications at Lovely Professional University, India. He holds a PhD from Banasthali University and has established expertise in algorithmic security, key management, and secure communication for wireless sensor networks. His research contribution includes decentralized and zonal key distribution protocols, intrusion detection systems, and security-aware routing mechanisms for resource-constrained networks. He has also worked extensively on optimization techniques for optical interconnection networks, addressing performance and scalability challenges. In addition, Dr. Choudhary has applied fuzzy logic and intelligent techniques to a broad range of software engineering and networking problems, including software test effort estimation, mobile and wireless network routing, and decision-making under uncertainty. His work demonstrates a strong balance between theoretical rigor and practical applicability, with publications in reputed journals and conferences. His current research interests include wireless sensor network security, intelligent and adaptive security models, optimization algorithms, and AI-driven solutions for modern communication systems.
- B. Vivekanandam**, deputy dean of the Faculty of Computer Science and Multimedia at Lincoln University College, Malaysia, specializes in deep learning, machine learning, and artificial intelligence. With 15 years of teaching and 8 years of research experience, he is a recognized reviewer, curriculum developer, and one of the university's top-ranked scientists.

1 Introduction to Mobile and IoT Ecosystems

*S. Gokilapriya, K. Sakthivel, Ramani Kannan,
and K. Karthikeyan*

1.1 OVERVIEW OF MOBILE TECHNOLOGIES

Mobile technologies evolved with great speed, transforming the way individuals communicate, automate, and digitalize business. The emergence of 5G influenced the development of smart automation significantly by enabling huge machine-type connectivity and incredibly dependable low-latency communication. Through these technological advancements, industries are increasingly adopting automation systems powered by mobile technologies, enhancing efficiency and scalability. Furthermore, the evolution from 1G to 5G has revolutionized mobile wireless technology by improving data transmission speeds and enabling seamless connectivity (Kumar 2021). These improvements have supported applications such as cloud computing, remote health care, and infrastructure for smart cities. The growing influence of artificial intelligence (AI) in mobile computing has also reshaped cloud infrastructures, providing enhanced data processing and storage capabilities. AI-powered mobile apps are now ubiquitous in predictive analytics, voice recognition, and intelligent automation, facilitating industry-wide real-time decision-making. 5G and AI work together to accelerate mobile apps' processing rates, security, and network stability. 5G also has a significant part in the Internet of Things (IoT) by tying together a vast array of gadgets, from self-driving automobiles to smart household appliances, thereby making the whole ecosystem an entirely connected world. Cloud-based mobile platforms also offer additional scalability and resource management to enable edge computing and distributed data processing (Luitse 2024). Future digital transformations are anticipated to be shaped by the ongoing development of mobile technologies, which is predicted to spur innovation across several industries.

1.1.1 THE EVOLUTION OF MOBILE DEVICES

The journey of mobile phones and IoT technologies has seen a continuous advancement through various significant stages. In the 1980s, mobile communication began with 1G analog systems that supported only voice calls with minimal security. The 1990s brought 2G digital technology, enabling text messaging and improved connectivity. With the arrival of 3G in the early 2000s, mobile internet access, video calling, and multimedia features became common, encouraging the use of smartphones and the initial development of connected devices through machine-to-machine communication. The expansion of 4G networks in the 2010s allowed faster data transmission, supporting real-time applications and the wider adoption of IoT devices in homes, health care, and industries. As more devices connected, edge computing emerged to process data closer to its source, improving speed and reducing network load. The rollout of 5G in the 2020s further transformed connectivity by offering extremely low latency and supporting vast numbers of devices, paving the way for technologies like smart cities, autonomous systems, and AI-based applications. Moving forward, research into 6G aims to create more intelligent, immersive, and highly integrated environments where devices, data, and users are seamlessly connected.

The mobile phone has drastically changed communication and computing capabilities over the decades. The earliest mobile phones, developed in the 1980s, were constructed on first-generation (1G) analog technology, which supported only voice calls and poor security with limited coverage. The introduction of second-generation (2G) digital networks during the 1990s offered text messaging (SMS) and limited data services, with greater connectivity and efficiency. Third-generation (3G) technology during the early 2000s offered mobile internet access, video calling, and multimedia applications, leading to the boom of smartphones with higher computing powers and internet-based services (Luitse 2024). The move to fourth-generation (4G) networks was a milestone in the provision of high-speed data, allowing for broadcasting in real-time, cloud computing, improved user engagements. The newest breakthrough, fifth-generation (5G) technology, has brought extremely low latency, massive device connections, and increased dependability of the network, allowing for new technologies like the IoT, augmented reality (AR), and artificial intelligence (AI) (Kumar 2021). With continuous innovations in mobile technology, future developments are expected to focus on AI-driven applications, edge computing, and the seamless integration of smart devices for improved automation and connectivity.

1.1.2 MOBILE COMMUNICATION TECHNOLOGIES (5G, WI-FI, BLUETOOTH)

Mobile technologies have advanced significantly, enabling seamless communication and connectivity across various devices and applications. Among the most prominent mobile communication technologies are **5G, Wi-Fi, and Bluetooth**, each playing a critical role in different aspects of connectivity and data exchange.

1.1.2.1 5G Technology

- **Dynamic Spectrum Sharing (DSS).** Allows 5G to share spectrum with existing 4G networks, improving efficiency by dynamically allocating available spectrum resources (Miftahudin et al. 2023).
- **Carrier Aggregation.** Combines multiple frequency bands to increase data rates, enhancing overall network performance and user experience.
- **Massive MIMO.** Uses multiple antennas to improve capacity and coverage by transmitting multiple data streams simultaneously.
- **Millimeter Wave (mmWave).** Enables short-distance, high-speed data transfer, utilizing higher-frequency bands for increased bandwidth (Miftahudin et al. 2023).

1.1.2.2 Wi-Fi Technology

Wi-Fi technology has advanced, and today's standards provide improved performance:

- **Wi-Fi 6.** Offers increased performance, speed, and capacity; enhancement in dense situations through improved use of available spectrum.
- **Wi-Fi 6E.** Expand Wi-Fi 6 to the 6 GHz frequency range, leveraging additional channels with lower interference to provide improved and lower-latency connections.
- **Mesh Wi-Fi.** Uses several access points to provide seamless coverage in a whole home or office, with uninterrupted connectivity and no dead spots (Lin et al. 2023).

1.1.2.3 Bluetooth Technology

Bluetooth technology allows devices to communicate wirelessly across short distances. Some key developments are:

- **Bluetooth 5.0.** Offers improved speeds, range, and data broadcasting, for improved data transfer and connectivity performance.

- **Bluetooth Low Energy (BLE).** Low-power design for wearables and IoT applications, with efficient and extended battery life.
- **Bluetooth Mesh.** Enables devices to create a mesh network, enhancing coverage and reliability by allowing multiple devices to directly communicate with one another (Yu et al. 2023).

The growth of 5G, Wi-Fi, and Bluetooth technologies is propelling the future of mobile communications. 5G's low-latency and high-speed feature will fuel new applications, including autonomous vehicles and smart cities. The growth of Wi-Fi provides secure and rapid internet access in increasingly dense settings. Bluetooth enhancements meet the increasing number of connected gadgets in an Internet of Things (IoT) environment. When combined, these three technologies are changing the globe. More connected and efficient.

1.1.2.4 IoT Applications in Smart Cities

The Internet of Things (IoT) connects devices, sensors, and systems to collect and exchange data. In smart cities, IoT helps manage resources efficiently, improve services, and enhance the quality of urban life.

IoT applications are transforming smart cities, health care, transportation, and industry by connecting sensors, devices, and analytics to deliver measurable improvements in efficiency, cost savings, and sustainability. In smart cities like Barcelona, IoT-enabled water management, smart parking, adaptive lighting, and waste collection have reduced operational costs by millions while cutting emissions. Projects such as Smart Santander in Spain show how thousands of sensors for air quality, parking, noise, and waste monitoring can enable multiple services from a single platform, improving responsiveness and service quality. In health care, remote patient monitoring and hospital-at-home programs have lowered hospitalizations, reduced emergency visits, and improved patient outcomes, with telemedicine adoption in the United States increasing from about 15% in 2019 to over 80% in 2021. Transportation systems like Singapore's Intelligent Transport System use real-time traffic data to reduce congestion and travel times, while sensor-based parking guidance reduces emissions from vehicles searching for spaces. In industry, predictive maintenance powered by IoT reduces equipment downtime, extends asset life, and lowers maintenance costs, generating millions in savings for large-scale operations. These advancements bring significant societal benefits, such as better public services and improved health access, economic gains through operational savings and job creation, and environmental advantages by lowering emissions and optimizing resource use, though they also raise challenges around privacy, equity, and e-waste management.

1.2 IOT'S PROGRESS: ADDRESSING THE WORLD

IoT is revolutionizing our lives and work habits by connecting devices and enabling them to talk and engage with each other without human intervention. The Internet of Things is a network of physical items that are equipped using software, sensors, and other technologies to establish an online connection and share data with other systems and devices. The devices range from basic home goods, like thermostats and refrigerators, to sophisticated industrial machinery and equipment (Zanella et al. 2014).

The IoT industry has been growing at a record pace in the last few years, driven by technological innovation, the expansion of gadgets with internet access, and the rising demand for automation and efficiency. Over 35 billion IoT electronic devices are estimated to be linked by 2025, compared to only 15 billion in 2015 (Gubbi et al. 2013).

IoT technology is used across sectors, revolutionizing processes and providing potential areas for innovation. Smart cities, smart homes, industrial IoT (IIoT), and health care are some of the most popular uses of IoT. IoT devices for smart homes enable users to remotely monitor and control a variety of home features, including appliances, lights, security, and heating (Da Xu et al. 2014).

1.2.1 DEFINING IoT (INTERNET OF THINGS)

IoT is an innovative paradigm that makes physical objects possible to be linked to the internet, communicate with each other, and generate useful information for decision-making and automation. IoT extends the internet beyond traditional computing devices by integrating sensors, embedded systems, and intelligent analytics, permitting real-time observation and control of interconnected devices (Gubbi et al. 2013). This connected world improves workforce productivity, reduces operational costs, and enables predictive insights in many sectors, like health care, smart cities, industrial automation, and transport. With cloud computing, edge computing, and artificial intelligence, IoT provides a data-driven, seamless environment that enables intelligent decision-making and automated processes (Atzori et al. 2010).

Although it has many advantages, IoT is also plagued by security attacks, privacy, and interoperability problems, owing to the wide variety of devices and manufacturers. The vast data stream from IoT devices calls for strong cybersecurity to avoid unauthorized access and data leakage. Moreover, interoperability of heterogeneous devices is also a primary challenge, demanding standard protocols and architectures (Gubbi et al. 2013). Addressing these issues will be essential to achieving IoT's maximum potential in a variety of fields as it develops, guaranteeing a safe, scalable, and effective connected world (Atzori et al. 2010).

IoT has developed into a revolutionary technology that enables seamless communication among devices connected to it and facilitates automation in different industries. With the integration of smart systems, IoT achieves maximum efficiency, improves decision-making, and encourages innovation in sectors like health care, automation in industry, and smart cities, but its widespread adoption also brings challenges, particularly in ensuring data security, privacy protection, and device interoperability. Addressing these issues requires standardized protocols, robust cybersecurity measures, and scalable architectures to support the growing network of interconnected devices. Future developments in IoT security frameworks and infrastructure will be essential to achieving its maximum potential and paving the way for a future that is more intelligent and connected.

TABLE 1.1
Distinct Features of Cloud, Fog, and Edge Computing Based on Processing Location, Latency, and Use Cases

Term	Definition	Latency	Location of Processing	Typical Application Scenarios
Cloud computing	A centralized computing model where data is stored and processed in large remote data centers accessible via the internet	High (due to distance from the source)	Located far from end users, often in large data centers	Data backup, web applications, streaming services, email platforms
Fog computing	An intermediate layer that extends cloud capabilities closer to the data source by using local network nodes or gateways	Medium	Near the data source, typically on local area network (LAN) nodes or routers	Smart traffic control, industrial automation, energy management
Edge computing	A decentralized approach where data processing takes place directly on or near the devices that generate the data	Low (near-instant response)	Directly on devices or nearby edge servers (e.g., IoT sensors, gateways)	Autonomous vehicles, real-time health monitoring, AR/VR systems

1.2.2 IoT NETWORKS AND COMMUNICATION PROTOCOLS

IoT is an enormous network of devices with internet access which exchange information and communicate with one another using various networking protocols and technologies. The protocols used are designed to meet the various needs of Internet of Things applications, like range, power usage, bandwidth, and reliability (Al-Fuqaha et al. 2015).

1.2.2.1 Short-Range Communication Protocols

- **Wi-Fi** is employed for high-speed data communication and is extensively used in smart homes and industrial IoT applications but is extremely power-hungry.
- **Bluetooth Low Energy (BLE)** are especially well-suited for short-range, low-power applications, like health monitoring and wearables.
- **Zigbee and Z-Wave** offer low-power mesh networking features that enhance home automation and smart grid communications.

1.2.2.2 Wide-Area Networks with Low Power Consumption (LPWANs)

- **Long-Range Wide Area Network** provides a long range and minimal power consumption, which is ideal for environmental monitoring and smart agriculture.
- **Sigfox** is also an LPWAN technology that provides small data communication over long distances, appropriate for smart metering and asset tracking.

1.2.2.3 Low-Power and Lossy Network Routing Protocols (RPL)

One of the most well-known routing protocols for lossy link-constrained IoT networks is RPL, which is extensively used in industrial and city IoT applications. RPL achieves maximum data delivery with energy savings.

IoT networks and communication protocols are central to facilitating easy data exchange among devices. Protocol selection is based on the application's specific requirements, such as range, power usage, and data rate. With the future development of IoT, LPWANs, cellular networks, and routing protocols will be pivotal in enhancing network efficiency, security, and scalability (Al-Fuqaha et al. 2015). Addressing issues like security and interoperability will further enhance IoT adoption across industries.

1.3 ESSENTIAL COMPONENTS AND STRUCTURE OF INTERNET OF THINGS ECOSYSTEM

The Internet of Things' (IoT) explosive growth has changed how we engage with technology and the outside world at large. IoT ecosystems consist of sensors and networked devices and actuators that gather and share information, which makes it possible to create smart environments and optimize operations. It is urgent to understand the major elements and anatomy of IoT in order to realize its maximum potential. In this chapter, we explore the fundamental components, including devices, communication networks, and computation paradigms, in order to give a thorough summary of IoT ecosystems. Through the exploration of these components, we aim to shed light on the intricate interactions that drive innovation in various domains.

1.3.1 DEVICES, ACTUATORS, AND SENSORS

Devices, actuators, and sensors are the cornerstones of Internet of Things systems. *Devices* are tangible devices coupled with sensors and actuators that work in concert with the surroundings. *Sensors* sense the environment and pass it in digital format to devices. *Actuators* get directives from the IoT system and undertake action, that is, a switch being flipped or a thermostat adjusted. These elements collaborate to allow IoT devices to sense, react, and interact with their environment. The

combination of these elements enables the development of smart environments where devices can automatically monitor and regulate different parameters, resulting in greater efficiency and convenience. In a smart home, for instance, sensors can identify occupancy and regulate lighting and temperature, while actuators can manage appliances and security systems.

1.3.2 COMMUNICATION NETWORKS (LPWAN, ZIGBEE, ETC.)

Communication networks are required for IoT device interconnection and data exchange. LPWAN technologies, such as NB-IoT and LoRaWAN, offer low power consumption and long-distance communication, making them appropriate for battery-powered devices and distant gadgets. Zigbee is a low-power, short-range communication protocol used in industrial and household automation settings. Cellular networks, Bluetooth, and Wi-Fi are additional communication methods, with their respective strengths and applications. Wi-Fi, for example, offers high data rates and is appropriate for large data transfer applications, while Bluetooth is more suitable for short-range, low-power communication between personal devices. The communication protocol chosen depends on factors such as range, power consumption, rate of data, and application needs (Raza et al. 2017).

1.3.3 CLOUD AND IoT EDGE COMPUTING

Edge and cloud computing are important in IoT ecosystems through the provision of infrastructure for data processing, analysis, and storage. Cloud computing provides scalable and elastic resources to manage the massive volumes of data generated by IoT devices. It makes analytics, machine learning, and real-time data processing easier. Edge computing reduces latency and bandwidth usage by bringing data processing and storage closer to the devices. IoT solutions are more responsive and efficient because of this hybrid approach. For example, cloud computing can be used for long-term data storage and advanced analytics, whereas edge computing can be utilized in industrial IoT applications to analyze data locally and make choices in real-time. When cloud and edge computing are combined, it enables a balanced distribution of computational resources, ensuring optimal performance and cost-effectiveness (Shi et al. 2016).

Key elements of IoT ecosystems, like devices, actuators, sensors, communication, cloud computing, networks, and edge computing, are necessary for developing connected, smart environments. Sensors and actuator-enabled devices support monitoring and management in real-time, which leads to the development of smart environments. Communication networks like LPWAN and Zigbee provide effective data exchange, and scalable cloud computing offers resources for storing data and complex analytics. Edge computing optimizes responsiveness through the localization of computation closer to devices. These technologies, in synergy, create innovations across all domains, ranging from home automation to industrial control, which ends up maximizing the efficiency and performance of IoT systems.

1.4 THE ROLE OF MOBILE DEVICES IN THE IOT ECOSYSTEM

The ongoing developments in mobile technology have transformed communication, networking, and online interaction. The advent of 5G networks has introduced dramatic enhancements regarding velocity, capacity, and low latency, which facilitate effective communication among devices and enable upcoming technologies like artificial intelligence as well as the Internet of Things. The combination of 5G and intelligent automation has increased industrial digitization, increasing efficiency and driving innovation in several industries. Through the years, mobile wireless technology has progressed from second-generation analog networks to very advanced 5G networks, facilitating quicker data transmission, better reliability, and increased global connectivity (Attaran 2023; Kumar 2021).

Improvements in mobile technology have also contributed significantly to the development of edge computing, cloud computing, and smart apps, which allow for real-time data processing and decision-making. The introduction of 5G has improved networks' scalability and resiliency, enabling innovation in industrial automation, smart cities, and autonomous systems. Moreover, improvements in mobile wireless technology have enhanced energy efficiency and security in digital communications, addressing the growing demands of an increasingly connected world. As mobile technology continues to progress, it paves the way for future innovations that will further enhance connectivity and enable smarter digital solutions (Attaran 2023; Kumar 2021).

1.4.1 MOBILE DEVICES AS IOT GATEWAYS

Since they act as gateways, connecting low-power sensor nodes to cloud computing resources, mobile devices are essential to the Internet of Things (IoT) ecosystem. Because of their processing capabilities, connectivity features, and mobility, mobile devices support data gathering, processing, and transmission in real-time in Internet of Things environments. Middleware solutions such as MOSDEN have been developed to optimize resource-constrained mobile devices for IoT applications, enabling efficient sensor data aggregation and management (Perera et al. 2014). These middleware platforms enhance interoperability among heterogeneous IoT devices and improve data handling capabilities while minimizing resource consumption.

The inclusion of fog computing extends the mobile device role as IoT gateways further by moving computation nearer to the data's source. This saves on latency as well as bandwidth consumption, making mobile devices more efficient when managing IoT networks. Fog computing as a paradigm enables the dispersal of intelligence among edge devices to support IoT systems' real-time data analytics and decision-making (Rahmani et al. 2018). However, challenges to maximize their performance as IoT gateways, factors including energy efficiency, security, and the dynamic nature of mobile networks, must be taken into consideration. By leveraging advancements in middleware and fog computing, mobile devices will continue to serve as essential components in the growing IoT landscape.

1.4.2 MOBILE APPLICATIONS FOR IOT CONTROL

1.4.2.1 Uses of Internet of Things in Industrial Management

The inclusion of Internet of Things (IoT) in industrial administration has brought on vast improvements in operation efficiency, predictive maintenance, and data-empowered decisions. IoT can provide real-time tracking of the processes of manufacturing through the interfacing of sensors, devices, and cloud computers, thereby maximally optimizing workflows and keeping downtimes down. Among the most important advantages, predictive maintenance is a use of IoT in industrial management, where sensors that are IoT-enabled gather and analyze data to predict machinery failure before it happens. This is done to enable industries to reduce maintenance expenses and increase asset lifespan (Figure 1.1).

Additionally, IoT enables better supply chain management through end-to-end visibility of logistics operations. Sensors and RFID technology allow goods in transit to be tracked and monitored, allowing for improved inventory management and diminished losses due to theft or loss. With the application of big data analysis, industries can streamline supply chain routes, anticipate demand fluctuations, and enhance customer satisfaction.

Another critical application of IoT in industrial management is energy optimization. Smart energy management systems powered by IoT allow industries to monitor energy consumption patterns and implement energy-saving measures. This is particularly beneficial for reducing operational costs and achieving sustainability goals. For instance, IoT-driven automation systems can reduce waste and promote environmental sustainability by dynamically adjusting energy usage depending on real-time demand (Mu & Antwi-Afari 2024).

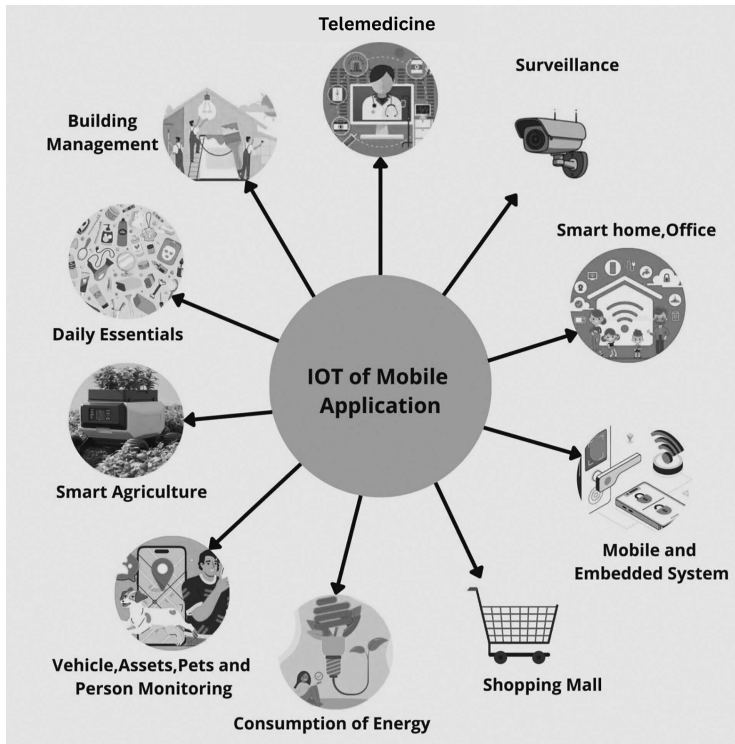


FIGURE 1.1 IoT-based mobile applications enable users to monitor, control, and interact with connected devices remotely, enhancing convenience and efficiency in daily tasks.

1.4.2.2 IoT Sensor Devices for Effective Health-Care System Management

Internet of Things (IoT) integration of sensor devices in medical care has significantly improved patient monitoring, real-time diagnostics, and hospital management. IoT-based health-care systems enhance remote patient monitoring (RPM) by continuously collecting and analyzing patient data, enabling timely medical interventions. With the increasing prevalence of long-term illnesses like diabetes, heart diseases, and lung diseases, IoT-driven solutions provide continuous health tracking and real-time alerts to medical professionals, reducing emergency response times.

Automated medication administration is among the primary benefits of IoT in the medical field. Smart pill dispensers integrated with IoT sensors ensure that patients adhere to prescribed medication schedules by sending reminders and alerts. This technology is particularly beneficial for elderly patients and those with cognitive impairments. Additionally, IoT-enabled wearables, such as smartwatches and biosensors, track vital signs, such as blood pressure, heart rate, and oxygen saturation, sending data to cloud-based platforms for analysis and early illness identification.

Hospital medical facilities utilize IoT for the effective management of resources. Medical gadget availability and utilization are monitored via IoT-enabled asset tracking systems, eliminating operational inefficiencies. Moreover, intelligent IoT-enabled HVAC systems improve energy consumption in hospitals by regulating temperature and humidity levels automatically in accordance with occupancy information. IoT-enabled robotic assistance is also being used in hospitals to disinfect patient rooms, distribute medicines, and aid surgeries (Gopichand et al. 2024).

1.4.2.3 IoT-Based Baby Monitoring Systems

Baby monitoring using Internet of Things (IoT) technology has made it easier for parents to monitor their infants remotely. Conventional baby monitoring devices depend on simple audio or video

monitoring, while advanced IoT-based autonomous monitoring devices provide real-time monitoring of several parameters, like temperature, humidity, movement, and cry detection. These devices use wireless sensors along with mobile apps, enabling parents to keep an eye on their babies from anywhere with an internet connection.

A key advantage of Internet of Things–based newborn monitoring is its capacity to offer automated alerts and notifications. For instance, if the baby wakes up and starts crying or the room temperature exceeds a set threshold, the system immediately notifies parents via a mobile application. The smart sensors installed in the baby’s environment continuously collect and process data, transmitting it to a cloud-based platform where AI algorithms analyze behavioral patterns. This predictive analysis helps parents anticipate and address potential discomforts before they escalate.

Additionally, mobile applications integrated with IoT baby monitors enable real-time control of connected devices, such as adjusting room temperature, humidity, and lighting to ensure a comfortable environment for the infant. Some systems also allow remote control of lullabies and white noise generators, promoting better sleep patterns. Advanced versions of these systems incorporate wearable biosensors to monitor vital signs, including oxygen levels and heart rate, which might be important for newborns with health issues (Chung et al. 2022).

IoT-enabled mobile applications are transforming various domains, including industry, health care, home automation, and baby monitoring. These applications enhance efficiency, security, and user friendliness. Yet security is a great concern that requires the adoption of sophisticated cybersecurity measures. Future studies need to improve IoT-enabled mobile applications’ scalability and security in order to accommodate mass adoption across sectors.

1.5 OPPORTUNITIES AND DIFFICULTIES IN INTEGRATING MOBILE AND IOT

1.5.1 INTEROPERABILITY ISSUES

Interoperability within the term “Internet of Things” (IoT) describes a fundamental issue that prevents smooth communication and integration between disparate platforms, devices, and services. *Interoperability* means that various IoT systems can interoperate effectively irrespective of variations in manufacturers, protocols for communication, data formats, and regulatory approaches (Noura et al. 2019). IoT networks become fragmented due to a lack of interoperability, which restricts their efficacy and scalability.

1.5.2 INTEROPERABILITY CHALLENGES

Interoperability challenges in IoT arise when devices, platforms, and protocols from different vendors struggle to communicate seamlessly. These issues often lead to integration complexity, reduced efficiency, and increased deployment costs.

1.5.2.1 Technical Interoperability

This is a challenge that results from the heterogeneity of communication protocols, hardware platforms, and network architectures in IoT systems. Different technologies for wireless communication, like Zigbee, Bluetooth, LoRa, and Wi-Fi, use different frequency bands and standards, which create integration challenges (Noura et al. 2019). The adoption of universal standards like the Open Connectivity Foundation (OCF) and oneM2M is crucial for overcoming this issue.

Interoperability remains one of the most pressing challenges in IoT, as the diversity of devices, communication protocols, and network infrastructures often leads to fragmentation. Beyond differences in frequency bands and transmission standards, variations in data formats, device discovery mechanisms, and security frameworks further complicate seamless integration. For example, a smart home gateway designed to manage Zigbee-based lighting systems may face compatibility issues when attempting to communicate with LoRa-based environmental sensors

or Bluetooth-enabled wearables, requiring protocol translation or middleware solutions. These technical gaps can hinder large-scale deployments, increase system complexity, and raise operational costs. To address this, middleware frameworks, protocol converters, and unified APIs are increasingly being adopted to bridge heterogeneous systems. Additionally, collaborative industry efforts toward developing cross-domain interoperability standards aim to ensure that devices from different manufacturers can operate cohesively. The push for such universal frameworks is not only a technical necessity but also a driver for accelerating IoT adoption, enabling scalability, and supporting more complex, cross-sector applications in smart cities, health care, transportation, and industrial automation.

1.5.3 NETWORK SCALABILITY AND MANAGEMENT

As IoT ecosystems expand from small-scale deployments to millions of interconnected devices, the demands on network capacity, latency management, and system orchestration increase significantly. Managing this growth is not simply a matter of adding bandwidth; it also requires intelligent traffic prioritization, dynamic load balancing, and real-time fault detection to prevent performance bottlenecks. For example, in large-scale smart city implementations, thousands of sensors may transmit data simultaneously, requiring adaptive routing protocols and distributed processing to maintain responsiveness. Emerging architectures leverage edge computing to process data closer to the source, reducing latency and alleviating core network congestion, while AI-driven network analytics predict traffic surges and allocate resources accordingly. Blockchain integration adds a layer of decentralized trust, enabling secure and verifiable device interactions without over-reliance on centralized authorities. Furthermore, hybrid cloud–edge frameworks allow for scalable storage and computation while maintaining efficiency in data-intensive applications, such as autonomous transportation, industrial IoT, and remote patient monitoring. Together, these strategies create resilient, adaptable infrastructures capable of supporting the exponential growth and complexity of future IoT deployments.

1.5.3.1 Scalability in IoT Networks

Scalability in the context of the Internet of Things refers to a network's ability to support an increasing number of devices while preserving effective data processing and communication. Traditional centralized network architectures often struggle with high latency, bottlenecks, and security concerns. To address these challenges, decentralized models, such as blockchain-based access control systems, offer improved security and eliminate the need for a central authority (Novo 2018). Additionally, AI-driven learning mechanisms can dynamically adjust network parameters, optimize traffic flow, and enhance overall scalability (Chen et al. 2019).

1.5.3.2 Adaptive and Efficient Network Management

Intelligent solutions that can adjust to changing circumstances are necessary for the efficient administration of IoT networks. Automated fault identification, congestion management, and predictive maintenance are made possible by AI and machine learning approaches, reducing downtime and improving efficiency. Furthermore, edge computing and cloud integration help distribute processing tasks, minimizing latency and enhancing network responsiveness. These advancements contribute to better performance in large-scale IoT environments.

1.5.3.3 Challenges in IoT Network Management

Managing large-scale IoT networks comes with various challenges, including interoperability, energy consumption, security risks, and real-time monitoring. Traditional network management strategies often fail to provide the flexibility needed for complex IoT ecosystems. Software-defined networking (SDN) and network function virtualization (NFV) are examples of emerging technologies

that provide programmable and scalable ways to increase network efficiency. (Aboubakar et al. 2022). These approaches enable dynamic resource allocation, automated traffic management, and enhanced security mechanisms.

The scalability and management of IoT networks are critical factors in ensuring their long-term efficiency and reliability. As the quantity of linked gadgets keeps increasing, traditional centralized approaches face challenges, such as latency, security risks, and resource limitations. Emerging technologies like blockchain, artificial intelligence, and cloud–edge computing provide promising solutions to enhance scalability and improve network management. AI-driven automation can optimize resource allocation and predict network failures, while blockchain-based access control ensures secure and decentralized management. Furthermore, software-defined networking (SDN) and network function virtualization (NFV) together offer greater flexibility in handling complex IoT environments. Moving forward, a combination of these innovative technologies will be essential in creating scalable, adaptive, and resilient IoT networks that can efficiently support the increasing demand for connectivity.

1.6 FUTURE TRENDS IN MOBILE AND INTERNET OF THINGS

Significant advancements in connectivity, automation, and real-time data processing are being driven by the development of mobile technology and the Internet of Things (IoT). IoT applications will become more effective, pervasive, and intelligent with the introduction of 6G networks, enabling smooth integration across a range of sectors, including health care, smart cities, industrial automation, and agriculture. These advancements will result in increased device connectivity, accelerated data transmission, and better security features, making IoT a critical component of future digital ecosystems (Kim 2021).

1.6.1 6G AND THE NEXT GENERATION OF IoT

The upcoming 6G era is expected to redefine IoT by delivering ultra-low latency, massive device connectivity, and unprecedented data transfer speeds, far surpassing the capabilities of 5G. With projected peak data rates in the terabit-per-second range and sub-millisecond response times, 6G will enable real-time interactions for mission-critical applications, such as autonomous transportation, immersive extended reality (XR), and large-scale industrial automation. Its integration of advanced features like AI-driven network orchestration, intelligent resource allocation, and built-in security frameworks will allow IoT systems to operate more efficiently and adapt dynamically to changing demands. Moreover, the convergence of 6G with emerging paradigms such as fog computing will bring processing power closer to IoT devices, reducing latency and improving reliability for time-sensitive operations. This evolution will also support massive machine-type communications (mMTC), opening opportunities for interconnected smart cities, precision agriculture, and next-generation health-care systems. By combining intelligence at the edge with near-instant communication, 6G will not only expand the scale of IoT but also enable innovative services that were previously beyond reach, laying the groundwork for a hyper-connected, autonomous digital ecosystem.

1.6.2 AI AND EDGE COMPUTING IN INTERNET OF THINGS

Artificial intelligence (AI) and edge computing are becoming the backbone of IoT, enabling devices to handle data near the source instead of depending on cloud infrastructure alone. This reduces network traffic, boosts security, and enhances response time (Kim 2021). AI-driven IoT applications are especially useful in sectors like manufacturing, logistics, and smart agriculture because they can evaluate sensor data, anticipate equipment faults, and automate decision-making.

1.6.3 IoT in Aquaculture and Smart Agriculture

The application of IoT in aquaculture and agriculture is revolutionizing resource management and productivity enhancement. Smart aquaculture with IoT integration uses sensors to track water quality, fish health, and feeding behavior, minimizing wastage of resources and enhancing yield (Yadav et al. 2023). Similarly, precision agriculture relies on IoT technology for automated irrigation, soil health monitoring, and real-time pest detection, optimizing crop production while minimizing environmental impact.

IoT and mobile technology's future will be shaped by advancements in 6G, AI, edge computing, and enhanced security frameworks. These innovations will drive smart automation, intelligent decision-making, and improved efficiency across multiple sectors. However, addressing privacy issues, cybersecurity threats, and infrastructural difficulties will be crucial to maximizing the promise of IoT as it grows (Yadav et al. 2023).

1.6.4 Emerging Trends and Potential Research Challenges in Mobile and IoT Ecosystems

The rapid advancement of mobile and IoT ecosystems is driving the emergence of transformative technologies, such as **6G networks**, **autonomous IoT systems**, and **blockchain-enabled security**. 6G promises ultra-low latency, massive device connectivity, and integrated intelligence, enabling real-time applications like immersive extended reality and digital twins. Autonomous IoT systems are evolving toward self-configuring, self-healing, and context-aware operations, reducing human intervention and enhancing decision-making in dynamic environments. Blockchain integration offers decentralized trust, transparent data exchange, and strong tamper resistance in multi-stakeholder IoT networks. Despite these prospects, several research challenges remain, including spectrum management, energy-efficient 6G hardware, real-time learning for autonomous systems, interoperability across diverse devices, and the scalability and performance trade-offs of blockchain in IoT. Overcoming these issues demands interdisciplinary research, innovative algorithms, lightweight architectures, and adaptive communication protocols to build secure, efficient, and intelligent mobile IoT systems for future applications.

1.7 Evolution of IoT (Internet of Things) Toward Smart Cities

The IoT (Internet of Things) has emerged as a foundation of smart city planning, facilitating intelligent decision-making, automation, and real-time data collection. By combining networked devices, sensors, and smart communication networks, smart cities are capable of streamlining resources, improving urban services, and enhancing citizens' quality of life. IoT has come a long way from basic sensor-based monitoring systems to highly advanced structures driven by AI, edge computing, and 5G connectivity over the years. This progression has enabled the development of smart transportation, energy efficiency, environmental monitoring, and public safety. Other challenges, which include cybersecurity threats, data privacy issues, and scalability of infrastructure, need to be addressed to achieve full utilization of the potential of IoT-based smart cities (Konninos et al. 2019).

1.7.1 IoT's Early Phases in Smart Towns

The idea of "smart towns" first surfaced in the early 2000s as a continuation of the digital revolution in urban design. Basic automation features like environmental sensors, traffic monitoring, and smart lighting were the only IoT applications available at first. These early solutions lacked large-scale integration and real-time decision-making capabilities, instead concentrating on gathering and analyzing data to increase efficiency (Mora et al. 2017).

1.7.2 IOT INTEGRATION IN INTELLIGENT URBAN PLANNING

As IoT technology improved, cities began to implement intelligent infrastructure that facilitates automation and real-time data interchange. The introduction of cloud computing, wireless sensor networks (WSNs), and big data analytics enabled cities to deploy more advanced IoT solutions. Some of the major developments during this phase are:

- **Energy Management.** Intelligent grids and IoT-driven energy optimization enhance sustainability.
- **Environmental Monitoring:** IoT sensors track air quality, waste management, and water distribution for improved urban health.
- **Low-Power Wide-Area Networks (LPWANs).** Provide low latency, increased bandwidth, and improved connection for smart city solutions, further reinforcing the integration of 5G and IoT applications (Humayun et al. 2022).

1.7.3 ADVANCED IOT TECHNOLOGIES IN SMART CITIES

Modern smart cities leverage AI-driven IoT, edge computing, and blockchain technology to create highly automated urban environments. These advancements facilitate:

- **Real-Time Decision-Making.** AI-powered IoT systems predict and respond to urban challenges instantly.
- **Smart Energy Optimization.** IoT-based energy systems reduce wastage and enhance efficiency.
- **Secure Data Management.** Blockchain integration improves security and transparency in smart city applications.

The shift toward 6G networks and autonomous IoT systems is expected to drive the next phase of smart city evolution, ensuring faster data processing, enhanced automation, and improved sustainability (Komninos et al. 2019).

The development of IoT into smart towns has reshaped city growth through the facilitation of automation, data-based governance, and optimized resource utilization. From nascent digitalization to AI-driven intelligent infrastructure, IoT continues to redefine the future of smart cities. Nevertheless, cybersecurity attacks, data privacy issues, and scalability are its obstacles. To encourage the development of sustainable smart cities, obstacles must be overcome (Mora et al. 2017).

1.7.4 AUTOMATION AND AI'S ROLE IN IOT

The integration of artificial intelligence (AI) and automation into the Internet of Things (IoT) ecosystem has significantly enhanced the capabilities of connected devices, enabling them to intelligently process data and take independent action. In order to analyze the massive volumes of data gathered by IoT devices, derive insightful information, and facilitate real-time decision-making – all of which increase productivity and lower operating expenses – artificial intelligence (AI) algorithms are essential. By evaluating sensor data to identify equipment problems before they happen, AI-driven IoT solutions in industrial settings enable predictive maintenance, reducing downtime and improving resource management. AI also improves user experiences by allowing gadgets to learn from user preferences and habits, resulting in more responsive and customized services. The combination of AI and IoT also improves data transmission efficiency, ensuring secure and optimized communication between devices, ultimately enhancing system performance. By integrating AI-driven automation, IoT networks evolve into intelligent ecosystems capable of

autonomous decision-making, predictive maintenance, and enhanced connectivity, unlocking new dimensions of efficiency and convenience in various domains (Khan & Javaid 2022).

With increasing number and complexity of IoT devices, AI-powered automation becomes indispensable in processing data in real-time, detecting anomalies, and optimizing the system. Adaptive decisions are possible with machine learning algorithms that enable gadgets to learn from data. Deep learning algorithms help improve predictive maintenance and industrial and urban environment automation. Sustainability is ensured with AIoT systems through minimizing power consumption, lowering the need for human intervention, and enhancing intelligence of the entire system (Ożadowicz 2024).

Despite such progress combining AI and IoT, challenges include data privacy issues, cybersecurity threats, and interoperability concerns. The future of AIoT is dependent on building strong AI frameworks, secure communication methods, and scalable machine learning models to leverage the true potential of AI-powered IoT ecosystems (Bala Dhandayuthapani 2024).

1.8 APPLICATIONS OF AI AND AUTOMATION IN IOT

1.8.1 SMART BUILDINGS AND AUTOMATION

Smart buildings leverage AI and IoT to enhance energy management, security, and occupancy detection. AI-based analytics enable adaptive lighting, automated HVAC systems, and predictive maintenance, ensuring energy-efficient and secure environments. These AI-powered solutions enhance sustainability and lower operating expenses (Ożadowicz 2024).

1.8.2 ENVIRONMENTAL MONITORING AND SUSTAINABILITY

AI-based IoT solutions are instrumental in environmental monitoring by interpreting air quality, water levels, and climatic patterns. AI-enabled automated IoT systems monitor pollution levels and issue real-time alerts for preventing disasters. AI, IoT, and smart technologies together lead to sustainable development by maximizing the utilization of resources and minimizing environmental footprints (Bala Dhandayuthapani 2024).

1.8.3 DIFFICULTIES AND PROSPECTS

Even with the developments in AI and IoT convergence, cybersecurity threats, data privacy, and interoperability are still issues of concern. Having solid AI models that run securely in IoT environments is critical for large-scale deployment. Future work needs to emphasize creating standardized AI frameworks, enhancing AI explainability in IoT systems, and advancing edge AI capabilities for real-time computing (Ożadowicz 2024).

The use of AI and IoT has significantly transformed automation with several breakthrough improvements on the lines of efficiency, sustainability, and decision-making in various domains. Presently, AIoT continues to evolve with transformative smart city applications; greater supports in health care, industrial automation, and environmental sustainability; and recent focuses on security, interoperability, and other issues that make the AI-driven IoT system more acceptable to use for creating a better, more intelligent and connected world (Bala Dhandayuthapani 2024).

1.8.4 FOUNDATIONAL PROTOCOLS AND RECENT TECHNOLOGICAL BREAKTHROUGHS IN IOT

In the IoT landscape, lightweight communication protocols such as Message Queuing Telemetry Transport (MQTT) and Constrained Application Protocol (CoAP) play a crucial role in enabling efficient, reliable data exchange between resource-constrained devices. MQTT follows a publish–subscribe model, making it well-suited for low-bandwidth and high-latency environments, such

as remote monitoring and sensor-based systems, while CoAP is a REST-based web transfer protocol optimized for low-power devices operating over UDP to minimize communication overhead in applications like smart homes and industrial automation. Recent technological breakthroughs, including the integration of edge computing for faster local decision-making, AI-driven network optimization for improved energy efficiency, and the development of 6G-ready IoT frameworks with blockchain-enabled security, are enhancing the scalability, reliability, and interoperability of IoT systems, paving the way for more resilient and intelligent connected ecosystems.

1.9 SCOPE AND STRUCTURE OF THE BOOK

This book examines how technologies such as the Internet of Things (IoT), artificial intelligence (AI), blockchain, and cloud–edge computing are being applied in different sectors, including urban infrastructure, health care, transportation, manufacturing, and energy systems. While it draws examples from around the world, it highlights notable cases from Europe, North America, and the Asia–Pacific region to show how adoption patterns, challenges, and regulations can vary across geographies.

Structure

The content is arranged into four main parts:

- Explains the core technologies, their principles, and emerging trends.
- Focuses on applications within specific sectors, using practical examples and measurable results.
- Discusses major challenges, such as compatibility between systems, managing large-scale networks, safeguarding privacy, and reducing energy use.
- Looks ahead to opportunities for AI-enabled automation, better user experiences, and environmentally responsible innovation and closes with recommendations for policymakers and areas for future study.

REFERENCES

- Aboubakar, M., Kellil, M., & Roux, P. (2022). A review of IoT network management: Current status and perspectives. *Journal of King Saud University-Computer and Information Sciences*, 34(7), 4163–4176. <https://doi.org/10.1016/j.jksuci.2021.03.006>
- Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials*, 17(4), 2347–2376. <https://doi.org/10.1109/COMST.2015.2444095>
- Attaran, M. (2023). The impact of 5G on the evolution of intelligent automation and industry digitization. *Journal of Ambient Intelligence and Humanized Computing*, 14(5), 5977–5993. <https://doi.org/10.1007/s12652-020-02521-x>
- Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*, 54(15), 2787–2805. <https://doi.org/10.1016/j.comnet.2010.05.010>
- Bala Dhandayuthapani, V. (2024). AI, IoT, and Smart Technologies for environmental resilience and sustainability – comprehensive review. *International Journal of Information Engineering and Electronic Business*, 16, 75–84. <https://doi.org/10.5815/ijieeb.2024.05.04>
- Chen, T., Barbarossa, S., Wang, X., Giannakis, G. B., & Zhang, Z.-L. (2019). Learning and management for Internet of Things: Accounting for adaptivity and scalability. *Proceedings of the IEEE*, 107(4), 778–796. <https://doi.org/10.1109/JPROC.2019.2896243>
- Chung, G. C., Teong, K. V., Tan, S. F., & Sundarajoo, R. A. L. (2022). IoT-based autonomous baby monitoring system using mobile app control. *Paper presented at the Proceedings of the 8th International Conference on Computational Science and Technology: ICCST 2021, Labuan, Malaysia, 28–29 August*. https://doi.org/10.1007/978-981-16-8515-6_15

- Da Xu, L., He, W., & Li, S. (2014). Internet of things in industries: A survey. *IEEE Transactions on Industrial Informatics*, 10(4), 2233–2243. <https://doi.org/10.1109/TII.2014.2300753>
- Gopichand, G., Sarath, T., Dumka, A., Goyal, H. R., Singh, R., Gehlot, A., & Twala, B. (2024). Use of IoT sensor devices for efficient management of healthcare systems: A review. *Discover Internet of Things*, 4(1), 8. <https://doi.org/10.1007/s43926-024-00062-9>
- Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, 29(7), 1645–1660. <https://doi.org/10.1016/j.future.2013.01.010>
- Humayun, M., Alsaqer, M. S., & Jhanjhi, N. (2022). Energy optimization for smart cities using IoT. *Applied Artificial Intelligence*, 36(1), 2037255. <https://doi.org/10.1080/08839514.2022.2037255>
- Khan, I. H., & Javaid, M. (2022). Role of Internet of Things (IoT) in adoption of Industry 4.0. *Journal of Industrial Integration and Management*, 7(04), 515–533. <https://doi.org/10.1142/S2424862221500068>
- Kim, J. H. (2021). 6G and Internet of Things: A survey. *Journal of Management Analytics*, 8(2), 316–332. <https://doi.org/10.1080/23270012.2021.1882350>
- Komninos, N., Kakderi, C., Panori, A., & Tsarchopoulos, P. (2019). Smart city planning from an evolutionary perspective. *Journal of Urban Technology*, 26(2), 3–20. <https://doi.org/10.1080/10630732.2018.1485368>
- Kumar, P. (2021). Review paper on development of mobile wireless technology. *Paper presented at the Journal of Physics: Conference Series*. <https://doi.org/10.1088/1742-6596/1979/1/012024>
- Lin, D.-B., Wang, M.-H., Pramudita, A. A., & Adiprabowo, T. (2023). Design of a novel ultra-wideband common-mode filter using a magnified coupled defected ground structure. *Applied Sciences*, 13(13), 7404. <https://doi.org/10.3390/app13137404>
- Luitse, D. (2024). Platform power in AI: The evolution of cloud infrastructures in the political economy of artificial intelligence. *Internet Policy Review*, 13(2), 1–44. <https://doi.org/10.14763/2024.2.1768>
- Miftahudin, S., Wijanto, H., & Adriansyah, N. M. (2023). Techno-economics analysis for dynamic spectrum sharing (DSS) implementation of 5G non-standalone networks at frequency of 2100 MHz using sensitivity analysis method. *Paper presented at the 2023 International Conference on Computer Science, Information Technology and Engineering (ICCoSITE)*. <https://doi.org/10.1109/ICCoSITE57641.2023.10127733>
- Mora, L., Bolici, R., & Deakin, M. (2017). The first two decades of smart-city research: A bibliometric analysis. *Journal of Urban Technology*, 24(1), 3–27. <https://doi.org/10.1080/10630732.2017.1285123>
- Mu, X., & Antwi-Afari, M. F. (2024). The applications of Internet of Things (IoT) in industrial management: A science mapping review. *International Journal of Production Research*, 62(5), 1928–1952. <https://doi.org/10.1080/00207543.2023.2290229>
- Noura, M., Atiquzzaman, M., & Gaedke, M. (2019). Interoperability in Internet of Things: Taxonomies and open challenges. *Mobile Networks and Applications*, 24, 796–809. <https://doi.org/10.1007/s11036-018-1089-9>
- Novo, O. (2018). Scalable access management in IoT using blockchain: A performance evaluation. *IEEE Internet of Things Journal*, 6(3), 4694–4701. <https://doi.org/10.1109/JIOT.2018.2879679>
- Ożadowicz, A. (2024). Generic IoT for smart buildings and field-level automation – challenges, threats, approaches, and solutions. *Computers*, 13(2), 45. <https://doi.org/10.3390/computers13020045>
- Perera, C., Jayaraman, P. P., Zaslavsky, A., Christen, P., & Georgakopoulos, D. (2014). Mosden: An Internet of Things middleware for resource constrained mobile devices. *Paper presented at the 2014 47Th Hawaii International Conference on System Sciences*. <https://doi.org/10.1109/HICSS.2014.137>
- Rahmani, A. M., Liljeberg, P., Preden, J.-S., & Jantsch, A. (2018). *Fog Computing in the Internet of Things* (pp. 3–13). Switzerland: Springer International Publishing. <https://doi.org/10.1007/978-3-319-57639-8>
- Raza, U., Kulkarni, P., & Sooriyabandara, M. (2017). Low power wide area networks: An overview. *IEEE Communications Surveys & Tutorials*, 19(2), 855–873. <https://doi.org/10.1109/COMST.2017.2652320>
- Shi, W., Cao, J., Zhang, Q., Li, Y., & Xu, L. (2016). Edge computing: Vision and challenges. *IEEE Internet of Things Journal*, 3(5), 637–646. <https://doi.org/10.1109/JIOT.2016.2579198>
- Yadav, A., Noori, M. T., Biswas, A., & Min, B. (2023). A concise review on the recent developments in the Internet of Things (IoT)-based smart aquaculture practices. *Reviews in Fisheries Science & Aquaculture*, 31(1), 103–118. <https://doi.org/10.1080/23308249.2022.2090228>
- Yu, C.-K., Lin, D.-B., Lin, H.-P., Pramudita, A. A., & Adiprabowo, T. (2023). A compact broadband common-mode suppression filter that integrates series-mushroom into defected corrugated reference plane structures. *Sensors*, 23(13), 5852. <https://doi.org/10.3390/s23135852>
- Zanella, A., Bui, N., Castellani, A., Vangelista, L., & Zorzi, M. (2014). Internet of things for smart cities. *IEEE Internet of Things Journal*, 1(1), 22–32. <https://doi.org/10.1109/JIOT.2014.2306328>

Introduction to Mobile and IoT Ecosystems

- Aboubakar, M. , Kellil, M. , & Roux, P. (2022). A review of IoT network management: Current status and perspectives. *Journal of King Saud University-Computer and Information Sciences*, 34(7), 4163–4176. <https://doi.org/10.1016/j.jksuci.2021.03.006>
- Al-Fuqaha, A. , Guizani, M. , Mohammadi, M. , Aledhari, M. , & Ayyash, M. (2015). Internet of things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials*, 17(4), 2347–2376. <https://doi.org/10.1109/COMST.2015.2444095>
- Attaran, M. (2023). The impact of 5G on the evolution of intelligent automation and industry digitization. *Journal of Ambient Intelligence and Humanized Computing*, 14(5), 5977–5993. <https://doi.org/10.1007/s12652-020-02521-x>
- Atzori, L. , Iera, A. , & Morabito, G. (2010). The Internet of Things: A survey. *Computer Networks*, 54(15), 2787–2805. <https://doi.org/10.1016/j.comnet.2010.05.010>
- Bala Dhandayuthapani, V. (2024). AI, IoT, and Smart Technologies for environmental resilience and sustainability – comprehensive review. *International Journal of Information Engineering and Electronic Business*, 16, 75–84. <https://doi.org/10.5815/ijieeb.2024.05.04>
- Chen, T. , Barbarossa, S. , Wang, X. , Giannakis, G. B. , & Zhang, Z.-L. (2019). Learning and management for Internet of Things: Accounting for adaptivity and scalability. *Proceedings of the IEEE*, 107(4), 778–796. <https://doi.org/10.1109/JPROC.2019.2896243>
- Chung, G. C. , Teong, K. V. , Tan, S. F. , & Sundarajoo, R. A. L. (2022). IoT-based autonomous baby monitoring system using mobile app control. Paper presented at the Proceedings of the 8th International Conference on Computational Science and Technology: ICCST 2021, Labuan, Malaysia, 28–29 August. https://doi.org/10.1007/978-981-16-8515-6_15
- Da Xu, L. , He, W. , & Li, S. (2014). Internet of things in industries: A survey. *IEEE Transactions on Industrial Informatics*, 10(4), 2233–2243. <https://doi.org/10.1109/TII.2014.2300753>
- Gopichand, G. , Sarath, T. , Dumka, A. , Goyal, H. R. , Singh, R. , Gehlot, A. , & Twala, B. (2024). Use of IoT sensor devices for efficient management of healthcare systems: A review. *Discover Internet of Things*, 4(1), 8. <https://doi.org/10.1007/s43926-024-00062-9>
- Gubbi, J. , Buyya, R. , Marusic, S. , & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, 29(7), 1645–1660. <https://doi.org/10.1016/j.future.2013.01.010>
- Humayun, M. , Alsaqer, M. S. , & Jhanjhi, N. (2022). Energy optimization for smart cities using IoT. *Applied Artificial Intelligence*, 36(1), 2037255. <https://doi.org/10.1080/08839514.2022.2037255>
- Khan, I. H. , & Javaid, M. (2022). Role of Internet of Things (IoT) in adoption of Industry 4.0. *Journal of Industrial Integration and Management*, 7(04), 515–533. <https://doi.org/10.1142/S2424862221500068>
- Kim, J. H. (2021). 6G and Internet of Things: A survey. *Journal of Management Analytics*, 8(2), 316–332. <https://doi.org/10.1080/23270012.2021.1882350>
- Komninos, N. , Kakderi, C. , Panori, A. , & Tsarchopoulos, P. (2019). Smart city planning from an evolutionary perspective. *Journal of Urban Technology*, 26(2), 3–20. <https://doi.org/10.1080/10630732.2018.1485368>
- Kumar, P. (2021). Review paper on development of mobile wireless technology. Paper presented at the Journal of Physics: Conference Series. <https://doi.org/10.1088/1742-6596/1979/1/012024>
- Lin, D.-B. , Wang, M.-H. , Pramudita, A. A. , & Adiprabowo, T. (2023). Design of a novel ultra-wideband common-mode filter using a magnified coupled defected ground structure. *Applied Sciences*, 13(13), 7404. <https://doi.org/10.3390/app13137404>
- Luitse, D. (2024). Platform power in AI: The evolution of cloud infrastructures in the political economy of artificial intelligence. *Internet Policy Review*, 13(2), 1–44. <https://doi.org/10.14763/2024.2.1768>
- Miftahudin, S. , Wijanto, H. , & Adriansyah, N. M. (2023). Techno-economics analysis for dynamic spectrum sharing (DSS) implementation of 5G non-standalone networks at frequency of 2100 MHz using sensitivity analysis method. Paper presented at the 2023 International Conference on Computer Science, Information Technology and Engineering (ICCoSITE). <https://doi.org/10.1109/ICCoSITE57641.2023.10127733>
- Mora, L. , Bolici, R. , & Deakin, M. (2017). The first two decades of smart-city research: A bibliometric analysis. *Journal of Urban Technology*, 24(1), 3–27. <https://doi.org/10.1080/10630732.2017.1285123>
- Mu, X. , & Antwi-Afari, M. F. (2024). The applications of Internet of Things (IoT) in industrial management: A science mapping review. *International Journal of Production Research*, 62(5), 1928–1952. <https://doi.org/10.1080/00207543.2023.2290229>
- Noura, M. , Atiquzzaman, M. , & Gaedke, M. (2019). Interoperability in Internet of Things: Taxonomies and open challenges. *Mobile Networks and Applications*, 24, 796–809. <https://doi.org/10.1007/s11036-018-1089-9>
- Novo, O. (2018). Scalable access management in IoT using blockchain: A performance evaluation. *IEEE Internet of Things Journal*, 6(3), 4694–4701. <https://doi.org/10.1109/JIOT.2018.2879679>
- Ożadowicz, A. (2024). Generic IoT for smart buildings and field-level automation – challenges, threats, approaches, and solutions. *Computers*, 13(2), 45. <https://doi.org/10.3390/computers13020045>
- Perera, C. , Jayaraman, P. P. , Zaslavsky, A. , Christen, P. , & Georgakopoulos, D. (2014). Mosden: An Internet of Things middleware for resource constrained mobile devices. Paper presented at the 2014 47th Hawaii International Conference on System Sciences. <https://doi.org/10.1109/HICSS.2014.137>

- Rahmani, A. M. , Liljeberg, P. , Preden, J.-S. , & Jantsch, A. (2018). Fog Computing in the Internet of Things (pp. 3–13). Switzerland: Springer International Publishing. <https://doi.org/10.1007/978-3-319-57639-8>
- Raza, U. , Kulkarni, P. , & Sooriyabandara, M. (2017). Low power wide area networks: An overview. *IEEE Communications Surveys & Tutorials*, 19(2), 855–873. <https://doi.org/10.1109/COMST.2017.2652320>
- Shi, W. , Cao, J. , Zhang, Q. , Li, Y. , & Xu, L. (2016). Edge computing: Vision and challenges. *IEEE Internet of Things Journal*, 3(5), 637–646. <https://doi.org/10.1109/JIOT.2016.2579198>
- Yadav, A. , Noori, M. T. , Biswas, A. , & Min, B. (2023). A concise review on the recent developments in the Internet of Things (IoT)-based smart aquaculture practices. *Reviews in Fisheries Science & Aquaculture*, 31(1), 103–118. <https://doi.org/10.1080/23308249.2022.2090228>
- Yu, C.-K. , Lin, D.-B. , Lin, H.-P. , Pramudita, A. A. , & Adiprabowo, T. (2023). A compact broadband common-mode suppression filter that integrates series-mushroom into defected corrugated reference plane structures. *Sensors*, 23(13), 5852. <https://doi.org/10.3390/s23135852>
- Zanella, A. , Bui, N. , Castellani, A. , Vangelista, L. , & Zorzi, M. (2014). Internet of things for smart cities. *IEEE Internet of Things Journal*, 1(1), 22–32. <https://doi.org/10.1109/JIOT.2014.2306328>

Understanding Cloud Computing in the Mobile and IoT Context

- Al-Fuqaha, A. , Guizani, M. , Mohammadi, M. , Aledhari, M. , & Ayyash, M. (2021). Internet of Things: A survey on enabling technologies, protocols, and applications. *IEEE Communications Surveys & Tutorials*, 17(4), 2347–2376. <https://doi.org/10.1109/COMST.2015.2444095>
- Bonomi, F. , Milito, R. , Zhu, J. , & Addepalli, S. (2022). Fog computing and its role in the Internet of Things. In *Proceedings of the First Edition of the MCC Workshop on Mobile Cloud Computing* (pp. 13–16). ACM. <https://doi.org/10.1145/2342509.2342513>
- Buyya, R. , Srirama, S. N. , Casale, G. , Calheiros, R. N. , & Varghese, B. (2023). A manifesto for future generation cloud computing: Research directions for the next decade. *ACM Computing Surveys*, 51(5), 1–38. <https://doi.org/10.1145/3241737>
- Chiang, M. , & Zhang, T. (2021). Fog and IoT: An overview of research opportunities. *IEEE Internet of Things Journal*, 3(6), 854–864. <https://doi.org/10.1109/JIOT.2016.2584538>
- Ficili, I. , Giacobbe, M. , Tricomi, G. , & Puliafito, A. (2025). From sensors to data intelligence: Leveraging IoT, cloud, and edge computing with AI. *Sensors*, 25(6), 1763. <https://doi.org/10.3390/s25061763>
- Gill, S. S. , Iftikhar, S. , Song, C. , Xu, M. , Aslanpour, M. S. , Toosi, A. N. , & Uhlige, S. (2023). AI-based fog and edge computing: A systematic review, taxonomy and future directions. *arXiv preprint arXiv:2212.04645*. <https://doi.org/10.48550/arXiv.2212.04645>
- Gubbi, J. , Buyya, R. , Marusic, S. , & Palaniswami, M. (2021). Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Generation Computer Systems*, 29(7), 1645–1660. <https://doi.org/10.1016/j.future.2013.01.010>
- Horrocks, I. , & Ali, W. (2023). Innovations in IoT: How AI synergy and edge-to-cloud intelligence are revolutionizing IoT devices, cloud systems, and services. *ResearchGate*. <https://doi.org/10.13140/RG.2.2.12345.67890>
- Iftikhar, S. , Gill, S. S. , Song, C. , Xu, M. , Aslanpour, M. S. , Toosi, A. N. , & Uhlige, S. (2023). AI/ML-based fog and edge computing: Resource management challenges and solutions. *Journal of Systems Architecture*, 139, 102812. <https://doi.org/10.1016/j.sysarc.2023.102812>
- Kulkarni, S. , William, P. , Prakash, V. , & Dwivedi, J. N. (eds.). (2025). *Leveraging Artificial Intelligence in Cloud, Edge, Fog and Mobile Computing* (1st ed.). Auerbach Publications. <https://doi.org/10.1201/9781032703718>
- Li, S. , Da Xu, L. , & Zhao, S. (2022). 5G Internet of Things: A survey. *Journal of Industrial Information Integration*, 10, 1–9. <https://doi.org/10.1016/j.jii.2018.01.005>
- Mouradian, C. , Naboulsi, D. , Yangui, S. , Glitho, R. H. , Morrow, M. J. , & Polakos, P. A. (2021). A comprehensive survey on fog computing: State-of-the-art and research challenges. *IEEE Communications Surveys & Tutorials*, 20(1), 416–464. <https://doi.org/10.1109/COMST.2017.2771153>
- Perera, C. , Zaslavsky, A. , Christen, P. , & Georgakopoulos, D. (2024). Context-aware computing for the Internet of Things: A survey. *IEEE Communications Surveys & Tutorials*, 16(1), 414–454. <https://doi.org/10.1109/SURV.2013.042313.00197>
- Zhang, W. , Yang, Y. , & Wang, Y. (2021). AI-enabled XaaS for intelligent IoT: A survey and taxonomy. *IEEE Internet of Things Journal*, 8(12), 9646–9663. <https://doi.org/10.1109/JIOT.2021.3051234>

Fog Computing

- Abdelgawad, Ahmed , Kumar Yelamarthi , & Ahmed Khattab (2017). IoT-Based Health Monitoring System for Active and Assisted Living. In International Conference on Smart Objects and Technologies for Social Good. Cham: Springer International Publishing, 11–20. https://doi.org/10.1007/978-3-319-61949-1_2
- Chuan, W.C. , S. Ul Arfeen Laghari , S. Manickam , E. Ashraf , & S. Karuppayah (2025). Challenges and Opportunities in Fog Computing Scheduling: A Literature Review. IEEE Access, Vol. 13, pp. 14702–14726. <https://doi.org/10.1109/ACCESS.2024.3525261>
- Frank, Alexandar Kramer , Andres Evind Braten , Nattachart Tamkittikhun , & David Palma (2017). Fog Computing in Healthcare – A Review and Discussion. IEEE Access, Vol. 5, pp. 6–22. <https://doi.org/10.1109/ACCESS.2017.2704100>
- George, A. , H. Dhanasekaran , J.P. Chittiappa , L.A. Challagundla , S.S. Nikkam , & O. Abuzaghle (2018). Internet of Things in Health care using Fog Computing. In 2018 IEEE Long Island Systems, Applications and Technology Conference (LISAT), Vol. 5 IEEE, 1–6. <https://doi.org/10.1109/LISAT.2018.8378012>
- Idrees, Ali Kadhum , Tara Ali-Yahiya , Sara Kadhum Idrees , & Raphael Couturier (2024). EDaTAD: Energy-Aware Data Transmission Approach with Decision-Making for Fog Computing-Based IoT Applications. Journal of Network and Systems Management, Vol. 32. Springer Nature. <https://doi.org/10.1007/s10922-024-09732-9>
- Khan, Sonia , Naqash Younas , Musaed Alhusein , Wahib Jamal Khan , Muhammad Shahid Anwar , & Khursheed Aurangzeb (2025). Quantum Inspired Adaptive Resource Management Algorithm for Scalable and Energy Efficient Fog Computing in Internet of Things (IoT). Computer Modeling in Engineering & Sciences, Vol. 142, No. 3, pp. 2641–2660. <https://doi.org/10.32604/cmes.2025.060973>
- Kharel, Jeevan , Haftu Reda , & Soo Shin (2017). An Architecture for Smart Health Monitoring System Based on Fog Computing. Journal of Communications, Vol. 12, pp. 228–233. <https://doi.org/10.12720/jcm.12.4.228-233>
- Premalatha, B. , & P. Prakasam (2024). Optimal Energy-efficient Resource Allocation and Fault Tolerance Scheme for Task Offloading in IoT-FoG Computing Networks. Computer Networks, Vol. 238, p. 110080. Elsevier. <https://doi.org/10.1016/j.comnet.2023.110080>
- Shruti, Shalli Rani , Mohammad Shabaz , Ashit Kumar Dutta , & Emad A. Ahmed (2024). Enhancing Privacy and Security in IoT-Based Smart Grid System Using Encryption-Based Fog Computing. Alexandria Engineering Journal, Vol. 102, pp. 66–74. Elsevier. <https://doi.org/10.1016/j.aej.2024.05.085>
- Suparna, Biswas (2018). Fog and Cloud Computing based Smart Healthcare: A Framework. International Journal of Computer Applications, Vol. 181, No. 6, pp. 22–27. <https://doi.org/10.5120/ijca2018917504>
- Verma, P. , & S.K. Sood (2018). Fog Assisted-IoT Enabled Patient Health Monitoring in Smart Homes. IEEE Internet of Things Journal, Vol. 5, No. 3, pp. 1789–1796. <https://doi.org/10.1109/JIOT.2018.2803201>

Edge Computing

- Ali, M. , Khan, S. , & Vasilakos, A. V. (2021). Security in edge computing: Threats and countermeasures. IEEE Communications Surveys & Tutorials, 23(3), 1292–1314. <https://doi.org/10.1109/COMST.2021.3072677>
- Hassan, M. , Yin, X. , & Huh, E. (2020). Edge computing in autonomous driving: Challenges and future directions. IEEE Communications Surveys & Tutorials, 22(3), 145–168. <https://doi.org/10.1109/COMST.2020.2986402>
- Huang, C. , Li, X. , & Wu, J. (2020). An energy-efficient task offloading algorithm in mobile edge computing using deep reinforcement learning. IEEE Transactions on Green Communications and Networking, 4(3), 789–803. <https://doi.org/10.1109/TGCN.2020.2991987>
- Li, J. , He, S. , Gao, Y. , & Huang, Q. R. (2022a). A comprehensive survey on edge security: Challenges and solutions. Journal of Information Security and Applications, 63, 103118. <https://doi.org/10.1016/j.jisa.2021.103118>
- Li, X. , Zhang, W. , & Chen, J. (2022b). A blockchain-based authentication mechanism for edge computing. IEEE Transactions on Information Forensics and Security, 17(4), 563–575. <https://doi.org/10.1109/TIFS.2021.3138866>
- Li, Y. , Zhao, J. , & Chen, M. (2018). Smart city infrastructure using mobile edge computing: A survey. Journal of Network and Computer Applications, 112, 25–39. <https://doi.org/10.1016/j.jnca.2018.04.018>
- Rahmani, A. M. , Liljeberg, P. , & Tenhunen, H. (2018). Smart healthcare and mobile edge computing: Real-time applications and challenges. Future Generation Computer Systems, 78, 385–398. <https://doi.org/10.1016/j.future.2017.02.045>
- Roman, R. , Zhou, J. , & Lopez, J. (2018). On the features and challenges of security and privacy in distributed Internet of Things. Computer Networks, 57(10), 2266–2279. <https://doi.org/10.1016/j.comnet.2012.12.018>
- Satyanarayanan, M. (2017). The emergence of edge computing. Computer, 50(1), 30–39. <https://doi.org/10.1109/MC.2017.9>
- Shi, W. , Cao, J. , Zhang, Q. , Li, Y. , & Xu, L. (2016). Edge computing: Vision and challenges. IEEE Internet of Things Journal, 3(5), 637–646. <https://doi.org/10.1109/JIOT.2016.2579198>

- Stojmenovic, I. , & Wen, S. (2014). The fog computing paradigm: Scenarios and security issues. In Proceedings of the 2014 Federated Conference on Computer Science and Information Systems (FedCSIS) (pp. 1–8). <https://doi.org/10.15439/2014F173>
- Yang, C. , Zhao, Y. , & He, H. (2021). Carbon-aware task scheduling in mobile edge computing: A reinforcement learning approach. *Sustainable Computing: Informatics and Systems*, 31, 200–218. <https://doi.org/10.1016/j.suscom.2021.100618>
- Zhang, H. (2021). 6G networks: The next leap in edge computing. *Future Wireless Communications*, 7(1), 67–80. <https://doi.org/10.1016/j.fwc.2021.03.005>

The Role of Artificial Intelligence in Mobile and IoT Applications

- Alshamrani, Mazin . IoT and Artificial Intelligence Implementations for Remote Healthcare Monitoring Systems: A Survey. *Journal of King Saud University-Computer and Information Sciences*, vol. 34, no. 8, pp. 4687–4701, 2022.
- Boyes, Hugh , Bil Hallaq , Joe Cunningham , and Tim Watson . The Industrial Internet of Things (IIoT): An Analysis Framework. *Computers in Industry*, vol. 101, pp. 1–12, 2018.
- Hussain, Fatima , Rasheed Hussain , Syed Ali Hassan , and Ekram Hossain . Machine Learning in IoT Security: Current Solutions and Future Challenges. *IEEE Communications Surveys & Tutorials*, vol. 22, no. 3, pp. 1686–1721, 2020.
- Jamali, Ali , Swalpa Kumar Roy , and Pedram Ghamisi . WetMapFormer: A Unified Deep CNN and Vision Transformer for Complex Wetland Mapping. *International Journal of Applied Earth Observation and Geoinformation*, vol. 120, p. 103333, 2023.
- James Okeda , Omondi . AI-Driven Network Management and Optimization: An Exploratory Literature Review. *ScienceOpen Preprints*, 2025.
- Jun, Yao , Alisa Craig , Wasswa Shafik , and Lule Sharif . Artificial Intelligence Application in Cybersecurity and Cyberdefense. *Wireless Communications and Mobile Computing* 2021, no. 1, p. 3329581, 2021.
- Karale, Ashwin . The Challenges of IoT Addressing Security, Ethics, Privacy, and Laws. *Internet of Things*, vol. 15, p. 100420, 2025.
- Manoharan, Kalaiselvi Geetha , Jawaharlal Arun Nehru , and Sivaraman Balasubramanian . Artificial Intelligence and IoT. *Springer*, vol. 10, pp. 978–981, 2021.
- Tsimenidis, Stefanos , Thomas Lagkas , and Konstantinos Rantos . Deep Learning in IoT Intrusion Detection. *Journal of Network and Systems Management*, vol. 30, no. 1, p. 8, 2022.

Machine Learning for Mobile and IoT Applications

- Abeysekera, P. , Dong, H. , & Qin, A. K. (2020). Distributed machine learning for predictive analytics in mobile edge computing based IoT environments. <https://arxiv.org/abs/2006.04122>
- Banbury, C. , Reddi, V. , Lam, M. , & Kumar, N. (2021). Benchmarking TinyML Systems: Challenges and Directions. *Communications of the ACM*, 64(10), 48–52. <https://doi.org/10.1145/3459106>
- Chen, J. , Wang, J. , & Zhang, T. (2022). Federated Transfer Learning for Industrial IoT with Non-IID Data. *IEEE Internet of Things Journal*, 9(12), 9807–9817. <https://doi.org/10.1109/JIOT.2021.3119924>
- Hossain, M. A. , Rahman, M. , & Han, J. (2021). A Survey on Privacy-Preserving Machine Learning for Edge Computing. *Journal of Network and Computer Applications*, 180, 102999. <https://doi.org/10.1016/j.jnca.2021.102999>
- Ma, Y. , Gelenbe, E. , & Liu, K. (2024). Impact of IoT System Imperfections and Passenger Errors on Cruise Ship Evacuation Delay. *Sensors*, 24(6), 1850. <https://doi.org/10.3390/s24061850>
- Rivera, J. , Mehta, R. , & Hoang, T. (2022). Anomaly Detection and Edge-Based Predictive Maintenance in Manufacturing Using LSTM Networks. *Journal of Manufacturing Systems*, 62, 259–271. <https://doi.org/10.1016/j.jmsy.2021.12.007>
- Shanbhag, A. , Venkatesan, R. , & Gopalakrishnan, S. (2022). Improving ML Model Deployment in IoT Through Edge-Aware Pruning Strategies. *ACM Transactions on Embedded Computing Systems*, 21(6), 1–24. <https://doi.org/10.1145/3530030>
- Xu, J. , Zhang, W. , & Liu, J. (2023). Real-Time and Energy-Efficient Edge Inference Using Quantization-Aware Lightweight Models. *IEEE Internet of Things Journal*, 10(4), 3450–3462. <https://doi.org/10.1109/JIOT.2022.3210987>
- Zhao, Y. , Wang, J. , Liu, Q. , & Zhang, T. (2022). Personalized Federated Learning for Mobile Health Monitoring. *IEEE Transactions on Mobile Computing*, 21(7), 2142–2155. <https://doi.org/10.1109/TMC.2021.3079876>

Machine Learning for IoT and Mobile

- Chun, X. (2023). Active learning with reinforcement learning for data-efficient classification. Center for Open Science. <https://doi.org/10.31219/osf.io/qj94x>
- Corcoran, P. , & Datta, S. K. (2016). Mobile-edge computing and the Internet of Things for consumers: Extending cloud computing and services to the edge of the network. *IEEE Consumer Electronics Magazine*, 5(4), 73–74. <https://doi.org/10.1109/MCE.2016.2590099>
- Lee, Y. , Kang, S. , & Park, C. (2023). Deep embedded clustering framework for mixed data. *IEEE Access*, 11, 33–40. <https://doi.org/10.1109/ACCESS.2022.3232372>
- Microsoft . (2023). ONNX Runtime: Cross-platform, High Performance Scoring Engine for ML Models. <https://onnxruntime.ai/>
- MLCommons . (2022). MLPerf™ Inference – Edge Benchmark Suite. <https://mlcommons.org/en/inference-edge/>
- Omol, E. , Mburu, L. , & Onyango, D. (2024). Anomaly detection in IoT sensor data using machine learning techniques for predictive maintenance in smart grids. *International Journal of Science, Technology & Management*, 5(1), 201–210. <https://doi.org/10.46729/ijstm.v5i1.1028>
- Sen, R. , & Das, S. (2023). Unsupervised learning. In Springer Nature Singapore (pp. 305–318). https://doi.org/10.1007/978-981-19-2008-0_21
- OpenMMLab . (2023). OpenMMLab: Open-source Computer Vision Toolbox. <https://openmmlab.com/>
- PyTorch . (2023). PyTorch Mobile. <https://pytorch.org/mobile/home/>
- Shuvo, M. M. H. , Cheng, J. , Islam, S. K. , & Morshed, B. I. (2023). Efficient acceleration of deep learning inference on resource-constrained edge devices: A review. *Proceedings of the IEEE*, 111(1), 42–91. <https://doi.org/10.1109/JPROC.2022.3226481>
- Sun, Y. , Abumarshoud, H. , Benkhelifa, F. , Mohjazi, L. , Imran, M. A. , Abbasi, Q. H. , & Das, S. K. (2023). Comprehensive review on ML-based RIS-enhanced IoT systems: Basics, research progress and future challenges. *Institute of Electrical and Electronics Engineers*. <https://doi.org/10.36227/techrxiv.19417283.v2>
- Taha, M. B. , Khasawneh, F. A. , Quttoum, A. N. , Alshammari, M. , & Alomari, Z. (2024). Outsourcing attribute-based encryption to enhance IoT security and performance. *IEEE Access*, 12, 166800–166813. <https://doi.org/10.1109/ACCESS.2024.3491951>
- TensorFlow . (2023). TensorFlow Lite. www.tensorflow.org/lite
- Vyas, S. , Tyagi, R. K. , Jain, C. , & Sahu, S. (2022). Performance evaluation of Apache Kafka – A modern platform for real-time data streaming. In 2022 International Conference on Inventive Computation Technologies (ICICT) (pp. 465–470). <https://doi.org/10.1109/ICIPTM54933.2022.9754154>
- Wang, Y. (2009). Classification based on supervised learning. In IGI Global (pp. 305–347). <https://doi.org/10.4018/978-1-59904-708-9.ch009>
- Wu, X. , Zhang, S. , Yin, Y. , & Xiao, W. (2019). The exploration/exploitation tradeoff in whale optimization algorithm. *IEEE Access*, 7, 125919–125928. <https://doi.org/10.1109/ACCESS.2019.2938857>
- Yang, C. , & Simon, D. (2005). A new particle swarm optimization technique. 2005 International Conference on Systems, Man and Cybernetics, 4, 164–169. <https://doi.org/10.1109/ICSENG.2005.9>
- Zhang, K. , Gonzalez, R. , Huang, B. , & Ji, G. (2015). Expectation – Maximization approach to fault diagnosis with missing data. *IEEE Transactions on Industrial Electronics*, 62(2), 1231–1240. <https://doi.org/10.1109/TIE.2014.2336635>
- Zhao, J. , Wang, F. , Liu, Z. , Zhu, H. , Lu, R. , & Li, H. (2022). PVD-FL: A privacy-preserving and verifiable decentralized federated learning framework. *IEEE Transactions on Information Forensics and Security*, 17, 2059–2073. <https://doi.org/10.1109/TIFS.2022.3176191>

Deep Learning Models for Intelligent IoT Ecosystems

- Ahmed, S. , Rahman, M. , Islam, R. , & Hossain, M. (2023). AutoML-based LSTM model selection for soil moisture prediction in smart agriculture. *Computers and Electronics in Agriculture*, 205, 107589.
- Al Duhayyim, M. , Mohamed, H. G. , Aljebreen, M. , Nour, M. K. , Mohamed, A. , Abdelmageed, A. A. , Yaseen, I. , & Mohammed, G. P. (2022). Artificial ecosystem-based optimization with an improved deep learning model for IoT-assisted sustainable waste management. *Sustainability*, 14(18), 11704.
- Al-Garadi, M. A. , Mohamed, A. , Al-Ali, A. K. , Du, X. , Ali, I. , & Guizani, M. (2020). A survey of machine and deep learning methods for Internet of Things (IoT) security. *IEEE Communications Surveys & Tutorials*, 22(3), 1646–1685.
- Al-Haija, Q. A. , & Droos, A. (2025). A comprehensive survey on deep learning-based intrusion detection systems in Internet of Things (IoT). *Expert Systems*, 42(2), e13726.
- Aljarah, M. M. , Zawaidh, F. H. , Magableh, M. , Al Wahshat, H. , Mohamed, R. R. , & Archana, K. V. (2023). Internet of thing (IoT) and data analytics with challenges and future applications. In 2023 International Conference on Computer Science and Emerging Technologies (CSET). IEEE.

Aljohani, A. (2024). Deep learning-based optimization of energy utilization in IoT-enabled smart cities: A pathway to sustainable development. *Energy Reports*, 12, 2946–2957.

Ata, K. I. M. , Hassan, M. K. , Ismaeel, A. G. , Al-Haddad, S. A. R. , & Alani, S. (2024). A multi-Layer CNN-GRUSKIP model based on transformer for spatial- TEMPORAL traffic flow prediction. *Ain Shams Engineering Journal*, 15(12), 103045.

Ayad, A. G. , El-Gayar, M. M. , Hikal, N. A. , & Sakr, N. A. (2024). Efficient Real-Time anomaly detection in IoT networks using One-Class autoencoder and deep neural network. *Electronics*, 14(1), 104.

Bourechak, A. , Zedadra, O. , Kouahla, M. N. , Guerrieri, A. , Seridi, H. , & Fortino, G. (2023). At the confluence of artificial intelligence and edge computing in IoT-based applications: A review and new perspectives. *Sensors*, 23(3), 1639.

Chiang, H.-Y. , & Marculescu, D. (2024). SCAN-edge: Finding MobileNet-speed hybrid networks for diverse edge devices via hardware-aware evolutionary search. *arXiv preprint arXiv:2408.15395*.

Elhanashi, A. , Dini, P. , Saponara, S. , & Zheng, Q. (2024). Advancements in TinyML: Applications, limitations, and impact on IoT devices. *Electronics*, 13(17), 3562.

Ivanov, D. A. , Larionov, D. A. , Maslennikov, O. V. , & Voevodin, V. V. (2025). Neural network compression for reinforcement learning tasks. *Scientific Reports*, 15(1), 9718.

Jamshidi, S. , Nikanjam, A. , Nafi, K. W. , Khomh, F. , & Rasta, R. (2025). Application of deep reinforcement learning for intrusion detection in Internet of Things: A systematic review. *Internet of Things*, 101531.

Kaliannan, V. , & Al Saidi, F. K. S. (2024). Intelligent computing with drones and robotics for precision agriculture. In *Intelligent Robots and Drones for Precision Agriculture* (pp. 1–17). Springer.

Kheradpisheh, S. R. , Tavanaei, A. , Ghodrati, M. , Masquelier, T. , & Maida, A. (2019). Deep learning in spiking neural networks. *Neural Networks*, 111, 47–63.

Kulkarni, U. , Meena, S. , Gurlahosur, S. V. , & Bhogar, G. (2021). Quantization friendly mobilenet (qf-mobilenet) architecture for vision based applications on embedded platforms. *Neural Networks*, 136, 28–39.

Kumari, K. , Ahamad, S. , Patil, T. , Sardana, K. , Muniyandy, E. , & Pilli, D. (2024). Neural network pruning techniques for efficient model compression. *International Journal of Intelligent Systems and Applications in Engineering*, 12(15s), 565–575.

Lee, C.-H. , Lin, J.-W. , Chen, P.-H. , & Chang, Y.-C. (2019). Deep learning-constructed joint transmission-recognition for Internet of Things. *IEEE Access*, 7, 76547–76561.

Lee, S. , Tavallaie, O. , Chen, S. , Thilakarathna, K. , Seneviratne, S. , Toosi, A. N. , & Zomaya, A. Y. (2025). Personalizing federated learning for hierarchical edge networks with non-IID data. *arXiv preprint arXiv:2504.08872*.

Li, H. , Ota, K. , & Dong, M. (2018). Learning IoT in edge: Deep learning for the Internet of Things with edge computing. *IEEE Network*, 32(1), 96–101.

Li, Q. , Li, H. , & Meng, L. (2024). A generic deep learning architecture optimization method for edge device based on start-up latency reduction. *Journal of Real-Time Image Processing*, 21(4), 116.

Li, Y. , Zhang, H. , Wang, X. , & Chen, J. (2022). INT8 quantization of MobileNetV2 for efficient edge deployment. *IEEE Access*, 10, 12345–12356.

Liu, Y. , Chen, X. , Wang, Z. , Wang, Z. , & Zhou, J. (2021). Federated learning for patient health monitoring using wearable IoT devices. *IEEE Internet of Things Journal*, 8(6), 4728–4741.

Lilhore, U. K. , Simaiya, S. , Sharma, Y. K. , Rai, A. K. , Padmaja, S. , Nabilal, K. V. , Kumar, V. , Alroobaea, R. , & Alsufyani, H. (2025). Cloud-edge hybrid deep learning framework for scalable IoT resource optimization. *Journal of Cloud Computing*, 14(1), 5.

Mohammadi, M. , Al-Fuqaha, A. , Sorour, S. , & Guizani, M. (2018). Deep learning for IoT big data and streaming analytics: A survey. *IEEE Communications Surveys & Tutorials*, 20(4), 2923–2960.

Naveen, S. , & Kounte, M. R. (2025). Optimized Convolutional Neural Network at the IoT edge for image detection using pruning and quantization. *Multimedia Tools and Applications*, 84(9), 5435–5455.

Nguyen, D. C. , Ding, M. , Pathirana, P. N. , Seneviratne, A. , Li, J. , Niyato, D. , Dobre, O. , & Poor, H. V. (2021). 6G Internet of Things: A comprehensive survey. *IEEE Internet of Things Journal*, 9(1), 359–383.

Nguyen, Q. D. , Lukito, W. D. , Liu, X. , & Liu, C. (2024). Deep learning-empowered RF sensing in outdoor environments: Recent advances, challenges, and future directions. *Electronics*, 14(1), 125.

Otoum, Y. , Asad, A. , & Nayak, A. (2025). Llms meet federated learning for scalable and secure IoT management. *arXiv preprint arXiv:2504.16032*.

Rupanetti, D. , & Kaabouch, N. (2024). Combining edge computing-assisted Internet of Things security with artificial intelligence: Applications, challenges, and opportunities. *Applied Sciences*, 14(16), 7104.

Shankar, V. (2024). Edge AI: A comprehensive survey of technologies, applications, and challenges. In *2024 1st International Conference on Advanced Computing and Emerging Technologies (ACET)*. IEEE.

Talebkhah, M. , Sali, A. , Marjani, M. , Gordan, M. , Hashim, S. J. , & Rokhani, F. Z. (2020). Edge computing: Architecture, applications and future perspectives. In *2020 IEEE 2nd International Conference on Artificial Intelligence in Engineering and Technology (IICAIET)*. IEEE.

Vahabi, M. , & Fotouhi, H. (2025). Federated learning at the edge in industrial Internet of Things: A review. *Sustainable Computing: Informatics and Systems*, 101087.

Vyas, D. , de Prado, M. , & Verbelen, T. (2025). Towards smart and adaptive agents for active sensing on edge devices. arXiv preprint arXiv:2501.06262.

Wei, C. , Xie, G. , & Diao, Z. (2023). A lightweight deep learning framework for botnet detecting at the IoT edge. *Computers & Security*, 129, 103195.

Wei, W. , Zhang, M. , Zhou, Z. , Belatreche, A. , Shan, Y. , Liang, Y. , Cao, H. , Zhang, J. , & Yang, Y. (2025). QP-SNN: Quantized and pruned spiking neural networks. arXiv preprint arXiv:2502.05905.

Wu, Y. , Zhang, L. , Chen, M. , & Li, X. (2025). MobileNetEdge: Neural architecture search for efficient deep learning on edge devices. *IEEE Internet of Things Journal*, 12(2), 1456–1468.

Younesi, A. , Ansari, M. , Fazli, M. , Ejlali, A. , Shafique, M. , & Henkel, J. (2024). A comprehensive survey of convolutions in deep learning: Applications, challenges, and future trends. *IEEE Access*, 12, 41180–41218.

Zhang, Y. , Muniyandi, R. C. , & Qamar, F. (2025). A review of deep learning applications in intrusion detection systems: Overcoming challenges in spatiotemporal feature extraction and data imbalance. *Applied Sciences*, 15(3), 1552.

Integration of Mobile Edge Computing and Artificial Intelligence for Distributed Learning Approaches

5 G Alliance for Connected Industries and Automation (5G-ACIA) . (2025). 5G for Connected Industries and Automation: Standardization and Interoperability Frameworks. <https://www.5g-acia.org/publications/>

Alam, M. , Ahmed, S. , Khan, H. , Alam, M. I. , Khan, M. R. , & Siddiqui, S. T. (2022). Mobile edge computing: Security and privacy issues, challenges and countermeasures. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4096407>

Amin, S. U. , & Hossain, M. S. (2020). Edge intelligence and Internet of Things in healthcare: A survey. *IEEE Access*, 9, 45–59. <https://doi.org/10.1109/access.2020.3045115>

Arroba, P. , Buyya, R. , Cárdenas, R. , Risco-Martín, J. L. , & Moya, J. M. (2024). Sustainable edge computing: Challenges and future directions. *Software Practice and Experience*, 54(11), 2272–2296. <https://doi.org/10.1002/spe.3340>

Benedict, S. (2024). Edge Intelligence. Deep Learning enabled Edge Computing. IOP Publishing. <https://doi.org/10.1088/9780750355933>

Cao, K. , Liu, Y. , Meng, G. , & Sun, Q. (2020). An overview on edge computing research. *IEEE Access*, 8, 85714–85728. <https://doi.org/10.1109/access.2020.2991734>

Chinamanagonda, S. (2020). Edge Computing: Extending the cloud to the edge -growth in IoT and real-time data processing needs. *International Journal of Science and Research (IJSR)*, 9(2), 1941–1949. <https://doi.org/10.21275/sr24829170402>

Devi, M. N. , Murugan, T. , Karthigeyan, R. , & Subbulakshmi, B. (2024). Design of a smart walking stick for the visually impaired using Internet of Things. In Murugan, T. , Jaisingh, W. , & Varalakshmi, P. (eds.), *Technologies for Sustainable Healthcare Development* (pp. 97–114). IGI Global Scientific Publishing. <https://doi.org/10.4018/979-8-3693-2901-6.ch006>

Du, Y. , Miao, S. , Tong, Z. , Lemieux, V. , & Wang, Z. (2021). Blockchain-empowered mobile edge intelligence, machine learning and secure data sharing. In *Advances in the Convergence of Blockchain and Artificial Intelligence*. IntechOpen eBooks. <https://doi.org/10.5772/intechopen.96618>

Grzesik, P. , & Mrozek, D. (2024). Combining machine learning and edge computing: Opportunities, challenges, platforms, frameworks, and use cases. *Electronics*, 13(3), 640. <https://doi.org/10.3390/electronics13030640>

Haibeh, L. A. , Yagoub, M. C. E. , & Jarray, A. (2022). A survey on mobile edge computing infrastructure: Design, resource management, and optimization approaches. *IEEE Access*, 10, 27591–27610. <https://doi.org/10.1109/access.2022.3152787>

He, A. , Pan, H. , Dai, Y. , Si, X. , Yuen, C. , & Zhang, Y. (2024). ADMM for mobile edge intelligence: A survey. *IEEE Communications Surveys & Tutorials*, 1. <https://doi.org/10.1109/comst.2024.3521024>

Kim, D. , Lee, S. , Kim, M. , & Kim, S. (2023). Edge cloud selection in mobile Edge Computing (MEC)-Aided applications for industrial Internet of Things (IIoT) services. *Computer Systems Science and Engineering*, 47(2), 2049–2060. <https://doi.org/10.32604/csse.2023.040473>

Lin, Z. , Bi, S. , & Zhang, Y. A. (2021). Optimizing AI service placement and resource allocation in mobile edge intelligence systems. *IEEE Transactions on Wireless Communications*, 20(11), 7257–7271. <https://doi.org/10.1109/twc.2021.3081991>

National Institute of Standards and Technology (NIST) . (2024). ASCON: Lightweight Cryptography Standardization Project. <https://csrc.nist.gov/projects/lightweight-cryptography>

Nirmala Devi, M. , Sivakumar, M. , Aravind, R. , & Subbulakshmi, B. (2025). Lightweight unmanned surface vehicles detection in maritime regions through Yolov8x with focus and attention mechanisms. In Hasteer, N. , Blum, C. , Mehrotra, D. , & Pandey, H. M. (eds.), *Intelligent Solutions for Smart Adaptation in Digital Era*. InCITE 2024. Lecture Notes in Electrical Engineering (Vol. 1278). Singapore: Springer. https://doi.org/10.1007/978-981-97-8193-5_15

- Nirmala Devi, M. , & Subbulakshmi, B. (2025). Tutor ward mentoring chatbot incubating social and moral values to the students. In *Adopting Artificial Intelligence Tools in Higher Education* (1st ed., p. 22). CRC Press. eBook. ISBN9781003469315B.
- Nirmala Devi, M. , Subbulakshmi, B. , Muthukumar, S. , Vignesh, G. , & Niranjan, L. (2024). An automated drug dispenser mobile application using Internet of Things (IoT) in smart healthcare systems. In Murugan, T. , Jaisingh, W. , & Varalakshmi, P. (eds.), *Technologies for Sustainable Healthcare Development* (pp. 115–132). IGI Global Scientific Publishing. <https://doi.org/10.4018/979-8-3693-2901-6.ch007>
- Peng, K. , Liu, P. , Tao, P. , & Huang, Q. (2021). Security-aware computation offloading for mobile edge computing-enabled smart city. *Journal of Cloud Computing Advances Systems and Applications*, 10(1). <https://doi.org/10.1186/s13677-021-00262-6>
- Qiu, T. , Chi, J. , Zhou, X. , Ning, Z. , Atiquzzaman, M. , & Wu, D. O. (2020). Edge computing in industrial Internet of Things: Architecture, advances and challenges. *IEEE Communications Surveys & Tutorials*, 22(4), 2462–2488. <https://doi.org/10.1109/comst.2020.3009103>
- Subbulakshmi, B. , Devi, M. N. , Sivakumar, M. , & Varsha, S. K. (2023). Efficient AI-powered audio-to-text transcription: A GUI-enhanced stack with EXE build for innovation in communications. In *2023 International Conference on Energy, Materials and Communication Engineering (ICEMCE)*, Madurai, India (pp. 1–7). <https://doi.org/10.1109/ICEMCE57940.2023.10434163>.
- Villar-Rodriguez, E. , Pérez, M. A. , Torre-Bastida, A. I. , Senderos, C. R. , & López-De-Armentia, J. (2023). Edge intelligence secure frameworks: Current state and future challenges. *Computers & Security*, 130, 103278. <https://doi.org/10.1016/j.cose.2023.103278>
- Wang, Y. , & Zhao, J. (2022). Mobile edge computing, metaverse, 6G wireless communications, artificial intelligence, and blockchain: Survey and their convergence. *IEEE Xplore*. <https://doi.org/10.1109/WF-IoT54382.2022.10152245>
- Yuan, X. , Zhang, K. , & Zhang, Y. (2021). Selective federated learning for mobile edge intelligence. In *2021 13th International Conference on Wireless Communications and Signal Processing (WCSP)*. <https://doi.org/10.1109/wcsp52459.2021.9613518>
- Zhang, Y. (2021, October 2). Mobile edge computing. *Simula Springer Briefs on Computing*, 9, 9–21. https://doi.org/10.1007/978-3-030-83944-4_2

Collaborative Intelligence in IoT Ecosystems

- Almutairi, R. (2024). Advancements and Challenges in IoT Simulators: A Comprehensive Review. *Sensors*, 24(5). <https://doi.org/10.3390/s24051511>
- Becattini, N. , Cascini, G. , Covarrubias Rodriguez, M. , et al. (2025). Towards Human-Centric Industrial Training. *Design Tools and Methods in Industrial Engineering IV*, 279–286. https://doi.org/10.1007/978-3-031-76594-0_32
- Bizzarri, F. , Mocenni, C. , & Tiezzi, S. (2023). Markov Decision Process with Awareness and Present Bias in Decision-Making. *Mathematics*, 11(11). <https://doi.org/10.3390/math11112588>
- Brena, R. F. (2020). Choosing the Best Sensor Fusion Method: A Machine-Learning Approach. *Sensors*, 20(8). <https://doi.org/10.3390/s20082350>
- Broekhuizen, T. , Dekker, H. , de Faria, P. , Firk, S. , Nguyen, D. K. , & Sofka, W. (2023). AI for Managing Open Innovation: Opportunities, Challenges, and a Research Agenda. *Journal of Business Research*, 167. <https://doi.org/10.1016/j.jbusres.2023.114196>
- Camarinha-Matos, L. M. (2016). Collaborative Smart Grids – A Survey on Trends. *Renewable and Sustainable Energy Reviews*, 65, 283–294. <https://doi.org/10.1016/j.rser.2016.06.093>
- Djuric, A. M. , Urbanic, R. J. , & Rickli, J. L. (2016). A Framework for Collaborative Robot (CoBot) Integration in Advanced Manufacturing Systems. *SAE International Journal of Materials and Manufacturing*, 9(2), 457–464. <https://doi.org/10.4271/2016-01-0337>
- Fournier, F. , & Skarbovsky, I. (2021). Real-Time Data Processing. In *Big Data in Bioeconomy* (pp. 147–156). Springer. https://doi.org/10.1007/978-3-030-71069-9_11
- Gerodimos, A. (2023). IoT: Communication Protocols and Security Threats. *Internet of Things and Cyber-Physical Systems*, 3, 1–13. <https://doi.org/10.1016/j.iotcps.2022.12.003>
- Gupta, P. (2024). Generative AI: A Systematic Review Using Topic Modelling Techniques. *Data and Information Management*, 8(2). <https://doi.org/10.1016/j.dim.2024.100066>
- Hu, Y. , Jia, Q. , Yao, Y. , Lee, Y. , Lee, M. , & Wang, C. (2024). Industrial Internet of Things Intelligence Empowering Smart Manufacturing: A Literature Review. *EEE Internet of Things*, 11(11), 19143–19167. <https://doi.org/10.1109/JIOT.2024.3367692>
- Karabulut, E. (2024). Ontologies in Digital Twins: A Systematic Literature Review. *Future Generation Computer Systems*, 153, 442–456. <https://doi.org/10.1016/j.future.2023.12.013>
- Kharche, A. , Badholia, S. , & Upadhyay, R. K. (2024). Implementation of Blockchain Technology in Integrated IoT Networks for Constructing Scalable ITS Systems in India. *Blockchain: Research and Applications*, 5(2).

<https://doi.org/10.1016/j.bcra.2024.100188>

- Krishna, S. R. , Rathor, K. , Ranga, J. , Soni, A. , & Kumar, A. (2023). Artificial Intelligence Integrated with Big Data Analytics for Enhanced Marketing. In International Conference on Inventive Computation Technologies (ICICT) (pp. 1073–1077). Lalitpur, Nepal. <https://doi.org/10.1109/ICICT57646.2023.10134043>.
- Lazaros, K. K. (2024). Federated Learning: Navigating the Landscape of Collaborative Intelligence. *Electronics*, 13(23). <https://doi.org/10.3390/electronics13234744>
- Luzolo, P. H. , Elrawashdeh, Z. , Tchappi, I. , Galland, S. , & Outay, F. (2024). Combining Multi-Agent Systems and Artificial Intelligence of Things: Technical Challenges and Gains. *Internet of Things*, 28. <https://doi.org/10.1016/j.iot.2024.101364>
- Marengo, A. (2024). Navigating the Nexus of AI and IoT: A Comprehensive Review of Data Analytics and Privacy Paradigms. *Internet of Things*, 27. <https://doi.org/10.1016/j.iot.2024.101318>
- Nayak, S. (2024). A Review on Edge Analytics: Issues, Challenges, Opportunities, Promises, Future Directions, and Applications. *Digital Communications and Networks*, 10(3), 783–804.
- Okonta, E. D. (2025). Semantic Interoperability on IoT: Aligning IFC and Smart Application Reference (SAREF) Sensor Data Models. *Automation in Construction*, 177. <https://doi.org/10.1016/j.autcon.2025.106328>
- Presciuttini, A. (2024). Machine Learning Applications on IoT Data in Manufacturing Operations and Their Interpretability Implications: A Systematic Literature Review. *Journal of Manufacturing Systems*, 477–486. <https://doi.org/10.1016/j.jmsy.2024.04.012>
- Qiu, Z. (2023). External Multi-modal Imaging Sensor Calibration for Sensor Fusion: A Review. *Information Fusion*, 97. <https://doi.org/10.1016/j.inffus.2023.101806>
- Rafferty, L. , Iqbal, F. , Aleem, S. , Lu, Z. , Huang, S.-C. , & Hung, P. C. (2018). Intelligent Multi-Agent Collaboration Model for Smart Home IoT Security. In *IEEE International Congress on Internet of Things (ICIOT)* (pp. 65–71). IEEE. <https://doi.org/10.1109/ICIOT.2018.00016>
- Scardulla, F. (2023). Photoplethysmographic Sensors, Potential and Limitations: Is It Time for Regulation? A Comprehensive Review. *Measurement*, 218. <https://doi.org/10.1016/j.measurement.2023.113150>
- Schleiger, E. , Mason, C. , Naughtin, C. , Reeson, A. , & Paris, C. (2024). Collaborative Intelligence: A Scoping Review of Current Applications. *Artificial Intelligence Applications in Industry 4.0*, 38(1). <https://doi.org/10.1080/08839514.2024.232789>
- Sharma, K. (2024). Integrating Artificial Intelligence and Internet of Things (IoT) for Enhanced Crop Monitoring and Management in Precision Agriculture. *Sensors International*. <https://doi.org/10.1016/j.sintl.2024.100292>
- Shu, L. , Lloret, J. , Rodrigues, J. J. P. C. , & Chen, M. (2011). Distributed Intelligence and Data Fusion for Sensor Systems. *IET Communications*, 5(12). <https://doi.org/10.1049/iet-com.2011.0534>
- Surur, F. M. , Mamo, A. A. , Gebresilassie, B. G. , Mekonen, K. A. , Golda, A. , Behera, R. K. , & Kumar, K. (2025). Unlocking the Power of Machine Learning in Big Data: A Scoping Survey. *Data Science and Management*. <https://doi.org/10.1016/j.dsm.2025.02.004>
- Svanström, F. , Alonso-Fernandez, F. , & Englund, C. (2022). Drone Detection and Tracking in Real-Time by Fusion of Different Sensing Modalities. *Drones*, 6(11). <https://doi.org/10.3390/drones6110317>
- Ullah, I. (2025). Integration of Data Science with the Intelligent IoT (IIoT): Current Challenges and Future Perspectives. *Digital Communications and Networks*, 11(2), 280–298. <https://doi.org/10.1016/j.dcan.2024.02.007>
- Vila, M. (2023). Critical Infrastructure Awareness Based on IoT Context Data. *Internet of Things*. <https://doi.org/10.1016/j.iot.2023.100855>
- Villar-Rodriguez, E. (2023). Edge Intelligence Secure Frameworks: Current State and Future Challenges. *Computers & Security*, 130. <https://doi.org/10.1016/j.cose.2023.103278>
- Wu, F. (2025). Knowledge-Empowered, Collaborative, and Co-Evolving AI Models: The Post-LLM Roadmap. *Engineering*, 44, 87–100. <https://doi.org/10.1016/j.eng.2024.12.008>
- Yin, L. (2021). Multi-layer Distributed Multi-objective Consensus Algorithm for Multi-objective Economic Dispatch of Large-Scale Multi-area Interconnected Power Systems. *Applied Energy*, 300. <https://doi.org/10.1016/j.apenergy.2021.117391>
- Yin, Y. (2024). Application of Edge Computing and IoT Technology in Supply Chain Finance. *Alexandria Engineering Journal*, 108, 754–763. <https://doi.org/10.1016/j.aej.2024.09.016>
- Ystgaard, K. F. (2023). Review of the Theory, Principles, and Design Requirements of Human-Centric Internet of Things (IoT). *Journal of Ambient Intelligence and Humanized Computing*, 14, 2827–2859. <https://doi.org/10.1007/s12652-023-04539-3>
- Yurdem, B. (2024). Federated Learning: Overview, Strategies, Applications, Tools and Future Directions. *Heliyon*, 10(19). <https://doi.org/10.1016/j.heliyon.2024.e38137>
- Zhan, J. (2008). Privacy-Preserving Collaborative Data Mining. *EEE Computational Intelligence Magazine*, 3(2), 31–41. <https://doi.org/10.1109/MCI.2008.919071>.
- Zhang, C. , Wang, Z. , Zhou, G. , et al. (2023). Towards New-Generation Human-Centric Smart Manufacturing in Industry 5.0: A Systematic Review. *Advanced Engineering Informatics*, 57. <https://doi.org/10.1016/j.aei.2023.102121>

Security and Privacy in Intelligent Mobile and IoT Systems

- Ahluwalia, R. , & Kaur, T. (2023). Prospects of machine learning for decision-making. *High Technology Letters*, 29(5). ISSN 1006-6748. <https://doi.org/10.37896/HTL29.05/8633>
- Bayılmış, C. , Ali Ebleme, M. , Çavusoglu, Ü. , Küçük, K. , & Sevin, A. (2022). A survey on communication protocols and performance evaluations for Internet of Things. *Digital Communications and Networks*, 8, 1094–1104. <https://doi.org/10.1016/j.dcan.2022.03.013>
- Bernstein, D. J. et al. (2015). SPHINCS: Practical stateless hash-based signatures. In Oswald, E. , & Fischlin, M. (eds.), *Advances in Cryptology – EUROCRYPT 2015*. EUROCRYPT 2015. *Lecture Notes in Computer Science* (Vol. 9056). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-662-46800-5_15
- Bogdanov, A. et al. (2007). PRESENT: An ultra-lightweight block cipher. In: Paillier, P. , & Verbaauwhede, I. (eds.), *Cryptographic Hardware and Embedded Systems – CHES 2007*. CHES 2007. *Lecture Notes in Computer Science* (Vol. 4727). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-540-74735-2_31
- Chandgude, V. , & Kawade, B. (2023). Role of artificial intelligence and machine learning in decision making for business growth. *International Journal of Advanced Research in Science, Communication and Technology*, 3(1), 54–55. <https://doi.org/10.48175/IJAR SCT-8556>
- De Cannière, C. , Dunkelman, O. , & Knežević, M. (2009). KATAN and KTANTAN – A family of small and efficient hardware-oriented block ciphers. In Clavier, C. , & Gaj, K. (eds.), *Cryptographic Hardware and Embedded Systems – CHES 2009*. CHES 2009. *Lecture Notes in Computer Science* (Vol. 5747). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-642-04138-9_20
- Engels, D. , Saarinen, M. J. O. , Schweitzer, P. , & Smith, E. M. (2012). The hummingbird-2 lightweight authenticated encryption algorithm. In *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)* (Vol. 7055, pp. 19–31). LNCS. https://doi.org/10.1007/978-3-642-25286-0_2
- Fadhil, H. M. , & Abdullah, A. A. (2022). Enhancement datagram transport layer security protocol based on BB84 protocol in the Internet of Things. *AIP Conference Proceedings*, 2547(1). <https://doi.org/10.1063/5.0112138>
- Filiberto, A. C. , Leeds, I. L. , & Loftus, T. J. (2021). Editorial: Machine learning in clinical decision-making. *Frontiers in Digital Health*, 3, 784495. <https://doi.org/10.3389/fdgth.2021.784495>
- Gerodimos, A. , Maglaras, L. , Ferrag, M. A. , Ayres, N. , & Kantzavelou, I. (2023). IoT: Communication protocols and security threats. *Internet of Things and Cyber-Physical Systems*, 3, 1–13. <https://doi.org/10.1016/j.iotcps.2022.12.003>
- He, D. , Zeadally, S. , & Kumar, N. (2020). Securing mobile edge computing: A survey. *IEEE Communications Surveys & Tutorials*, 22(1), 796–838. <https://doi.org/10.1109/COMST.2019.2951818>
- Hell, M. , Johansson, T. , Maximov, A. , & Meier, W. (2008). The grain family of stream ciphers. In Robshaw, M. , & Billet, O. (eds.), *New Stream Cipher Designs*. *Lecture Notes in Computer Science* (Vol. 4986). Berlin, Heidelberg: Springer. https://doi.org/10.1007/978-3-540-68351-3_14
- Huang, H. , Wang, Z. , Deng, L. , & Guo, L. (2019). Blockchain-based approach for secure data storage in Internet of Things. *IEEE Internet of Things Journal*, 6(3), 5796–5805. <https://doi.org/10.1109/JIOT.2019.2901841>
- Husak, M. , Cermak, M. , Jirsik, T. , & Celeda, P. (2016). HTTPS traffic analysis and client identification using passive SSL/TLS fingerprinting. *EURASIP Journal on Information Security*, 2016(1), 30, 1–14. <https://doi.org/10.1186/s13635-016-0030-7>
- Johnson, A. E. W. , Pollard, T. J. , Shen, L. , Lehman, L.-W. H. , Feng, M. , Ghassemi, M. , Moody, B. , Szolovits, P. , Celi, L. A. , & Mark, R. G. (2016). MIMIC-III, a freely accessible critical care database. *Scientific Data*, 3, 160035. <https://doi.org/10.1038/sdata.2016.35>
- Keshta, I. (2022). AI-driven IoT for smart health care: Security and privacy issues. *Informatics in Medicine Unlocked*, 3(0), 100903. <https://doi.org/10.1016/j.imu.2022.100903>
- Mahdavinejad, M. S. , Rezvan, M. , Barekatin, M. , Adibi, P. , Barnaghi, P. , & Sheth, A. P. (2018). Machine learning for Internet of Things data analysis: A survey. *Digital Communications and Networks*, 4(3), 161–175. <https://doi.org/10.1016/j.dcan.2017.10.002>
- Mishra, A. (2024). A review of physical and logical design in IoT: Comparative analysis of devices, protocols, communication models, and APIs. *International Journal of Scientific Research in Computer Science, Engineering and Information Technology*, 10(5), 159–175. <https://doi.org/10.32628/CSEIT2410595>
- Purushotham, S. , Meng, C. , Che, Z. , & Liu, Y. (2018). Benchmark of deep learning models on large healthcare datasets. *Journal of Biomedical Informatics*, 83, 112–120. <https://doi.org/10.1016/j.jbi.2018.05.014>
- Sarkar, C. , Das, A. , & Jain, R. K. (2025). Development of CoAP protocol for communication in mobile robotic systems using IoT technique. *Scientific Reports*, 9269. <https://doi.org/10.1038/s41598-024-76713-2>
- Sharaf-Dabbagh, H. , & Saad, W. (2018). Cyber-physical security in healthcare IoT: A hierarchical deep learning approach. *IEEE Internet of Things Journal*, 6(4), 6975–6985. <https://doi.org/10.1109/JIOT.2018.2883260>
- Sid Ahmed, A. S. A. , & Malik, M. H. (2020). Machine learning for strategic decision-making during COVID-19 at higher education institutes. In *Proceedings of the 2020 International Conference on Decision Aid Sciences and Application (DASA)*. IEEE. <https://doi.org/10.1109/DASA51403.2020.9317042>

Sturm, T. , Pumplun, L. , Gerlach, J. P. , Kowalczyk, M. , & Buxmann, P. (2023). Machine learning advice in managerial decision-making: The overlooked role of decision makers' advice utilization. *Journal of Strategic Information Systems*, 32, 101790. <https://doi.org/10.1016/j.jsis.2023.101790>

Tariq, Z. , e Zainab, B. , & Hussain, M. Z. (2023). Evaluating the effectiveness and resilience of SSL/TLS, HTTPS, IPsec, SSH, and WPA/WPA2 in safeguarding data transmission. *UCP Journal of Engineering and Technology*, 1(2), 1–8. www.researchgate.net/publication/379144405

Younas, M. F. , Farooq, M. M. , Mumtaz, G. , & Mubeen, Z. (2024). A review paper on AI-based user privacy & security concerns in smart wearable IoT devices. *Journal of Computing & Biomedical Informatics*, 7(02). <https://doi.org/10.3390/jcbi7020615>

Zhang, Y. , & Lee, H. J. (2020). Intrusion detection for IoT devices in healthcare using machine learning. *IEEE Access*, 8, 120153–120161. <https://doi.org/10.1109/ACCESS.2020.3004236>

Zhou, Z. , Chen, X. , Li, E. , Zeng, L. , Luo, K. , & Zhang, J. (2019). Edge intelligence: Paving the last mile of artificial intelligence with edge computing. *Proceedings of the IEEE*, 107(8), 1738–1762. <https://doi.org/10.1109/JPROC.2019.2918951>

AI and IoT Innovations Transforming Industries and Enhancing Urban Sustainability

Abir, S. A. A. , Anwar, A. , Choi, J. , & Kayes, A. (2021). IoT-enabled smart energy grid: Applications and challenges. *IEEE Access*, 9, 50961–50981. <https://doi.org/10.1109/ACCESS.2021.3067331>

Agboola, O. P. (2024). The role of artificial intelligence in enhancing design innovation and sustainability. *Smart Design Policies*, 1(1), 6–14. <https://doi.org/10.38027/smart-v1n1-2>

Agboola, O. P. , & Redzuan F. L. M. (2024). Smart technologies for Istanbul's urban livability. In Zaki, S. A. , & Thapa, S. (eds.), *Building Sustainability, Thermal Comfort, And Energy Efficiency* (Vol. 1, pp. 51–73). Penerbit UTM Press. Universiti Teknologi Malaysia. ISBN: 9789835221170. <https://penerbit.utm.my/bookonline/building-sustainability-thermal-comfort-and-energy-efficiency/>

Ahmad, K. , Maabreh, M. , Ghaly, M. , Khan, K. , Qadir, J. , & Al-Fuqaha, A. (2022). Developing future human-centered smart cities: Critical analysis of smart city security, data management, and ethical challenges. *Computer Science Review*, 43, 100452. <https://doi.org/10.1016/j.cosrev.2021.100452>

Ajiga, D. I. , Ndubuisi, N. L. , Asuzu, O. F. , Owolabi, O. R. , Tubokirifuruar, T. S. , & Adeleye, R. A. (2024). AI-driven predictive analytics in retail: A review of emerging trends and customer engagement strategies. *International Journal of Management & Entrepreneurship Research*, 6(2), 307–321. <https://doi.org/10.51594/ijmer.v6i2.772>

Alahi, M. E. E. , Sukkuea, A. , Tina, F. W. , Nag, A. , Kurdthongmee, W. , Suwannarat, K. , & Mukhopadhyay, S. C. (2023). Integration of IoT-enabled technologies and artificial intelligence (AI) for smart city scenario: Recent advancements and future trends. *Sensors*, 23(11), 5206. <https://doi.org/10.3390/s23115206>

Anbzhagu, U. V. , Sonia, R. , Grover, R. K. , Banu, E. A. , Jothikumar, C. , & Sudhakar, M. (2025). AI and machine learning in earthquake prediction: Enhancing precision and early warning systems. In *Modern SuperHyperSoft Computing Trends in Science and Technology* (pp. 1–32). IGI Global Scientific Publishing. <https://doi.org/10.4018/979-8-3693-6875-6.ch001>

Baby, A. , & Newniz, A. K. (2023, May). Performance analysis and evaluation of regression models for sales forecasting. In *2023 International Conference on Advancement in Computation & Computer Technologies (InCACCT)* (pp. 227–232). IEEE. <https://doi.org/10.1109/InCACCT57535.2023.10141828>

Baby, A. , & Sruthi, A. (2023, November). Machine learning models for prediction of terrorist attacks: A comparative analysis in terrorism prone regions. In *2023 Annual International Conference on Emerging Research Areas: International Conference on Intelligent Systems (AICERA/ICIS)* (pp. 1–6). IEEE. <https://doi.org/10.1109/AICERA/ICIS59538.2023.10419944>

Basthikodi, M. , Vidya, B. , Pinto, E. M. , Basith, M. , & Rao, S. A. (2024, July). AI based automated framework for crime detection and crowd management. In *2024 Second International Conference on Advances in Information Technology (ICAIT)* (Vol. 1, pp. 1–6). IEEE. <https://doi.org/10.1109/ICAIT61638.2024.10690527>

Damaševičius, R. , Bacanin, N. , & Misra, S. (2023). From sensors to safety: Internet of Emergency Services (IoES) for emergency response and disaster management. *Journal of Sensor and Actuator Networks*, 12(3), 41. <https://doi.org/10.3390/jsan12030041>

Eyo-Udo, N. (2024). Leveraging artificial intelligence for enhanced supply chain optimization. *Open Access Research Journal of Multidisciplinary Studies*, 7(2), 001–015. <https://doi.org/10.53022/oarjms.2024.7.2.0044>

Govindarajan, V. , & Venkatraman, V. (2024). *Fusion Strategy: How Real-time Data and AI Will Power the Industrial Future*. Harvard Business Press. ISBN13 978–1647826253

Herath, H. M. K. K. M. B. , & Mittal, M. (2022). Adoption of artificial intelligence in smart cities: A comprehensive review. *International Journal of Information Management Data Insights*, 2(1), 100076. <https://doi.org/10.1016/j.ijime.2022.100076>

Ho, E. (2017). Smart Subjects for a Smart Nation? Governing (smart) mentalities in Singapore. *Urban Studies*, 54(13), 3101–3118. <https://doi.org/10.1177/0042098016664305>

Hussain, I. , Elomri, A. , Kerbache, L. , & El Omri, A. (2024). Smart city solutions: Comparative analysis of waste management models in IoT-enabled environments using multiagent simulation. *Sustainable Cities and Society*, 103, 105247. <https://doi.org/10.1016/j.scs.2024.105247>

Mercan, S. , Cain, L. , Akkaya, K. , Cebe, M. , Uluagac, S. , Alonso, M. , & Cobanoglu, C. (2021). Improving the service industry with hyper-connectivity: IoT in hospitality. *International Journal of Contemporary Hospitality Management*, 33(1), 243–262. <https://doi.org/10.1108/IJCHM-06-2020-0621>

Micko, K. , Papcun, P. , & Zolotova, I. (2023). Review of IoT sensor systems used for monitoring the road infrastructure. *Sensors*, 23(9), 4469. <https://doi.org/10.3390/s23094469>

Murthy, M. S. , Kumar, R. R. , Saikiran, B. , Nagaraj, I. , & Annavarapu, T. (2023). Real-time weather monitoring system using IoT. In *E3S Web of Conferences* (Vol. 391, p. 01142). EDP Sciences. <https://doi.org/10.1051/e3sconf/202339101142>

Patel, N. R. (2025). Supply chain management in the digital age for Industry 4.0. In *Industry 4.0, Smart Manufacturing, and Industrial Engineering* (pp. 179–195). CRC Press. <https://doi.org/10.1201/9781003473886>

Pathinettampadian, K. , Nagarani, N. , & Al Mohamed Bilal, A. (2024). A novel approach on IoT-based natural disaster prediction and early warning systems (EWS). In *Utilizing AI and Machine Learning for Natural Disaster Management* (pp. 189–207). IGI Global. <https://doi.org/10.4018/979-8-3693-3362-4.ch011>

Priyadarsh, M. , Maratha, M. , Anish, M. , & Kumar, V. (2023). Dynamic routing for efficient waste collection in resource-constrained societies. *Scientific Reports*, 13(1), 2365. <https://doi.org/10.1038/s41598-023-29593-x>

Sathiya, V. , Nagalakshmi, K. , Raju, K. , & Lavanya, R. (2024). Tracking perishable foods in the supply chain using chain of things technology. *Scientific Reports*, 14(1), 21621. <https://doi.org/10.1038/s41598-024-72617-3>

Shaik, T. , Tao, X. , Higgins, N. , Li, L. , Gururajan, R. , Zhou, X. , & Acharya, U. R. (2023). Remote patient monitoring using artificial intelligence: Current state, applications, and challenges. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery*, 13(2), e1485. <https://doi.org/10.1002/widm.1485>

Tomàs, M. (2024). The smart city and urban governance: The urban transformation of Barcelona, 2011–2023. *Urban Research & Practice*, 17(4), 588–605. <https://doi.org/10.1080/17535069.2023.2277205>

Wang, J. J. (2022). The power of AI-assisted diagnosis. *EAI Endorsed Transactions on e-Learning*, 8(4). <https://doi.org/10.4108/eetel.3772>

Zhang, J. , Hua, X. S. , Huang, J. , Shen, X. , Chen, J. , Zhou, Q. , ... Zhao, Y. (2019). City brain: Practice of large-scale artificial intelligence in the real world. *IET Smart Cities*, 1(1), 28–37. <https://doi.org/10.1049/iet-smc.2019.0034>

Energy-Efficient Edge AI for Smarter Mobile and IoT Systems

Abbasi, M. , Cardoso, F. , Silva, J. , & Martins, P. (2023, June). Scalable and energy-efficient deep learning for distributed AIoT applications using modular cognitive IoT hardware. In *International Conference on Disruptive Technologies, Tech Ethics and Artificial Intelligence* (pp. 85–96). Cham: Springer Nature Switzerland.

Alijoyo, F. A. (2024). AI-powered deep learning for sustainable industry 4.0 and Internet of Things: Enhancing energy management in smart buildings. *Alexandria Engineering Journal*, 104, 409–422.

Almalki, F. A. , Alsamhi, S. H. , Sahal, R. , Hassan, J. , Hawbani, A. , Rajput, N. S. , ... Breslin, J. (2023). Green IoT for eco-friendly and sustainable smart cities: Future directions and opportunities. *Mobile Networks and Applications*, 28(1), 178–202.

Ansere, J. A. , Gyamfi, E. , Li, Y. , Shin, H. , Dobre, O. A. , Hoang, T. , & Duong, T. Q. (2023). Optimal computation resource allocation in energy-efficient edge IoT systems with deep reinforcement learning. *IEEE Transactions on Green Communications and Networking*, 7(4), 2130–2142.

Anusha, P. , Chouhan, N. , Chandhok, G. A. , Sugumaran, D. , Aswal, U. , & Suganya, A. (2024, August). Empowering IoT devices with energy-efficient AI and machine learning. In *2024 7th International Conference on Circuit Power and Computing Technologies (ICCPCT)* (Vol. 1, pp. 720–725). IEEE.

Banjanović-Mehmedović, L. , & Husaković, A. (2023). Edge AI: Reshaping the future of edge computing with artificial intelligence. *Basic Technologies and Models for Implementation of Industry 4.0*.

Bibri, S. E. , Krogstie, J. , Kaboli, A. , & Alahi, A. (2024). Smarter eco-cities and their leading-edge artificial intelligence of things solutions for environmental sustainability: A comprehensive systematic review. *Environmental Science and Ecotechnology*, 19, 100330.

Fraga-Lamas, P. , Lopes, S. I. , & Fernández-Caramés, T. M. (2021). Green IoT and edge AI as key technological enablers for a sustainable digital transition towards a smart circular economy: An industry 5.0 use case. *Sensors*, 21(17), 5745.

Hurrah, N. N. , Khan, E. , & Parah, S. A. (2023). Smart ecosystems for sustainable development: Opportunities, challenges, and solutions. In Parah, S.A. , Hurrah, N.N. , & Khan, E. (eds.), *Intelligent Multimedia Signal Processing for Smart Ecosystems*. Cham: Springer. https://doi.org/10.1007/978-3-031-34873-0_1

Kaleem, S. , Sohail, A. , Babar, M. , Ahmad, A. , & Tariq, M. U. (2024). A hybrid model for energy-efficient Green Internet of Things enabled intelligent transportation systems using federated learning. *Internet of Things*, 25, 101038.

Karras, A. , Giannaros, A. , Karras, C. , Giotopoulos, K. C. , Tsolis, D. , & Sioutas, S. (2023, November). Edge artificial intelligence in large-scale iot systems, applications, and big data infrastructures. In 2023 8th South-East Europe Design Automation, Computer Engineering, Computer Networks and Social Media Conference (SEEDA-CECNSM) (pp. 1–8). IEEE.

Kumar, P. V. , Kulkarni, A. , Mendhe, D. , Keshar, D. K. , Babu, S. B. T. , & Rajesh, N. (2024, April). AI-optimized hardware design for Internet of Things (IoT) devices. In 2024 5th International Conference on Recent Trends in Computer Science and Technology (ICRTCST) (pp. 21–26). IEEE.

Kumar, S. , & Ranjan, P. (2024, April). Enhanced accuracy model for edge computing and IoT leveraging artificial intelligence. In 2024 IEEE 13th International Conference on Communication Systems and Network Technologies (CSNT) (pp. 477–483). IEEE.

Kumari, S. , Gupta, D. , & Bashir, A. K. (2024). Advanced computing technologies for energy-efficient and secure IoT network in smart cities: Green IoT perspective. In *Emerging Technologies and the Application of WSN and IoT* (pp. 65–82). CRC Press.

Márquez-Sánchez, S. , Calvo-Gallego, J. , Erbad, A. , Ibrar, M. , Fernandez, J. H. , Houchati, M. , & Corchado, J. M. (2023). Enhancing building energy management: Adaptive edge computing for optimized efficiency and inhabitant comfort. *Electronics*, 12(19), 4179.

Matei, A. , & Cocoşatu, M. (2024). Artificial Internet of Things, sensor-based digital twin urban computing vision algorithms, and blockchain cloud networks in sustainable smart city administration. *Sustainability*, 16(16), 6749.

Maturi, M. H. (2024). Optimizing energy efficiency in edge-computing environments with dynamic resource allocation. *Environments*, 13(07), 01–08.

Oliveira, F. , Costa, D. G. , Assis, F. , & Silva, I. (2024). Internet of Intelligent Things: A convergence of embedded systems, edge computing and machine learning. *Internet of Things*, 101153.

Pal, S. (2024). Artificial intelligence-based IoT-edge environment for Industry 5.0. In *IoT Edge Intelligence* (pp. 111–148). Cham: Springer Nature Switzerland.

Raj, N. , Sinha, A. , Bharrdwaj, S. , & Yadav, A. L. (2024, May). AI-powered energy consumption optimization for smart homes using IoT. In 2024 International Conference on Computational Intelligence and Computing Applications (ICCICA) (Vol. 1, pp. 231–236). IEEE.

Reddy, K. V. , Reddy, B. K. , Goutham, V. , Mahesh, M. , Nisha, J. S. , Palanisamy, G. , ... & Ramkumar, V. (2024). Edge AI in sustainable farming: Deep learning-driven IOT framework to safeguard crops from wildlife threats. *IEEE Access*, 12, 77707–77723.

Santoso, A. , & Surya, Y. (2024). Maximizing decision efficiency with edge-based AI systems: Advanced strategies for real-time processing, scalability, and autonomous intelligence in distributed environments. *Quarterly Journal of Emerging Technologies and Innovations*, 9(2), 104–132.

Shekhar, A. , & Aleem, A. (2024, February). Improving energy efficiency through green cloud computing in IoT networks. In 2024 IEEE International Conference on Computing, Power and Communication Technologies (IC2PCT) (Vol. 5, pp. 929–933). IEEE.

Sudar, K. M. , Beulah, M. , Deepalakshmi, P. , Nagaraj, P. , & Chinnasamy, P. (2021). Detection of distributed denial of service attacks in SDN using machine learning techniques. In *International Conference on Computer Communication and Informatics, ICCCI 2021*. <https://doi.org/10.1109/ICCCI50826.2021.9402517>

Ullah, A. , Anwar, S. M. , Li, J. , Nadeem, L. , Mahmood, T. , Rehman, A. , & Saba, T. (2024). Smart cities: The role of Internet of Things and machine learning in realizing a data-centric smart environment. *Complex & Intelligent Systems*, 10(1), 1607–1637.

Zhang, Y. , & Feng, J. (2024). Towards a smart and sustainable future with edge computing-powered Internet of Things: Fundamentals, applications, challenges, and future research directions. *Journal of The Institution of Engineers (India): Series B*, 1–20.

Fostering Ethical Leadership and Sustainable Innovation in Intelligent Mobile and IoT Ecosystems

Alamelu, R. , Sudha, M. , & Purushothaman, R. (2024). Adoption of circular economy strategies with artificial intelligence. In *Advances in Logistics, Operations, and Management Science Book Series* (pp. 179–204). <https://doi.org/10.4018/979-8-3693-6205-1.ch007>

Andrzejewski, P. (2023, July 31). What are the ethical considerations when using IoT devices? WizzDev. <https://wizzdev.com/blog/what-are-the-ethical-considerations-when-using-iot-devices/>

Angwin, J. , Larson, J. , Mattu, S. , & Kirchner, L. (2016, May 23). Machine bias: There is software used nationwide to predict future criminals. Moreover, it is not very objective against blacks. ProPublica. www.propublica.org/article/machine-bias-risk-assessments-in-criminal-sentencing

Antoniou, J. , & Andreou, A. (2019). Case study The Internet of Things and ethics. *ORBIT Journal*, 2(2), 1–29. <https://doi.org/10.29297/orbit.v2i2.111>

Apple Inc. (2023). Supplier Responsibility Progress Report. www.apple.com/supplier-responsibility/

AutoAI-Enabled Next Generation Health Monitoring Systems Using IOMT Devices . (2023, November 25). IEEE Conference Publication | IEEE Xplore.
https://ieeexplore.ieee.org/abstract/document/10456452?casa_token=hi02aFzInLUAAAAA:HrtAFVae8QVaSX3a1AcQXujKQaUoD32gUuP6HwCUFzHWxTJTFpi1tud8f6RA_IBfG2XDpMeVfQ

Bhawana, N. , Kumar, S. , Rathore, R. S. , Mahmud, M. , Kaiwartya, O. , & Lloret, J. (2022). BEST – Blockchain-enabled secure and trusted public emergency services for smart cities environment. *Sensors*, 22(15), 5733. <https://doi.org/10.3390/s22155733>

Blockchain and Distributed Ledger Technology Use Cases . (2020). Google Books.
[https://books.google.co.in/books?hl=en&lr=&id=sZnpDwAAQBAJ&oi=fnd&pg=PA51&dq=IoTEnabled+Smart+Healthcare+Systems+\(MediConnect\)&ots=a_nnlbx32U&sig=IMUym9y3D7h5Qt53wMhwOAMERns#v=onepage&q&f=false](https://books.google.co.in/books?hl=en&lr=&id=sZnpDwAAQBAJ&oi=fnd&pg=PA51&dq=IoTEnabled+Smart+Healthcare+Systems+(MediConnect)&ots=a_nnlbx32U&sig=IMUym9y3D7h5Qt53wMhwOAMERns#v=onepage&q&f=false)

Brown, A. J. (2020). “Should I stay or should I leave?”: Exploring (dis)continued facebook use after the Cambridge analytica scandal. *Social Media + Society*, 6(1). <https://doi.org/10.1177/2056305120913884>

Cpe, A. E. J. C. C. E. (2024, October 12). Memo 31: Tim Cook’s Stoic Leadership – A Blueprint for Ethical Growth, Resilience, and Long-Term Vision. www.linkedin.com/pulse/memo-31-tim-cooks-stoic-leadership-blueprint-ethical-alejandro-tejac#:~:text=Wisdom%3A%20Ethical%20Leadership%20and%20Rational%20Decision%2DMaking&text=Cook%20has%20positioned%20Apple%20as,central%20to%20its%20product%20ecosystem

De Araujo Ventura, M. A., & Meirelles, D. S. E. (2024). Business model structuration in Industry 4.0: An analysis of the value-based strategies of smart service providers in Brazil. *Journal of Manufacturing Technology Management*. <https://doi.org/10.1108/jmtm-12-2023-0548>

Dhirani, L. L. , Mukhtiar, N. , Chowdhry, B. S. , & Neue, T. (2023). Ethical dilemmas and privacy issues in emerging technologies: A review. *Sensors*, 23(3), 1151. <https://doi.org/10.3390/s23031151>

Environmental Sustainability | Cisco Purpose Reporting Hub. (n.d.). www.cisco.com/c/m/en_us/about/csr/esg-hub/environment.html

Ethics Guidelines for Trustworthy AI . (2019). Shaping Europe’s Digital Future. <https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai>

Case-Specific References

Fairphone . (2023, October 2). Our Mission – We Care for People and Planet. www.fairphone.com/en/story/

Fowler, G. A. (2019). Ring doorbell data was leaked to employees and third parties. *The Washington Post*. www.washingtonpost.com/technology/2019/12/19/ring-doorbell-data-leaked/

Frehill, L. M. (2024). Digital inclusion and the Internet of Things: Convenience and the choice-compulsion continuum. *Policy & Internet*, 16(2), 272–293. <https://doi.org/10.1002/poi3.403>

Gerke, S. , Minssen, T. , & Cohen, G. (2020). Ethical and legal challenges of artificial intelligence-driven healthcare. In *Artificial Intelligence in Healthcare* (pp. 295–336). Elsevier eBooks. <https://doi.org/10.1016/b978-0-12-818438-7.00012-5>

Goodall, N. J. (2014). Machine ethics and automated vehicles. In *Lecture Notes in Mobility* (pp. 93–102). https://doi.org/10.1007/978-3-319-05990-7_9

HIPAA Journal . (2023). IoT in Healthcare: Privacy and Security Challenges. www.hipaajournal.com

Hussain, A. , Zafar, K. , & Baig, A. R. (2021). FOG-Centric IoT based framework for healthcare monitoring, management and early warning system. *IEEE Access*, 9, 74168–74179. <https://doi.org/10.1109/access.2021.3080237>

Kadayat, Y. , Sharma, S. , Agarwal, P. , & Mohan, S. (2024). Internet-of-Things enabled smart health monitoring system using AutoAI: A graphical tool of IBM Watson Studio. In *Internet of things* (pp. 427–445). https://doi.org/10.1007/978-981-97-0052-3_21

Kalsoom, T. , Ahmed, S. , Rafi-ul-Shan, P. M. , Azmat, M. , Akhtar, P. , Pervez, Z. , Imran, M. A. , & Ur-Rehman, M. (2021). Impact of IoT on manufacturing Industry 4.0: A new triangular systematic review. *Sustainability*, 13(22), 12506. <https://doi.org/10.3390/su132212506>

Kanakia, H. , Shenoy, G. , & Shah, J. (2019). Cambridge analytica a case study. *Indian Journal of Science and Technology*, 12(29), 1–5. <https://doi.org/10.17485/ijst/2019/v12i29/146977>

Khalil, U. , Malik, O. A. , Uddin, M. , & Chen, C. (2022). A comparative analysis on blockchain versus centralized authentication architectures for IoT-enabled smart devices in smart cities: A comprehensive review. Recent advances, and future research directions. *Sensors*, 22(14), 5168. <https://doi.org/10.3390/s22145168>

Khayyam, H. , Javadi, B. , Jalili, M. , & Jazar, R. N. (2019). Artificial intelligence and Internet of Things for autonomous vehicles. In *Nonlinear Approaches in Engineering Applications: Automotive Applications of Engineering Problems* (pp. 39–68). Springer eBooks. https://doi.org/10.1007/978-3-030-18963-1_2

Kitchin, R. (2021). Ethical issues in smart cities and urban IoT. *Journal of Urban Technology*, 28(1), 1–14.

Lahane, S. , & Kant, R. (2021). A hybrid Pythagorean fuzzy AHP – CoCoSo framework to rank the performance outcomes of circular supply chain due to adoption of its enablers. *Waste Management*, 130, 48–60. <https://doi.org/10.1016/j.wasman.2021.05.013>

Mittelstadt, B. D. , Allo, P. , Taddeo, M. , Wachter, S. , & Floridi, L. (2016). The ethics of algorithms: Mapping the debate. *Big Data & Society*, 3(2), 1–21.

Padovano, A. , & Ivanov, D. (2025). Towards resilient and viable supply chains: A multidimensional model and empirical analysis. *International Journal of Production Research*, 1–39. <https://doi.org/10.1080/00207543.2025.2470350>

Parihar, A. , Prajapati, J. B. , Prajapati, B. G. , Trambadiya, B. , Thakkar, A. , & Engineer, P. (2024). Role of IOT in healthcare: Applications, security & privacy concerns. *Intelligent Pharmacy*. <https://doi.org/10.1016/j.ipha.2024.01.003>

Powles, J. , & Hodson, H. (2017). Google DeepMind and healthcare in an age of algorithms. *Health and Technology*, 7(4), 351–367. <https://doi.org/10.1007/s12553-017-0179-1>

Purushothaman, R. , Alamelu, R. , & Sudha, M. (2025). Application of circular economy principles in Indian SME supply chain for sustainable value creation. In *Developing Dynamic and Sustainable Supply Chains to Achieve Sustainable Development Goals* (pp. 311–330). IGI Global eBooks. <https://doi.org/10.4018/979-8-3693-6284-6.ch011>

Schneier, B. (2020). Click here to kill everybody: Security and survival in a hyper-connected world. *St Antony's International Review*, 15(1), 206–208. www.jstor.org/stable/27027764

Smith, C. A. (2023, September 14). Ethical leadership and sustainability: Shaping future success. Join the Collective. www.jointhecollective.com/article/ethical-leadership-and-sustainability/

Stahl, B. C. , Schroeder, D. , & Rodrigues, R. (2022). The ethics of artificial intelligence: An introduction. In *Springer Briefs in Research and Innovation Governance* (pp. 1–7). https://doi.org/10.1007/978-3-031-17040-9_1.

Tonsager, L. , Ponder, J. , & Mcity Leadership Circle . (2023). Privacy Frameworks for Smart Cities. https://mcity.umich.edu/wp-content/uploads/2023/03/Privacy-Frameworks-for-Smart-Cities_White-Paper_2023.pdf

Tran, V. H. , Mehrotra, A. , Chetty, M. , Feamster, N. , Frankenreiter, J. , & Strahilevitz, L. (2024). Measuring compliance with the California consumer privacy act over space and time. *Human-Computer Interaction*, 1–19. <https://doi.org/10.1145/3613904.3642597>

Turner, S. , Pattnaik, N. , Nurse, J. R. , & Li, S. (2022). “You just assume it is in there, I guess”: Understanding UK families' application and knowledge of smart home cyber security. *Proceedings of the ACM on Human-Computer Interaction*, 6(CSCW2), 1–34. <https://doi.org/10.1145/3555159>

Udeh, E. O. , Amajuoyi, P. , Adeusi, K. B. , & Scott, A. O. (2024). The role of IoT in boosting supply chain transparency and efficiency. *Magna Scientia Advanced Research and Reviews*, 11(1), 178–197. <https://magnascientiapub.com/journals/msarr/sites/default/files/MSARR-2024-0081.pdf#page=1.41>

Umoren, O. , Singh, R. , Pervez, Z. , & Dahal, K. (2022). Securing fog computing with a decentralized user authentication approach based on blockchain. *Sensors*, 22(10), 3956. <https://doi.org/10.3390/s22103956>

Wodi, A. (2023). The EU general data protection regulation (GDPR): Five years after and the future of data privacy protection in review. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4601142>

Future Aspects of BC-IoT

Ai, X. , Badshah, A. , Tu, S. , Waqas, M. , & Ahmad, I. (2025). An improved ultra-lightweight anonymous authenticated key agreement protocol for wearable devices. *IEEE Transactions on Mobile Computing*, 1–14. <https://doi.org/10.1109/TMC.2025.3526076>

Al-Aswad, H. , El-Medany, W. M. , Balakrishna, C. , Ababneh, N. , & Curran, K. (2021). BZKP: Blockchain-based zero-knowledge proof model for enhancing healthcare security in Bahrain IoT smart cities and COVID-19 risk mitigation. *Arab Journal of Basic and Applied Sciences*, 28(1), 154–171. <https://doi.org/10.1080/25765299.2020.1870812>

Al Dawi, A. , Tezel, N. S. , Rahebi, J. , & Akbas, A. (2025). An approach to botnet attacks in the fog computing layer and Apache Spark for smart cities. *The Journal of Supercomputing*, 81(4), 582. <https://doi.org/10.1007/s11227-024-06915-y>

Aldahmani, A. , Ouni, B. , Lestable, T. , & Debbah, M. (2023). Cyber-security of embedded IoTs in smart homes: Challenges, requirements, countermeasures, and trends. *IEEE Open Journal of Vehicular Technology*, 4, 281–292. <https://doi.org/10.1109/OJVT.2023.3234069>

Alharbi, A. A. (2024). Federated transfer learning for attack detection for Internet of Medical Things. *International Journal of Information Security*, 23(1), 81–100. <https://doi.org/10.1007/s10207-023-00805-9>

Alwazeh, M. , Karaman, S. , & Shamma, M. N. (2020). Man in the middle attacks against SSL/TLS: Mitigation and defeat. *Journal of Cyber Security and Mobility*. <https://doi.org/10.13052/jcsm2245-1439.933>

Asensio-Garriga, R. , Alemany, P. , Zarca, A. M. , Sedar, R. , Kalalas, C. , Ortiz, J. , Vilalta, R. , Muñoz, R. , & Skarmeta, A. (2024). ZSM-based E2E security slice management for DDoS attack protection in MEC-enabled V2X environments. *IEEE Open Journal of Vehicular Technology*, 5, 485–495. <https://doi.org/10.1109/OJVT.2024.3375448>

Bhardwaj, A. , Bharany, S. , Osman Ibrahim, A. , Almogren, A. , Ur Rehman, A. , & Hamam, H. (2024). Unmasking vulnerabilities by a pioneering approach to securing smart IoT cameras through threat surface analysis and dynamic metrics. *Egyptian Informatics Journal*, 27, 100513. <https://doi.org/10.1016/j.eij.2024.100513>

Bhutta, M. N. M. , Bhattia, S. , Alojail, M. A. , Nisar, K. , Cao, Y. , Chaudhry, S. A. , & Sun, Z. (2022). Towards secure IoT-based payments by extension of payment card industry data security standard (PCI DSS). *Wireless Communications and Mobile Computing*, 2022, 1–10. <https://doi.org/10.1155/2022/9942270>

Chen, X. , Cheng, Q. , Yang, W. , & Luo, X. (2024). An anonymous authentication and secure data transmission scheme for the Internet of Things based on blockchain. *Frontiers of Computer Science*, 18(3), 183807. <https://doi.org/10.1007/s11704-023-2595-x>

Datta, S. , & Namasudra, S. (2024). Blockchain-based secure and scalable supply chain management system to prevent drug counterfeiting. *Cluster Computing*, 27(7), 9243–9260. <https://doi.org/10.1007/s10586-024-04417-3>

Ebrahim, N. S. (2023). Complexity of IoT world – Review of challenges and opportunities in application development. In *2023 International Conference on Smart Computing and Application (ICSCA)*, 1–5. <https://doi.org/10.1109/ICSCA57840.2023.10087783>

Fereidouni, H. , Fadeitcheva, O. , & Zalai, M. (2025). IoT and man-in-the-middle attacks. *Security and Privacy*, 8(2), e70016. <https://doi.org/10.1002/spy2.70016>

Fereira, R. J. , Ranaweera, C. , Lee, K. , & Schneider, J.-G. (2025). Energy efficient resource management for real-time IoT applications. *Internet of Things*, 30, 101515. <https://doi.org/10.1016/j.iot.2025.101515>

Fúster, J. , Solera-Cotanilla, S. , Pérez, J. , Vega-Barbas, M. , Palacios, R. , Álvarez-Campana, M. , & Lopez, G. (2024). Analysis of security and privacy issues in wearables for minors. *Wireless Networks*, 30(6), 5437–5453. <https://doi.org/10.1007/s11276-022-03211-6>

Greß, H. , Krüger, B. , & Tischhauser, E. (2025). The newer, the more secure? Standards-compliant bluetooth low energy man-in-the-middle attacks on fitness trackers. *Sensors*, 25(6), 1815. <https://doi.org/10.3390/s25061815>

Guo, H. , & Yu, X. (2022). A survey on blockchain technology and its security. *Blockchain: Research and Applications*, 3(2), 100067. <https://doi.org/10.1016/j.bcr.2022.100067>

Han, H.-S. , Choi, T. , & Yoon, J.-S. (2024). Enhancing security in low-power wide-area (LPWA) IoT environments: The role of HSM, tamper-proof technology, and quantum cryptography. *Journal of Web Engineering*, 787–800. <https://doi.org/10.13052/jwe1540-9589.2363>

Horak, T. , Strelec, P. , Huraj, L. , Tanuska, P. , Vaclavova, A. , & Kebisek, M. (2021). The vulnerability of the production line using industrial IoT systems under DDoS attack. *Electronics*, 10(4), 381. <https://doi.org/10.3390/electronics10040381>

Huang, W. , Chen, H. , Cao, H. , Ren, J. , Jiang, H. , Fu, Z. , & Zhang, Y. (2024). Manipulating voice assistants eavesdropping via inherent vulnerability unveiling in mobile systems. *IEEE Transactions on Mobile Computing*, 23(12), 11549–11563. <https://doi.org/10.1109/TMC.2024.3401096>

Hussain, K. , Rahmatyar, A. R. , Riskhan, B. , Sheikh, M. A. U. , & Sindiramutty, S. R. (2024). Threats and vulnerabilities of wireless networks in the Internet of Things (IoT). In *2024 IEEE 1st Karachi Section Humanitarian Technology Conference (KHI-HTC)*, 1–8. <https://doi.org/10.1109/KHI-HTC60760.2024.10482197>

Kato, G. A. , Yamongan, J. S. , Manao, J. M. N. , Arcega, R. A. A. , Espino, R. L. E. , Capili, R. D. S. , & Magsumbol, J.-A. V. (2023). Emerging technologies in the Philippines: Internet of Things (IoT). In Vasant, P. , Weber, G.-W. , Marmolejo-Saucedo, J. A. , Munapo, E. , & Thomas, J. J. (eds.), *Intelligent Computing & Optimization* (Vol. 569, pp. 300–308). Springer International Publishing. https://doi.org/10.1007/978-3-031-19958-5_28

Khan, S. A. , Bajwa, H. R. , Sundaram, J. , Pritika, & Shanmugam, B. (2024). Vulnerability analysis and exploitation attacks on smart wearable devices. In *2024 2nd International Conference on Advancement in Computation & Computer Technologies (InCACCT)* (pp. 911–916). <https://doi.org/10.1109/InCACCT61598.2024.10550999>

Kumar, V. , Malik, N. , Singla, J. , Jhanjhi, N. Z. , Amsaad, F. , & Razaque, A. (2022). Light weight authentication scheme for smart home IoT devices. *Cryptography*, 6(3), 37. <https://doi.org/10.3390/cryptography6030037>

Lin, J. , Long, W. , Zhang, A. , & Chai, Y. (2020). Blockchain and IoT-based architecture design for intellectual property protection. *International Journal of Crowd Science*, 4(3), 283–293. <https://doi.org/10.1108/IJCS-03-2020-0007>

Lu, L. , Chen, M. , Yu, J. , Ba, Z. , Lin, F. , Han, J. , Zhu, Y. , & Ren, K. (2024). An imperceptible eavesdropping attack on WiFi sensing systems. *IEEE/ACM Transactions on Networking*, 32(5), 4009–4024. <https://doi.org/10.1109/TNET.2024.3403839>

Magaia, N. , Gomes, P. , Silva, L. , Sousa, B. , Mavromoustakis, C. X. , & Mastorakis, G. (2021). Development of mobile IoT solutions: Approaches, architectures, and methodologies. *IEEE Internet of Things Journal*, 8(22), 16452–16472. <https://doi.org/10.1109/JIOT.2020.3046441>

Mustafa, I. , McGibney, A. , & Rea, S. (2024). Smart contract life-cycle management: An engineering framework for the generation of robust and verifiable smart contracts. *Frontiers in Blockchain*, 6, 1276233. <https://doi.org/10.3389/fbloc.2023.1276233>

Niboucha, R. , Saad, S. B. , Ksentini, A. , & Challal, Y. (2023). Zero-touch security management for mMTC network slices: DDoS attack detection and mitigation. *IEEE Internet of Things Journal*, 10(9), 7800–7812. <https://doi.org/10.1109/JIOT.2022.3230875>

Noshad, Z. , Khan, A. U. , Abbas, S. , Abubaker, Z. , Javaid, N. , Shafiq, M. , & Choi, J.-G. (2021). An incentive and reputation mechanism based on blockchain for crowd sensing network. *Journal of Sensors*, 2021(1), 1798256. <https://doi.org/10.1155/2021/1798256>

Nuzulastri, S. , Stiawan, D. , Satria, H. , & Budiarto, R. (2024). Clustering man in the middle attack on chain and graph-based blockchain in Internet of Things network using k-means. *Computer Science and Information Technologies*, 5(2), 176–185. <https://doi.org/10.11591/csit.v5i2.p176-185>

Okediran, T. M. , Vincent, O. R. , Abayomi-Alli, A. A. , & Adeniran, O. J. (2024). Securing the perceptual layer of E-payment-based Internet of Things devices using elliptic curve cryptography over binary field. *The Journal of Supercomputing*, 80(15), 21592–21614. <https://doi.org/10.1007/s11227-024-06270-y>

Pavlidis, A. , Dimolianis, M. , Giotis, K. , Anagnostou, L. , Kostopoulos, N. , Tsigkritis, T. , Kotinas, I. , Kalogeras, D. , & Maglaris, V. (2020). Orchestrating DDoS mitigation via blockchain-based network provider collaborations. *The Knowledge Engineering Review*, 35, e16. <https://doi.org/10.1017/S0269888920000259>

Pradhan, N. R. , & Singh, A. P. (2021). Smart contracts for automated control system in Blockchain based smart cities. *Journal of Ambient Intelligence and Smart Environments*, 13(3), 253–267. <https://doi.org/10.3233/AIS-210601>

Priya, J. C. , Nanthakumar, G. , Choudhury, T. , & Karthika, K. (2025). 6G-DeFLI: Enhanced quality-of-services using distributed hash table and blockchain-enabled federated learning approach in 6G IoT networks. *Wireless Networks*, 31(1), 361–375. <https://doi.org/10.1007/s11276-024-03759-5>

Qiao, L. , Dang, S. , Shihada, B. , Alouini, M.-S. , Nowak, R. , & Lv, Z. (2022). Can blockchain link the future? *Digital Communications and Networks*, 8(5), 687–694. <https://doi.org/10.1016/j.dcan.2021.07.004>

Qizi, L. R. M. , & Kamalovich, B. K. (2025). Blockchain technology usage on intellectual property rights. *International Journal for the Semiotics of Law – Revue Internationale de Sémiotique Juridique*, 38(2), 363–380. <https://doi.org/10.1007/s11196-024-10224-1>

Qudrat-Ullah, H. (2025). Enhancing supply chain resilience: The role of emerging technologies. *Transportation Research Procedia*, 84, 5–10. <https://doi.org/10.1016/j.trpro.2025.03.037>

Reshi, I. A. , & Sholla, S. (2024). Securing IoT data: Fog computing, blockchain, and tailored privacy-enhancing technologies in action. *Peer-to-Peer Networking and Applications*, 17(6), 3905–3933. <https://doi.org/10.1007/s12083-024-01801-z>

Roopak, M. , Parkinson, S. , Tian, G. Y. , Ran, Y. , Khan, S. , & Chandrasekaran, B. (2024). An unsupervised approach for the detection of zero-day distributed denial of service attacks in Internet of Things networks. *IET Networks*, 13(5–6), 513–527. <https://doi.org/10.1049/ntw2.12134>

Sahoo, S. S. , & Chaurasiya, V. K. (2023). VIBE: Blockchain-based virtual payment in IoT ecosystem: A secure decentralized marketplace. *Multimedia Tools and Applications*, 83(6), 16869–16894. <https://doi.org/10.1007/s11042-023-15634-0>

Sahraoui, S. , & Bachir, A. (2025). Lightweight consensus mechanisms in the Internet of Blockchain Things: Thorough analysis and research directions. *Digital Communications and Networks*, S2352864824001767. <https://doi.org/10.1016/j.dcan.2024.12.007>

Sapra, N. , Shaikh, I. , & Dash, A. (2023). Impact of proof of work (PoW)-based blockchain applications on the environment: A systematic review and research agenda. *Journal of Risk and Financial Management*, 16(4), 218. <https://doi.org/10.3390/jrfm16040218>

Shahidinejad, A. , & Abawajy, J. (2024). An all-inclusive taxonomy and critical review of blockchain-assisted authentication and session key generation protocols for IoT. *ACM Computing Surveys*, 56(7), 1–38. <https://doi.org/10.1145/3645087>

Shukla, P. , Krishna, C. R. , & Patil, N. V. (2025). Distributed ensemble method using deep learning to detect DDoS attacks in IoT networks. *Arabian Journal for Science and Engineering*, 50(2), 1143–1168. <https://doi.org/10.1007/s13369-024-09144-w>

Srinivasu, P. N. , Bhoi, A. K. , Nayak, S. R. , Bhutta, M. R. , & Woźniak, M. (2021). Blockchain technology for secured healthcare data communication among the non-terminal nodes in IoT architecture in 5G network. *Electronics*, 10(12), 1437. <https://doi.org/10.3390/electronics10121437>

Triveni, P. , Jaikishen, J. , & Sanjana, R. (2024). Analysis of blockchain law and regulations. *ITM Web of Conferences*, 68, 01010. <https://doi.org/10.1051/itmconf/20246801010>

Tu, Z. , Zhou, H. , Li, K. , Song, H. , & Yang, Y. (2022). A blockchain-based trust and reputation model with dynamic evaluation mechanism for IoT. *Computer Networks*, 218, 109404. <https://doi.org/10.1016/j.comnet.2022.109404>

Vivekanandan, M. , V. N., S., & U., S. R. (2021). BIDAPSCA5G: Blockchain based Internet of Things (IoT) device to device authentication protocol for smart city applications using 5G technology. *Peer-to-Peer Networking and Applications*, 14(1), 403–419. <https://doi.org/10.1007/s12083-020-00963-w>

Wan, S. , Lin, H. , Gan, W. , Chen, J. , & Yu, P. S. (2024). Web3: The next internet revolution. *IEEE Internet of Things Journal*, 11(21), 34811–34825. <https://doi.org/10.1109/JIOT.2024.3432116>

Wazzeah, M. , Ould-Slimane, H. , Talhi, C. , Mourad, A. , & Guizani, M. (2023). Privacy-preserving continuous authentication for mobile and IoT systems using warmup-based federated learning. *IEEE Network*, 37(3), 224–230. <https://doi.org/10.1109/MNET.121.2200099>

Yakubu, B. M. , Khan, M. I. , Khan, A. , Jabeen, F. , & Jeon, G. (2023). Blockchain-based DDoS attack mitigation protocol for device-to-device interaction in smart home. *Digital Communications and Networks*, 9(2),

383–392. <https://doi.org/10.1016/j.dcan.2023.01.013>

Yang, D. , Zhou, Y. , Huang, W. , & Zhou, X. (2021). 5G mobile communication convergence protocol architecture and key technologies in satellite Internet of Things system. *Alexandria Engineering Journal*, 60(1), 465–476. <https://doi.org/10.1016/j.aej.2020.09.019>

Zhang, Q. , Du, J. , Zheng, P. , Zhang, L. , Zhang, Y. , Xu, J. , Wei, Z. , & Chen, X. (2022). Blockchain and distributed ledger technology standardization in ITU-T: Diversification, globalization and future. In *2022 5th International Conference on Hot Information-Centric Networking (HotICN)* (pp. 48–54). <https://doi.org/10.1109/HotICN57539.2022.10036200>

Zhang, S. , Tian, H. , Wang, L. , Xu, S. , & Shao, W. (2024). A reputation-based dynamic reorganization scheme for blockchain network sharding. *Connection Science*, 36(1), 2327438. <https://doi.org/10.1080/09540091.2024.2327438>

Zhu, Q. , Sun, R. , Lv, D. , Cheng, R. X. , Zuo, J. , & Qin, S. (2024). Research on cognitive neural mechanism of consumers convinced by intelligent recommendation platform eavesdropping. *Scientific Reports*, 14(1), 28108. <https://doi.org/10.1038/s41598-024-79281-7>

Zhuk, A. (2025). Beyond the blockchain hype: Addressing legal and regulatory challenges. *SN Social Sciences*, 5(2), 11. <https://doi.org/10.1007/s43545-024-01044-y>

Zou, J. , Liu, H. , Liu, C. , Ren, X. , & Wang, X. (2024). Optimal privacy-preserving transmission schedule against eavesdropping attacks on remote state estimation. *IEEE Control Systems Letters*, 8, 538–543. <https://doi.org/10.1109/LCSYS.2024.3398200>