Frontiers of Artificial Intelligence,
Ethics and Multidisciplinary Applications

Rajeev Arya · Subhash Chander Sharma ·
Ajit Kumar Verma · Brijesh Iyer *Editors*

Recent Trends in Artificial Intelligence Towards a Smart World

Applications in Industries and Sectors

Springer

Frontiers of Artificial Intelligence, Ethics and Multidisciplinary Applications

Artificial Intelligence is now present in numerous spheres of our everyday lives. It is poised to lead new and efficient business models for effective and user-centric services in the private and public sectors. Advances in AI in deep learning, (deep) reinforcement learning, and neuroevolutionary techniques can pave the way forward for artificial general intelligence (AGI). However, the development and use of AI also present challenges. Inherent biases prevalent within data corpora used to train AI and machine learning systems attribute to most of these challenges. In addition, multiple instances have highlighted the need for privacy, fairness, and transparency in AI-powered decision-making. This book series will provide an avenue for researchers, leaders, decision-makers, and policymakers to share research and insights on the forefronts of AI, including its use in an Ethical, Explainable, Privacy-Preserving, Trustworthy, and Sustainable manner.

The series has relevance across disciplines and be multi-disciplinary. Advances in AI, explainability AI, privacy-preserving AI, and ethical AI explored in this book series are unexplored areas for research and competence building. Such developments can reduce hesitancy for AI integration in many domains. The book series thus fits in well as an essential and growing need among those who work on artificial intelligence in academia, business and industry, and the public sector to exploit the opportunities in the constantly evolving field of AI.

The series publishes research monographs, authored works by practitioners and case studies to highlight innovative and best practices, and edited volumes putting together varied perspectives.

Rajeev Arya · Subhash Chander Sharma ·
Ajit Kumar Verma · Brijesh Iyer
Editors

Recent Trends in Artificial Intelligence Towards a Smart World

Applications in Industries and Sectors

Springer

Editors
Rajeev Arya
Department of Electronics
and Communication Engineering
National Institute of Technology Patna
Patna, Bihar, India

Ajit Kumar Verma
Faculty of Technology
Environmental and Social Sciences
Western Norway University of Applied
Sciences
Haugesund, Norway

Subhash Chander Sharma
Electronics and Computer Discipline
Indian Institute of Technology Roorkee
Saharanpur, Uttar Pradesh, India

Brijesh Iyer
Dr. Babasaheb Ambedkar Technological
University
Lonere, Maharashtra, India

ISSN 2731-8125 ISSN 2731-8133 (electronic)
Frontiers of Artificial Intelligence, Ethics and Multidisciplinary Applications
ISBN 978-981-97-6789-2 ISBN 978-981-97-6790-8 (eBook)
https://doi.org/10.1007/978-981-97-6790-8

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

Recently, the development of artificial intelligence has shifted our horizon from the automation world to the smart world. Most of the time, it is impractical to solve issues with large data sets using an exhaustive data search. Powerful tools are available thanks to optimization methods for handling data analysis and learning problems. Several techniques are used to design and put optimization algorithms into practice, and they all work better. However, the search area expands exponentially with problem size in several applications. Moreover, the scope of applications using AI is also increasing day by day. There are various AI and machine learning algorithms which have been adapted to work in a dynamic environment. The variety of algorithms developed for automobiles, drones, road management, sensor data management and analysis etc. is motivated by new optimization research trends that are primarily founded on machine learning and artificial intelligence. The goal of AI computing method is to find a useful result out of random and dynamic data. Numerous fields, including engineering, medicine, industry, education, and the military, can handle optimization in high-dimensional real-world issues thanks to some machine learning algorithms with unsupervised frameworks.

A significant area of computational intelligence, soft computing, and optimization in general is the study of fast and effective algorithms which makes our world smarter. Since constrained and unconstrained algorithms are available, they are capable of handling a variety of problems effectively. The Internet of Things (IoTs), which uses smart devices, smart sensors, and machine learning, and cloud computing are other popular subjects. They encompass all kinds of systems, including business, finance, industry, manufacturing, management, and the environment, in addition to information and communication technology. IoT creates a significant quantity of data and links the physical world to the Internet. Big data processing is made easier by a cloud computing environment, which also uses machine learning and big data analysis to make wise choices. Additionally, the fusion of intellect and technology enables the reduction of human effort while increasing the precision and efficacy of the latter. By connecting innovative thinking with innovative action and innovative execution in nearly every aspect of human life, smart devices and systems are revolutionizing the world. A system becomes smart when it can collect data, process it, analyse it, and make right decisions. Sensors are typically used for data capture and gathering, and processing converts raw data into usable information. The task of making decisions is ultimately assisted by the analysis of data using clever algorithms.

This edited book's general goal is to compile the most recent chapter reviews on the interrelated fields of Internet of vehicles, internet of drones, and cognitive radios etc. This book is dedicated to the analysis, modelling, simulation, and applications in the interdisciplinary fields of these cutting-edge technologies, from challenges and current issues to foundations, latest research and development, and opportunities. We attempt to cover every facet of the interplay between various areas of the smart world like smart cities and smart homes etc. We intend to offer a thorough platform for researchers to present novel methods for handling various types of uncertainties in practical issues using the cutting-edge machine learning algorithms. We examine the potential future work in various domains using the internet and its novel approach to bridging the divide between theory and day-to-day practical problems. Additionally, we present a unified manifesto for applied scientists to use machine learning methods in many different engineering fields, such as IoTs and communication, as well as the difficulties they may encounter in the process. The book investigates new learning domains and includes case studies based on both synthetic and actual data from various domains. We anticipate that it acts as a one-stop resource for field researchers, scholars, scientists, and industrialists.

Chapter 1 discusses the use of AI to make communication world smarter. This chapter explains how AI has contributed to making cognitive radio smarter using various optimization techniques. The various challenges and solutions of AI driven cognitive radio network have also been discussed. The future trends of AI driven CRN and its impact on industries have also been explained in this chapter.

Chapter 2 focuses on healthcare system. Every patient wants to keep their data secure but with the development of IoT digital health records have been created. To keep this data safe while avoiding unethical access to this data is very important. This chapter explains the benefits of AI in solving various problems like remote surgery. The role of AI in various sectors of healthcare like drug discovery, radiology, and patient monitoring has been discussed.

Chapter 3 explains the enormous revolution that is happening within the healthcare industry in the 21st century with the development of Artificial Intelligence (AI). With the coming of artificial intelligence and its application in healthcare businesses, the chapter looks at the world- view move in smart healthcare. Having moved from Industry 4.0 to Industry 5.0, the healthcare industry has gone through a change that has given the industry an unused dimension and a sensational alter.

Chapter 4 explains the modern industrial environment influenced by smart manufacturing and logistics, which also drive competitiveness, efficiency, sustainability, and innovation in a variety of other sectors and industries. Businesses can detect possible hazards and opportunities using real-time data analytics and predictive capabilities, enabling them to act quickly and efficiently. The global industrial landscape is transformed by Smart manufacturing and logistics, which is often referred to as Industry 4.0 by leveraging advanced technologies to improve sustainability, efficiency, and productivity. The terms and key concepts associated with this transformation include Industry 4.0, IoT, AI, and Automation.

Chapter 5 discusses the importance of AI-powered machines in industrial automation, focusing on how they make operations more responsive and flexible in changing manufacturing environments. This chapter explores how industrial Internet of Things (IIOT) helps in performing various functions like remote monitoring and controlling, predictive maintenance, asset management, safety and compliance, and supply chain integration by analysing data, predicting challenges, optimizing processes, and introducing robotics in manufacturing. These systems can spot problems early on and prevent risks, resulting in less downtime and higher productivity. The chapter showcases case studies and success stories of AI solutions in various industries. It provides guidance for businesses wanting to capitalize on AI's potential to gain an edge in today's competitive market.

Chapter 6 deals with the applications and challenges of optimization in internet of vehicles (IoTs). It starts with the network optimization in internet of vehicle and then it covers the various cases of resource and network optimization by using computation capabilities of other devices.

Chapter 7 investigates how sensors work as IoT's sensory organs, allowing for the capture of massive volumes of data from the actual world. The chapter highlights the critical role of sensors in enabling real-time monitoring, predictive maintenance, and improved decision-making in a variety of areas, including healthcare, agriculture, transportation, and smart cities. Organizations that use sensor data can obtain significant insights into operational efficiency, resource optimization, and consumer behaviour. The chapter also discusses the problems and opportunities connected with sensor deployment in IoT ecosystems, which range from data privacy and security concerns to interoperability and scalability issues.

Chapter 8 explains the integration of smart homes. Smart homes, equipped with cutting-edge technologies and digital devices, seek to enhance safety, convenience, energy efficiency, and sustainability within residential settings. By seamlessly integrating smart homes into the broader framework of smart cities, a holistic approach to urban development can be achieved. This chapter explores the nuances of this integration, examining how smart homes contribute to the overall well-being and quality of life in urban environments. It addresses the challenges and opportunities inherent in building a connected urban habitat, emphasizing the imperative for sustainable urban development practices.

Chapter 9 explains about sorting the road traffic better, a new type of Custom Hierarchical Convolutional Neural Network (HCNN) is suggested. This HCNN uses the good parts of 1D and 2D CNNs. It can get important features from both image and video data in a big way. The use of HCNN helps make the identification of vehicle types better. This leads to a smarter study of road traffic situations. This study's findings are very important for smart transport systems, city planning, and traffic control.

Chapter 10 explores the transformative role of remote monitoring and control management systems in revolutionizing agricultural practices to achieve enhanced efficiency and sustainability. With the increasing demand for food production amidst growing environmental challenges, adopting advanced technologies becomes imperative to optimize resource utilization and mitigate risks. Remote monitoring and control systems offer a holistic approach to farm management by enabling real-time monitoring, data-driven decision-making, and automated control of critical agricultural operations.

Chapter 11 aims to explain the traffic detection system using deep learning algorithms. The goal of our deep learning-based method is to build a traffic detection system that is both quick and accurate, with no human involvement required. The study focuses on two critical aspects of intelligent traffic monitoring: accident detection and traffic flow analysis. The goal of this project is to improve future intelligent transportation systems by using TrafficNet technology. The TrafficNet system performs multiple activities, including dataset segmentation, data preparation, deep learning convolutional neural network (DLCNN) model training, traffic forecasting, and performance evaluation.

Chapter 12 delves into the foundational aspects of UANs, exploring their conceptualization, development, applications, and the challenges they present. As a multidisciplinary field, UANs incorporate principles from robotics, wireless communication, and artificial intelligence (AI) to create networks of unmanned aerial vehicles (UAVs) that can operate autonomously or be remotely controlled to perform a variety of tasks.

Chapter 13 explains the extensive integration of drones into the AI enabled IoT infrastructure also gives rise to concerns surrounding privacy, security, and adherence to legal requirements. Ensuring the appropriate and successful deployment of drone technology requires addressing crucial factors such as safeguarding data transfer, securing sensitive information, and complying with airspace rules.

Chapter 14 focuses on improving traffic sign detection and recognition (TSDR)-Net, a traffic sign recognition system for autonomous driverless vehicles that work in harsh weather conditions. The method uses multiple steps. It starts with hazy traffic sign images and uses deep learning techniques, particularly Deep Learning Convolutional Neural Network (DLCNN), to remove haze. The TSDR-Net begins by gathering hazy traffic sign images that have been affected by bad weather; using deep learning for haze removal to improve visibility; using a DLCNN to detect traffic signs; and evaluating model performance through accuracy and loss calculations. By addressing the crucial task of traffic sign recognition in harsh weather conditions, this research improves the safety and efficiency of autonomous driving systems.

Finally, Chap. 15 explores the transformative integration of artificial intelligence (AI) in higher education to build smart campuses that enhance both the learning experience and administrative efficiency. The foundation of smart campuses is laid out, emphasizing the role of technology in shaping the future of education. Various AI technologies, including machine learning, natural language processing, and predictive analytics, are examined in the context of personalized learning and student support.

Patna, India — Rajeev Arya
Saharanpur, India — Subhash Chander Sharma
Haugesund, Norway — Ajit Kumar Verma
Lonere, India — Brijesh Iyer

Contents

Editors and Contributors

About the Editors

Dr. Rajeev Arya received the Engineering Degree in Electronics & Communication Engineering from Government Engineering College, Ujjain, (RGPV University, Bhopal) India, and the Master of Technology in Electronics & Communication Engineering from Indian Institute of Technology (ISM), Dhanbad, India. He received the Ph.D. degree in Communication Engineering from Indian Institute of Technology (IIT Roorkee) Roorkee, India. He is currently an Assistant Professor at the Department of Electronics & Communication Engineering at National Institute of Technology, Patna, India. His current research interests are Applications of Artificial Intelligence (AI) and Machine Learning in Wireless Sensor Networks, soft computing techniques, 5G/6G Networks, UAV Networks, Signal Processing, Communication Systems, and Circuits Design.

Subhash Chander Sharma is a Professor in the Electronics and Computers discipline at the Indian Institute of Technology (IIT) Roorkee, Saharanpur Campus, India. He has an M.Sc. (electronics), M.Tech. (electronics & communication engineering), and Ph.D. (electronics & computer engineering) in 1981, 1983, and 1992 respectively from IIT Roorkee (erstwhile University of Roorkee). He began his career as an R&D Engineer in 1983, joining the teaching profession in January 1984 at IIT Roorkee, where he continues till date. He has more than 40 years of teaching and research experience. He has published over three hundred research papers in national and international journals/conferences, and supervised more than 30 projects/dissertations of PG students and 34 PhDs in the area of computer networking, wireless network, computer communication, applications of artificial intelligence (AI) and machine learning, internet of things (IoT), cloud & its security, and mobile computing.

Ajit Kumar Verma is a Professor in the Faculty of Technology, Environmental and Social Sciences, Western Norway University of Applied Sciences, Haugesund, Norway (since March 2012) and was Professor/HAG scale for 15 years with the

Department of Electrical Engineering/Reliability Engineering at IIT Bombay with a research focus in computational intelligence applications in reliability and safety engineering. He is also a Guest Professor at Lulea University of Technology, Sweden. He has several publications to his credit. He is the Series Editor of 5 book series, and has authored and edited several books with international publishers including Springer. He has served as the Editor-in-Chief of OPSEARCH (Jan 2008–Jan 2011), and is a Patron and Founding Editor-in-Chief of International Journal of System Assurance Engineering and Management besides being an Editor-in-Chief of Life Cycle Reliability and Safety Engineering, all published by Springer.

Dr. Brijesh Iyer is an Associate Professor in the Department of E&TC Engineering at the Dr. Babasaheb Ambedkar Technological University, Lonere, India. He is a recipient of an INAE research fellowship in the field of Engineering. His research interests include RF Front end design for 5G/6G, IoT, Biomedical Image and Signal Processing, Artificial Intelligence, and Soft Computing. He has patents to his credit, has authored five books on cutting-edge technologies such as Sensor Technology, and published over 40 research papers in peer-reviewed journals and conference proceedings. He has served as Program Committee Member of various international conferences. He holds a Ph.D. degree in Electronics and Telecommunication Engineering from Indian Institute of Technology, Roorkee, India.

Contributors

Swati Agrawal Christ University, Bengaluru, India

Bosco Paul Alapatt Christ University, Bengaluru, India

Nitin Arora Wireless Networks and Cloud Computing Lab, IIT Roorkee, Roorkee, India

Rajeev Arya Wireless Sensor Networks Lab, Department of Electronics and Communication Engineering, National Institute of Technology Patna, Patna, Bihar, India

V. Bharath Simha Reddy Malla Reddy Engineering College and Management Sciences, Medchal, Hyderabad, Telangana, India

Dara Eshwar SRKR Engineering College, Bhimavaram, Andhra Pradesh, India

Ankit Gambhir Delhi Technical Campus, Greater Noida, India

Aakansha Garg ABES Institute of Technology, Ghaziabad, UP, India

Aditi Garg J.C. Bose University of Science and Technology, YMCA, Faridabad, India

Varuna Gupta Christ University, Bengaluru, India

B. Hari Krishna St. Martins Engineering College, Kompally, Hyderabad, Telangana, India

Neha Jain Delhi Technical Campus, Greater Noida, India

Nandkishor Joshi Department of CSE, PIET, Parul University, Vadodara, India

Sapna Katiyar Impledge Technologies, Noida, India

M. Krishna Satya Varma SRKR Engineering College, Bhimavaram, Andhra Pradesh, India

Janapati Chaitanya Krishna Vardhaman College of Engineering, Hyderabad, Telangana, India

Dilip Mandloi Shri Vaishnav Vidyapeeth Vishwavidyalaya, Indore, MP, India

Vandana Mehndiratta Christ University, Bengaluru, India

Suman Mishra CMR Engineering College, Hyderabad, Telangana, India

Medhavi Pandey Galgotias College of Engineering and Technology, Greater Noida, India

U. Penchalaiah Geetanjali Institute of Science and Technology, Nellore, Andhra Pradesh, India

Ganga Rama Koteswara Rao Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur, Andhra Pradesh, India

P. Santosh Kumar Patra St. Martins Engineering College, Kompally, Hyderabad, Telangana, India

K. Satyanarayana Raju SRKR Engineering College, Bhimavaram, Andhra Pradesh, India

Dolly Sharma ABES Institute of Technology, Ghaziabad, UP, India

S. C. Sharma Wireless Networks and Cloud Computing Lab, IIT Roorkee, Roorkee, India;
DPT, Indian Institute of Engineering and Technology, Roorkee, Uttarakhand, India

Simran Delhi Technical Campus, Greater Noida, India

N. Soumya St. Martins Engineering College, Kompally, Hyderabad, Telangana, India

Yash Thakur Christ University, Bengaluru, India

Kitty Tripathi Babu Banarasi Das Northern India Institute of Technology, Lucknow, UP, India

Swati Tyagi Dronacharya Group of Institutions, Greater Noida, India

G. Udaya Sree St. Martins Engineering College, Kompally, Hyderabad, Telangana, India

Ajit Kumar Verma Faculty of Engineering and Natural Sciences, Western Norway University of Applied Sciences, Haugesund, Norway

Hemant Yadav Department of CSE, Future Institute of Engineering and Technology, Bareilly, Uttar Pradesh, India

Neelam Yadav ABES Engineering College, Ghaziabad, UP, India

Pooja Yadav Deptt. of CSIT, FET, MJP Rohilkhand University, Bareilly, Uttar Pradesh, India

Chapter 1
AI-Driven Cognitive Radio Networks for Transforming Industries and Sectors Towards a Smart World

Nandkishor Joshi, Nitin Arora, Hemant Yadav, and S. C. Sharma

Abstract In wireless communication technology, the incorporation of Artificial Intelligence (AI) into Cognitive Radio Networks (CRNs) has become a possible paradigm change. To address spectrum scarcity and inefficiencies in wireless communication networks, the CRN can make judgments for dynamic time–frequency-space resource allocation and adapt dynamically to the radio environment. However, CRNs still face significant challenges with dynamic and real-time scenarios. Because of this, cognitive radio (CR) is usually combined with machine learning and artificial intelligence methods for efficient real-time processing. Furthermore, CRNs have entered a new phase because of the development of AI technologies, which have allowed them to progress from passive spectrum sensing to proactive, intelligent, and self-optimizing systems. However, dynamic and real-time scenarios continue to be significant hurdles in cognitive radio networks. Therefore, Cognitive radio is typically integrated with artificial intelligence and machine learning techniques for effective real-time processing. Additionally, the advent of AI technologies has ushered in a new era for CRNs, enabling them to evolve from passive spectrum sensing to proactive, intelligent, and self-optimizing systems. The revolutionary potential of AI-driven CRNs in guiding sectors and industries towards the realization of a fully smart world is examined in this chapter. AI-driven CRNs provide efficient resource allocation, safe communication, and real-time data analytics. As a result, it boosts sustainability, productivity, and safety in a variety of sectors, including manufacturing, transportation, healthcare, and agriculture. To optimize spectrum utilization and network performance, it explains how machine learning algorithms, such as deep learning, reinforcement learning, neural networks, fuzzy logic, and various AI-based optimization methodologies—empower CRNs to sense, learn, and adapt to dynamic

N. Joshi (✉)
Department of CSE, PIET, Parul University, Vadodara, India
e-mail: njoshi@pp.iitr.ac.in

N. Arora · S. C. Sharma
Wireless Networks and Cloud Computing Lab, IIT Roorkee, Roorkee, India

H. Yadav
Department of CSE, Future Institute of Engineering and Technology, Bareilly, India

R. Arya et al. (eds.), *Recent Trends in Artificial Intelligence Towards a Smart World*, Frontiers of Artificial Intelligence, Ethics and Multidisciplinary Applications,
https://doi.org/10.1007/978-981-97-6790-8_1

spectrum conditions on their own. The current chapter delves into the obstacles that AI-driven cognitive radio networks face, outlining future research directions and highlighting persistent issues.

Keywords Cognitive Radio Networks (CRNs) · Artificial Intelligence (AI) · Spectrum utilization · Spectrum sensing · Machine learning

1.1 Introduction

Cognitive Radio Networks (CRNs) transform wireless communication by providing devices with cognitive, adaptive capabilities that challenge the traditional fixed spectrum assignment approach. Dynamic spectrum access is made possible by these networks, which let devices detect underutilized frequency bands on their own and take advantage of them in real-time without interfering with licensed users. The cognitive cycle, which consists of reconfiguration, intelligent decision-making, and spectrum sensing, is the central component of the CRN. During this cycle, cognitive radios adjust to variations in the radio frequency (RF) environment to guarantee better quality of service and effective spectrum utilization. In order to solve spectrum scarcity, reduce interference, and improve overall network performance, CRNs are essential. These networks optimize channel allocation, boost network capacity, and enable 5G and 6G technologies by dynamically managing spectrum resources. The ability to adapt and be flexible is one of CRNs' key contributions to the development of more dependable, strong, and effective wireless communication systems, which in turn opens the door to a more intelligent and connected world across numerous industries.

1.2 Integration of AI in CRNs

The integration of Artificial Intelligence (AI) in Cognitive Radio Networks (CRNs) marks a transformative leap in wireless communication technologies. AI augments the inherent capabilities of CRNs by providing advanced decision-making and learning mechanisms. Machine Learning (ML) algorithms play a crucial role in spectrum sensing, enabling cognitive radios to adapt dynamically to the ever-changing RF environment. Reinforcement Learning (RL) facilitates intelligent spectrum management, allowing devices to optimize their communication strategies based on real-time feedback. Deep Learning (DL) techniques, with their prowess in pattern recognition and signal processing, enhance the accuracy of spectrum sensing and decision-making processes. The synergy between AI and CRNs empowers networks to learn from past experiences, predict future spectrum conditions, and autonomously optimize their configurations, leading to more efficient spectrum utilization and improved overall network performance. This integration holds the potential to revolutionize how wireless communication systems operate, fostering adaptability and intelligence in the face of evolving technological landscapes. The fuzzy type-2-based cooperative spectrum sensing was introduced by Rasheed et al. (2018) for cognitive radio networks and later adopted to full duplex cognitive radio networks (Joshi and Sharma 2023). In order to ensure the QoS requirements of CR users, maximize the utilization of spectrum resources, and optimize base station (BSs) resource control strategy, Dan Wang et al. proposed the hierarchical distributed networking framework, which applies AI technologies to both channels resource allocation and base station (BSs) resources control of the 5G cellular networks (Wang et al. 2019).

In Abbas et al. (2015) and Morabit et al. (2019), the authors investigated a number of different learning approaches, such as artificial bee colony (ABC) algorithm, fuzzy logic (FL), game theory (GT), neural networks (NNs), reinforcement learning (RL), support vector machines (SVM), case-based reasoning (CBR), decision trees (DT), entropy, Bayesian approaches, Markov models (MM), multi-agent systems (MAS), and genetic algorithms (GAs).

In Morabit et al. (2019) and He et al. (2010), the authors of the study performed an in-depth analysis of state-of-the-art artificial intelligence (AI) applications in Cognitive Radio (CR). The objective was to determine workable alternatives for CR implementation and evaluate the benefits of different approaches in different scenarios. The methods covered in the review include rule-based systems (RBSs), ontology-based systems (OBSs), hidden Markov models (HMMs), artificial neural networks (ANNs), and case-based systems (CBSs). This extensive analysis provides valuable insights into the current landscape of AI applications in CR and underscores the unique strengths of each methodology for specific use cases.

In Bkassiny et al. (2013), an in-depth survey was conducted, presenting a comprehensive overview of various learning techniques, including RL, GT, NNs, SVM, and MM. The survey not only introduced these methodologies but also delved into a thorough exploration of their individual strengths, weaknesses, and the associated challenges. This meticulous examination provides a nuanced understanding of the practical implications and limitations of each learning technique, contributing to a more informed perspective on their applications in diverse contexts.

In Gavrilovska et al. (2013), the authors delved into an extensive exploration, scrutinizing game theory (GT), reinforcement learning (RL), and various reasoning approaches, including Bayesian networks (BNs), fuzzy logic (FL), and case-based reasoning (CBR). This thorough investigation illuminated the applications and interactions among these methodologies, offering a nuanced understanding of their roles and contributions within the context studied.

In Bello Salau et al. (2015), an inclusive survey unfolded, showcasing AI techniques, including genetic algorithms (GA), artificial neural networks (ANN), hidden Markov models (HMMs), and metaheuristic algorithms (MEAs). The exploration delved into a meticulous evaluation of their strengths and weaknesses, along with a thorough examination of open research issues pertinent to these techniques. This comprehensive scrutiny enhances our comprehension of the intricacies, potential, and areas for further investigation within the realm of AI methodologies.

1.3 The Potential for AI-Driven CRNs to Revolutionize a Variety of Industries

Artificial Intelligence-driven CRNs have the potential to revolutionize a wide range of sectors and usher in a new era of intelligent and flexible wireless communication. AI-driven CRNs in the healthcare industry optimize spectrum allocation for smooth medical device connection while enabling remote patient monitoring and telemedicine. The integration of CRNs improves operational efficiency in industries such as manufacturing, which can construct smart factories and use the Industrial Internet of Things (IIoT) for real-time control and monitoring. In transportation, CRNs help to create intelligent transportation systems and connected automobiles, with AI optimizing spectrum consumption for vehicle communication. To ensure adequate energy distribution, the energy sector uses AI-driven CRNs to facilitate communication and control of the smart grid. Precision farming and smart agriculture, made possible by CRNs and AI-driven sensor networks, are revolutionizing the agricultural industry. The combined influence of these sectors demonstrates the adaptability of AI-driven CRNs, which hold the promise of improved productivity, dependability, and connection and, in the end, open the door to the realization of a world that is smarter and more connected.

1.4 Cognitive Radio Networks and Artificial Intelligence

In this section, fundamental ideas of CRNs and artificial intelligence are elaborated. The incorporation of cognitive capabilities into wireless communication systems has emerged as a significant advancement in response to the constraints of traditional networks. CRNs provide a paradigm shift in dynamic and heterogeneous environments where spectrum conditions change due to different user demands and interference. The need for cognitive ability arises from the need to understand, evaluate, and adjust to the constantly changing radio frequency (RF) environment. CRNs' primary functions include sharing, adapting, and perceiving the spectrum. Real-time identification of available frequency bands through constant observation of the radio frequency environment is known as spectrum sensing. This enables CRNs to optimize spectrum utilization and prevent interference with primary users by dynamically allocating resources based on the situation. By enabling harmonious coexistence of numerous devices within the same frequency band, spectrum sharing encourages the effective use and distribution of spectrum resources. According to real-time observations, CRN adaptation entails modifying gearbox parameters, such as power levels and modulation techniques, to maximize performance. In order to overcome the drawbacks of conventional wireless communication networks and open the door for more effective and intelligent wireless communication systems, these cognitive skills work together to allow CRNs to negotiate the complexity of dynamic and heterogeneous surroundings. Due to the intelligent and dynamic behavior of CRNs, the AI methodologies are more appropriate to improve the performance of CRNs. The main fundamental concepts of CRNs and possible AI methodologies are elaborated in the following subsections.

1.4.1 Cognitive Radio Networks: An Overview

Cognitive Radio Networks (CRNs) owe their existence to the concept of Dynamic Spectrum Access.

Dynamic Spectrum Access (DSA)

Dynamic Spectrum Access (DSA) refers to a technique that enables wireless devices to access and use radio frequency spectrum dynamically, adapting to varying environmental and usage conditions (Akyildiz et al. 2006). It's a concept primarily associated with CRNs and Software-Defined Radio (SDR) technologies. DSA aims to address the issue of spectrum scarcity and underutilization by allowing unlicensed or secondary users to access and share the licensed frequency bands without causing interference to the primary (licensed) users.

In a simple way, the cognitive cycle of cognitive radio is described by Shah et al. (2012) as the seat cycle, which is an extension of the cognitive cycle. The cognitive radio SEAT cycle is shown in Fig. 1.1. "CR nodes are smart wireless equipment that can sense the environment around them, keep monitoring on network dynamics, and learn from previous encounters to make decisions that will allow them to take advantage of transmission opportunities. Constantly scanning the spectrum (S), exchanging control information (E), deciding on white space (A), and sending data (T) over the network are all part of this iterative process. This pattern, which is repeated to maximize communication efficiency, is known as the SEAT cycle" (Shah et al. 2012, 2013).

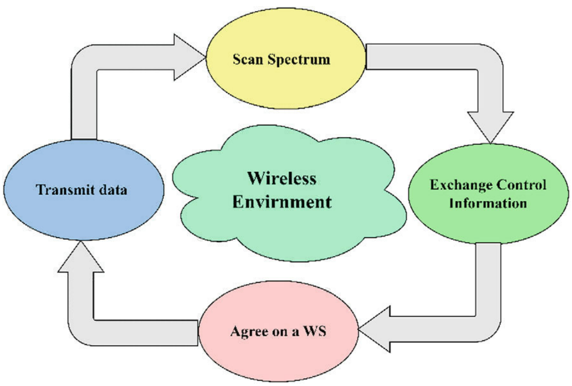

Fig. 1.1 Cognitive radio SEAT cycle. *Source* Author

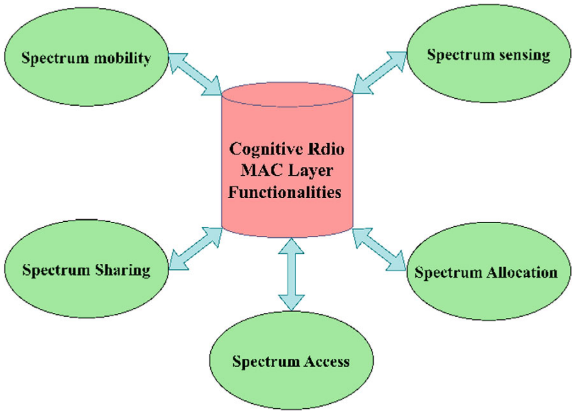

Fig. 1.2 Components of the cognitive radio network. *Source* Author

Components of Cognitive Radio Networks

The cognitive radio networks handle tasks such as channel sensing, spectrum sharing, resource allocation, and spectrum mobility (Sultana et al. 2017; Riahi Manesh and Kaabouch 2018). They are also called the primary components of the CR-MAC Protocols. Additionally, the functionality of the components is depicted in Fig. 1.2. The description of these components is described in Table 1.1.

Integration of Spectrum Sensing in Cognitive Radio Networks

Spectrum sensing is a fundamental requirement in CRNs, enabling cognitive radios to detect primary user (PUs) activities and identify vacant spectrum bands. Although spectrum sensing is part of the physical layer, spectrum sensing technologies also improve the performance of IEEE 802.11 DCF and guarantee that cognitive radios can access the spectrum when needed without negatively impacting primary users. When 802.11 DCF is used in cognitive radio networks, it can benefit from cognitive radio functionalities (components), which are described in the previous section.

There are two categories of sensing operations in cognitive radio, between which it is important to understand the difference: one is spectrum sensing, which is employed for identification of the primary user's operations in cognitive radio scenarios, and the other is carrier sensing, which is an integral part of the CSMA/CA protocol. The former must be done at very low detection SNR, which takes a lot of time and increases the likelihood of false alarms and misdetection (IEEE802.22-05/0007r46 2006). On the other hand, the later type of sensing, which is to detect an 802.11 peer transmission, is typically done at a significantly greater signal strength and is thus frequently believed to be flawless (negligible false alarms and misdetections (Bianchi 2000).

A number of sensing approaches, such as energy detection, matched filtering detection, cyclo stationary detection, and so on, are explained in detail for cognitive radio networks (Yücek and Arslan 2009; Sani et al. 2021). Although spectrum sensing is part of the physical layer, spectrum sensing technologies also improve the

Table 1.1 CR components description and functionality

CR components	Description	Functionality
Spectrum sensing	Spectrum sensing is the process of continuously monitoring the radio frequency spectrum to detect the presence of primary users (licensed users) and identify available frequency bands.	Cognitive radios use various sensing techniques (e.g., energy detection, matched filtering, cyclostationary feature detection) to detect signals from primary users and determine spectrum availability.
Spectrum access	Spectrum access involves the ability of cognitive radios to access and utilize available spectrum resources efficiently.	Cognitive radios employ policies and protocols to negotiate and request access to vacant or underutilized frequency bands, enabling secondary (unlicensed) usage without causing harmful interference to primary users.
Spectrum allocation	Spectrum allocation refers to the dynamic assignment of specific frequency bands or channels to cognitive radios for communication.	Cognitive radios can dynamically allocate spectrum resources to optimize bandwidth usage, often through negotiation or reservation mechanisms, such as time division multiple access (TDMA) or frequency division multiple access (FDMA).
Spectrum sharing	Spectrum sharing is the cooperative and non-interfering use of the same frequency band by multiple cognitive radio devices.	Cognitive radios employ sharing protocols and techniques to coexist with other cognitive radios and primary users, adjusting their transmit power, modulation schemes, or access timings to avoid interference.
Spectrum mobility	Spectrum mobility refers to the ability of cognitive radios to switch between different frequency bands or channels as needed.	Cognitive radios can perform rapid channel hopping or frequency band switching to maintain connectivity and optimize communication quality, especially in the presence of interference or changing network conditions.

Source Author

performance of IEEE 802.11 DCF and guarantee that cognitive radios can access the spectrum when needed without negatively impacting primary users.

Joshi et al. (2023) and Dappuri and Venkatesh (2018) have reported distinct sensing strategies for CRNs. Since, continuous sensing, a feature inherent in the 802.11 DCF protocol, leads to energy inefficiencies. To tackle this issue, the sensing strategy involves two specific sensing approaches: periodic sensing for detecting the ON state of the primary user, ensuring intermittent checks for their activity, and continuous sensing to monitor the OFF state, enabling a constant vigil for vacant spectrum periods. This combined approach aims to optimize energy usage while effectively identifying primary user activities within the network.

Joshi and Sharma (2023) have reported another sensing approach for FD-CRN since cooperative spectrum sensing is employed to optimize spectrum utilization and mitigate interference from licensed users. However, the multipath fading and shadowing problems are often mitigated by the detection function. Cooperative spectrum sensing uses spatial variety to improve detection, but it comes with overhead that affects overall performance in the form of delays, energy consumption, and longer operating times. The author proposed a type-2 fuzzy algorithm as a solution to address these issues, with the goal of improving cooperative sensing. It describes a type-2 fuzzy logic approach for spectrum-based energy detection that enhances cooperative sensing.

Consequently, sensing plays a critical role in cognitive radio. Its contribution to the creation of protocols that directly affect and decide the system's overall performance accounts for its significance.

1.4.2 Artificial Intelligence: An Overview

Artificial Intelligence (AI) is a field dedicated to creating computer systems capable of emulating human intelligence, encompassing tasks such as learning, reasoning, problem-solving, perception, language understanding, and decision-making. Machine Learning (ML), a subset of AI, focuses on developing algorithms that enable computers to learn and improve performance from data. Deep Learning, inspired by the human brain's structure, employs artificial neural networks, and has excelled in tasks like image recognition and natural language processing. Natural language processing (NLP) enables machines to interact with humans using language, while computer vision enables machines to interpret visual data. Robotics integrates AI for decision-making in physical tasks, and expert systems mimic human decision-making in specific domains. Reinforcement Learning involves agents learning by interacting with environments and receiving feedback. Ethical considerations, transparency, and addressing biases in AI algorithms are crucial. AI finds applications in healthcare, finance, transportation, and various industries. Ongoing trends include improving model interpretability, exploring quantum computing, and integrating AI with emerging technologies. Despite advancements, addressing challenges and ensuring ethical AI development remains a priority.

Artificial Intelligence (AI) is the engine that drives systems that replicate complex biological processes found in humans, such as self-adaptation, self-stability, self-organization, learning, and reasoning. In exploiting previous knowledge, allows intelligent machine to learn from its environment. Nevertheless, developing software that can adjust to various circumstances and adapt to deal with new limitations is a big task. The ability to learn and alter wireless signals based on the external radio environment is particularly important in the field of cognitive radios. Therefore, incorporating AI into the core of cognitive radio technology becomes crucial. Cognitive radio networks (CRNs) employ various AI techniques, including Artificial Neural Networks (ANNs), Markov Models (MMs), Federated Learning (FL), Game Theory (GT), Support Vector Machines (SVM), Multi-objective Evolutionary Algorithms (MEAs), Rule-Based Systems (RBSs), Ontology-Based Systems

(OBSs), Case-Based Systems (CBSs), Multi-Agent Systems (MASs), and evolutionary algorithms such as Genetic Algorithms (GA), Differential Evolution (DE), Particle Swarm Optimization (PSO), Bacterial Foraging Optimization (BFO), Ant Colony Optimization (ACO), Cuckoo Search Optimization (CSO), Artificial Bee Colony (ABC), and Artificial Immune Systems (AIS) (Morabit et al. 2019). The utilization of these diverse AI techniques in CRNs reflects the intricate nature of adapting and optimizing wireless communication strategies in dynamic and evolving environments.

1.5 Artificial Intelligence in Cognitive Radio Networks

In this section, we provide an overview of several AI techniques implemented in Cognitive Radio Networks (CRNs) (Morabit et al. 2019).

1.5.1 Artificial Intelligence Methodologies to Cognitive Radios Networks

1. **Artificial Neural Networks**
   Artificial Neural Networks (ANNs) are intricate networks of interconnected simple processors that do concurrent distributed processing. Each basic processor, sometimes referred to as an artificial neuron, is defined by its inputs (xi for $i = 0$ to n, weights), outputs $s = f(a)$, internal state of activation $a = F(x, w)$, transition function $f(a)$, and activation function $F(x, w)$. Every one of these artificial neurons computes an output based on the information it has received. Artificial Neural Networks (ANNs) are designed with inspiration from the behavioral principles present in the biological brain. The CRNs use three types of Artificial Neural Networks (ANNs): radial basis function networks (RBFN), and multilayer perceptron networks in both linear (MLPN) and nonlinear (MNPN) versions. Here, both MLPN and MNPN are made up of linked layers of computing units. While MNPN uses sigmoid activation functions, MLPN uses linear combinations of outputs from earlier layers. A unique family of multilayer feed-forward networks known as RBFN consists of two layers, with units in the hidden layer that use Gaussian kernels or other radial basis functions as activation functions. The centers of these functions are determined by the corresponding weight vectors (Jain et al. 1996).
2. **Markov Chains**
   In stochastic situations, Markov Models provide a mathematical foundation that extends beyond short-path techniques. These models include fundamental components such as states, which depict the agent's current state, actions that affect the dynamics of the state, and incentives related to changes in the state.

They successfully represent the temporal connections among a series of variables ($S_0 \ldots S_t \ldots$). When every variable in the series depends only on the one before it, the system is called a Markov chain, and it may be represented using the conditional probability $P(S_t|S_0, \ldots, S_{t-1}) = P(S_t|S_{t-1})$. The perspective shown here is helpful in explaining the stochastic and dynamic features of sequential processes.

3. **Game Theory**

In the field of Cognitive Radio (CR), game theory is important because it offers a useful framework for comprehending and maximizing interactions between various entities in the wireless communication spectrum. Game theory aids in the modeling and analysis of strategic decision-making processes in the setting of CR, where several users and systems share scarce spectrum resources. Spectrum allocation game modeling is a popular use of game theory in cognitive radio. Several cognitive radio users or secondary users fight for access to the available frequency bands in a spectrum-sharing scenario. With the aid of game theory, it is possible to analyze the tactics these users use to maximize their usage of the spectrum while taking other users' needs into account. One important idea in game theory is the Nash equilibrium, which may be used to find stable places where no user has an incentive to unilaterally stray from their preferred course of action (Bkassiny et al. 2013).

Three variables are involved in the mathematical representation of a game: $G = (N, S, U)$. In this case, N stands for the group of players, S for the group of strategies, and U for the group of utility functions. There are various sorts of game theoretic techniques, each providing distinct insights into strategic interactions. Four main classifications are frequently acknowledged (Wang et al. 2010).

Cooperative Games: In cooperative games, players establish alliances and cooperate to accomplish shared objectives. The distribution of rewards among the participating players and teamwork are the main points of emphasis.

Noncooperative Games: Individual players make decisions on their own in noncooperative games without overt cooperation. Every player follows their own interests, and their separate strategic decisions dictate the results.

Auction Games: Noncooperative games that involve bidding for products, services, or resources are known as auction games. How the products are distributed and how much each participant must pay are decided by the auction regulations.

Stochastic Games: A degree of uncertainty enters the decision-making process in stochastic games. Moreover, a stochastic game extends the Markov decision process by assessing the interactive rivalry between different actors (Wang et al. 2010). The modeling of strategic interactions becomes more dynamic because the outcomes are dependent not only on the actions of the players but also on random variables.

4. **Fuzzy Logic**

A mathematical paradigm known as fuzzy logic addresses thinking and decision-making in the face of uncertainty. In contrast to traditional binary logic, which relies on true or false values, fuzzy logic considers degrees of truth and enables the representation of ambiguous or inaccurate data. It's ideal for systems where ambiguity and uncertainty are common since it models human-like reasoning using fuzzy sets and linguistic variables. Applications for fuzzy logic can be found in many domains, such as artificial intelligence, control systems, and decision support systems. The framework based on fuzzy logic is employed to regulate the power and MAC protocol parameters, including delay and throughput (Joshi et al. 2023; Joshi and Jharia 2014, 2015).

5. **Support Vector Machine**
   One potent machine learning approach for regression and classification is the Support Vector Machine (SVM) (Qadir 2015). In the input data space, it finds the ideal hyperplane to divide several classes. Support vectors are essential data points that specify the location and direction of the hyperplane. The algorithm uses these data points to optimize the margin between classes. SVM is frequently used for applications like pattern recognition, text categorization, and image classification because it performs especially well in high-dimensional domains.
6. **Rule-Based Systems**
   Rule-Based Systems are a subset of artificial intelligence that carry out tasks or make choices based on a predetermined set of rules. These systems have a logical structure with rules that govern the behavior of the system, usually expressed as "if-then" statements. The rules are implemented in a sequential manner by the system to accomplish a particular task or arrive at a conclusion. Each rule is composed of conditions and matching actions.
   Expert systems, knowledge-based systems, and commercial applications are just a few of the fields in which these systems are frequently utilized for decision assistance and problem-solving. Rule-Based Systems perform well in situations where rules may express explicit information and offer an understandable and transparent framework for making decisions. They work especially well on activities involving rule-driven processes and logical thinking.
7. **Ontology-Based Systems**
   An artificial intelligence system class known as Ontology-Based Systems uses ontologies to organize and describe knowledge. A formal, clear specification of a common conceptualization that establishes the terminology and connections inside a specific area is called an ontology. This organized knowledge representation makes reasoning, decision-making, and data management in ontology-based systems more efficient. These systems provide a semantic foundation for information processing and interpretation by modeling the concepts, entities, and their interactions in a specific domain using ontologies. Systems based on ontologies are widely utilized in domains like semantic web applications, natural language processing, knowledge representation, and information retrieval. They encourage more intelligent and context-aware system behavior by enabling machines to read and reason about data in a way that is consistent with human comprehension. Ontology is used in Ontology-Based Systems (OBS) to facilitate reasoning about the characteristics related to the domain of interest (He et al. 2010). An ontology consists of the following key components:

Classes: Classes stand for groups or kinds of entities within a domain, the diverse ideas or things found in the ontology are defined by them.

Individuals: Individuals are members or occurrences of a class; they are also referred to as instances. They are the real things that exist in the realm.

Properties: Properties explain the connections between classes or between a person and a piece of data. Data properties link persons to data values, while object properties link classes and individuals. These are the two primary categories of attributes.

Attributes: Features or qualities that are connected to groups are called attributes. They offer more details regarding the ontology's entities.

Relations: Relationships define the connections between classes. In the ontology, they specify the connections and relationships between various items.

Axioms: Axioms are propositions that articulate limitations, guidelines, or rational connections within the ontology. They specify the rules and semantics that control the things and how they interact.

Hierarchy: A hierarchical structure known as a taxonomy or sub Sumption hierarchy is frequently seen in ontologies, which arrange classes into them. The specialization and generalization relationships between classes are shown in this hierarchy.

8. **Case-Based Systems**

Artificial intelligence systems that use cases previous experiences to address new challenges are known as case-based systems (Gavrilovska et al. 2013). These systems work by pulling solutions from a database of instances that have already been resolved and modifying them to fit the needs of the present situation. Key components of Case-Based Systems are elaborated as follows (Gavrilovska et al. 2013):

Case Base: This is a collection of previously resolved instances kept in one location. Each case includes a description of the problem, the solution used, and the result.

Retrieval Mechanism: Based on how closely the current issue and previous cases resemble one another, the system uses a retrieval technique to find pertinent cases from the case base.

Reuse Mechanism: The system uses cases that are relevant to its current problem-solving strategy and modifies or reuses its solutions. The process of adaptation is the adjustment of the retrieved answer to the unique circumstances of the novel challenge.

Revision Mechanism: The system may go through a revision process after using the recovered solution to assess the solution's effectiveness and update the case base appropriately. In the long run, this helps the system learn and get better.

Case-based systems provide a valuable method for handling dynamic and complicated scenarios in spectrum management in CRNs. In real wireless communication contexts, these systems make decisions based on past experiences and solutions. In cognitive radio, essential features of case-based systems are as follows:

Problem Representation: First, it is necessary to define the problem with respect to the CRNs. The system contains cases, which are past examples of spectrum management problems, along with a description of the problem, an applied solution, and the results.

Adaptation to Dynamic Environments: The available spectrum and network conditions dynamically alter in cognitive radio scenarios. Case-based systems can adjust to these modifications by retrieving and modifying case-based solutions.

Spectrum Allocation: Case-based systems can help optimize spectrum allocation by bringing efficient strategies from previous cases that are comparable to the available spectrum and consumption trends now.

Interference Mitigation: In order to address interference problems, Case-Based Systems are able to obtain and modify solutions from earlier cases that effectively reduce comparable interference scenarios.

Learning and Evolution: Case-based systems in cognitive radio can continuously evolve by modifying the case based on the success or failure of implemented solutions. This contributes to the system's ability to adapt to changing network dynamics.

9. **Genetic Algorithms**

In Cognitive Radio, Genetic Algorithms (GAs) are used as optimization methods to tackle intricate and dynamic spectrum management problems. This is the application of genetic algorithms in CRNs. The genetic algorithm is a vital optimization algorithm for spectrum management in CRNs, which provides the ability to find efficient and dynamic solutions to the challenges posed by changing network conditions and spectrum availability. The mechanism for this is as follows:

Representation of Solutions: Genetic Algorithms represent potential solutions to spectrum allocation and optimization problems using encoded structures. It often occurs in the form of binary strings or other data structures. These structures represent candidate solutions that are analogous to possible frequency assignments.

Initialization: To illustrate various spectrum allocation schemes, a population of probable solutions is initialized. The efficiency of spectrum utilization, interference levels, and overall network performance are some of the factors used to evaluate each solution.

Genetic Operators: Genetic algorithms make use of critical genetic operators to evolve the population over multiple generations. Among these operators are crossover (recombination), mutation, and selection. Crossover integrates information from two parent solutions to make new offspring, selection chooses solutions for reproduction based on fitness, and mutation adds random alterations to maintain diversity.

Fitness Evaluation: The fitness of each solution is assessed based on how well it addresses the specified objectives and constraints in spectrum allocation. It also considers factors such as interference reduction, improved throughput, and efficient utilization of available frequencies.

Iterative Evolution: To do this, genetic operators are used repeatedly over a number of generations, progressively enhancing the population's solutions. By simulating natural selection and evolution, this approach produces more optimal solutions.

Final Solution Selection: The final solution, or a set of solutions, is selected from the evolving population based on the convergence of the algorithm and achievement of the desired optimization goals.

10. **Differential Evolution**

In cognitive radio (CR) networks, differential evolution (DE) is an optimization technique that has been used to address issues with resource allocation and spectrum management. A flexible and effective method for resolving dynamic spectrum allocation issues is provided by differential evolution in CRNs. It works particularly well in situations with complicated optimization circumstances. They considered that it could be challenging for conventional optimization techniques to produce acceptable results. When network conditions change, DE can be used to optimize spectrum use by exploring a variety of solution spaces. Differential evolution is used in the following ways in CRNs:

Initialization: DE starts by initializing a population of candidate solutions, each of which stands for a possible method of allocating spectrum. Usually, vectors are used to encode these solutions.

Mutation: DE introduces variety by performing mutation procedures. This mutation in cognitive radio entails influencing solution vectors and generating new trial solutions. The algorithm can consider a wider range of alternatives because the mutation process traverses the solution space.

Crossover: DE uses crossover procedures to merge data from many solutions. This entails mixing the trial solutions with the existing population to promote knowledge sharing and maybe result in better solutions.

Selection: The fitness of each experimental solution is assessed using certain criteria such as spectrum efficiency, interference levels, and overall network performance. To keep solutions that enhance the optimization goals, DE uses a selection procedure.

Iterative Evolution: Over several generations, the mutation, crossover, and selection processes are applied iteratively. The population's solutions are improved through this iterative process, leading to more optimal plans for spectrum distribution.

Final Solution: The final solution is chosen according to convergence criteria or a specified number of iterations. In the cognitive radio network, these solutions stand for efficient spectrum management techniques.

11. **Particle Swarm Optimization**

To solve the problems of spectrum allocation and optimization in Cognitive Radio (CR) networks, Particle Swarm Optimization (PSO) is a meta-heuristic optimization technique. One collaborative and decentralized method of managing spectrum in CRNs is Particle Swarm optimization (Kennedy and Eberhart 1995). Swarm intelligence ideas are utilized by PSO to find effective