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AI-Driven Unified Channel Management in Cognitive Radio IoT Networks: Integration of OFDM, SDN, MRC, RIS, and Cloud Computing

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Abstract

Cognitive Radio Internet of Things (CR-IoT) networks are becoming more complicated, leading for reliable spectrum management solutions. By combining OFDM, SDN, MRC, and RIS, an AI-driven unified channel management framework successfully meets these needs. This framework optimizes energy consumption, spectrum efficiency, and dependability while facilitating smooth real-time adaptability to changing wireless network conditions. By utilizing OFDM for spectral efficiency and adaptive subcarrier allocation, SDN for centralized network control, MRC for signal reliability through multi-signal combination, and RIS for optimized signal propagation through phase shifts, AI enables dynamic spectrum management. Meanwhile, cloud computing handles massive data processing for in-the-moment decision-making. Developed to improve spectrum management, network scalability, signal reliability, and energy efficiency, the suggested AI-based model outperforms traditional methods like SAP, FBMC, IBN, and DAS in anomaly detection and efficiency, attaining a 92% anomaly

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detection rate, with 94% accuracy, 93% scalability, and a 95% F1 score. By combining these technologies, the framework improves wireless network performance and tackles important problems like energy efficiency and spectrum scarcity in extensive IoT installations.

Keywords: AI, OFDM, SDN, MRC, RIS, CRIoT.

1. Introduction

The advancement of wireless communication technologies has reached unprecedented levels, requiring the inclusion of sophisticated mechanisms to manage resources and enhance connectivity efficiently. [1]. Cognitive Radio Internet of Things (CR-IoT) networks are a technological advancement that allows devices to automatically adapt to changing conditions, spectrum availability, and user demands. AI-driven unified channel management has emerged as an important approach for seamless functionality and scalability in such networks [2]. The present work integrates several technologies, such as Orthogonal Frequency Division Multiplexing (OFDM), Software-Defined Networking (SDN), Maximum Ratio Combining (MRC), Reconfigurable Intelligent Surfaces (RIS), and Cloud Computing, to channelize an optimization of resources in the CR-IoT environments.

Unified channel management is the handling of communication channels in a comprehensive manner to ensure optimal and efficient use of resources within a network, interference mitigation, and an assured quality of service (QoS). Cognitive radio adds intelligence to this process that allows for dynamic spectrum access where devices adaptively and dynamically select frequencies based upon real-time spectrum analysis. When applied to IoT, this capability addresses the constantly growing demand for seamless efficiency and reliability in connectivity in billions of devices.

Such advanced features are further enhanced by adding the capabilities of AI, as it enables predictive analytics and automated decision-making with the flexibility to make real-time adaptations. A system based on AI processes large amounts of data across a CR-IoT network identifies patterns, and dynamically optimizes channel use. This integration of OFDM for efficient spectrum use, SDN for centralized network management, and MRC for signal enhancement [3]. RIS for channel reconfiguration, and cloud computing for scalable processing power comprises a robust framework for modern wireless communication.

The exponential growth of IoT devices poses serious challenges to existing wireless communication infrastructures. Spectrum management techniques, such as traditional ones, cannot cater to the demands of high traffic, low latency, and efficient energy consumption. The emergence of Cognitive Radio technology for solving spectrum scarcity has facilitated dynamic spectrum access by allowing secondary users to access underutilized frequency bands without causing interference to primary users. However, the increasing complexity of IoT networks calls for more sophisticated solutions.

All these complexities are being addressed by the integration of OFDM, SDN, MRC, RIS, and cloud computing. OFDM is a well-adopted multicarrier modulation technique that offers improved spectral efficiency and minimizes interference [4]. SDN brings centralized network control, so it allows real-time adaptation in varying network conditions. MRC enhances the quality of signals by combining multiple received signals. RIS is an emerging technology that enables intelligent reconfiguration of the wireless environment to improve signal propagation. Finally, cloud computing has the computational power to run large-scale data processing algorithms and execute AI-driven computations.

The following objectives are:

- Create an AI-powered framework for optimal spectrum and channel management.
- Integrate OFDM to achieve reliable and high-capacity data transfer.
- SDN allows for more flexible and programmable network administration.
- Apply MRC to improve signal dependability and quality.
- Implement RIS to improve network coverage and energy efficiency.
- Cloud computing can help with scalability and real-time decision-making in CR-IoT.

The research highlights the analysis of traffic for C-RAN but overlooks the impact of variability in network conditions, user behavior, and traffic spikes on the accuracy of AI-driven prediction. Being effective in reducing congestion and optimizing bandwidth, further research is needed to evaluate scalability, robustness, and adaptability in complex and diverse network environments. An AI-driven solution is required for real-time adaptability in Cognitive Radio

IoT (CR-IoT) networks, which encounter difficulties with spectrum management, dependability, and energy efficiency. By joining OFDM, SDN, MRC, and RIS, spectral efficiency is increased, centralized control is ensured, signal dependability is reinforced, and signal propagation is optimized. Dynamic spectrum access is made possible by OFDM, network reconfiguration is made easier by SDN, signal-to-noise ratio is improved by MRC, and coverage is improved while using less energy by RIS. Large-scale IoT deployments are supported by this cohesive strategy, which also optimizes spectrum consumption and guarantees smooth network adaptability.

To classify the heterogeneous traffic, the bandwidth and execution time are utilized to reduce congestion in a Cloud Radio Access Network [5]. The model aims to improve resource allocation so that it optimizes the bandwidth and reduces job execution latency, which is found to have a 17.07% improvement in bandwidth utilization and 18% reduction in job execution latency.

2. Literature Survey

The study discuss the incorporation of cognitive radio in LPWANs for IoT applications, such as smart cities and industries. The research reviews LPWAN technologies, discusses the potential of CR to mitigate issues like interference and low data rates, and presents benefits, research gaps, and future directions for CR-LPWAN systems [6].

The study emphasize the underlay spectrum access in cognitive radio systems as a way to allow primary and cognitive users to share spectrum in a manner that reduces interference. They discuss power allocation methods such as game theory and convex optimization, analyse performance for various levels of channel information, and examine challenges in CR power management [7].

IoT spectrum scarcity by integrating CRNs with a direct strategy selection mechanism to promote cooperation between SUs and a fair spectrum allocation scheme is discussed. This method enhanced cooperation, fairness, and satisfaction by gaining 22% in terms of satisfaction under challenging network conditions [8].

The OFDM with All Index Modulation (OFDM-AIM), which substitutes the modulator of the PSK/QAM system with the subblock modulator that simplifies its structure to achieve a diversity order more than the standard index-modulated OFDM techniques is proposed. It gives a novel approach to designing sub-blocks of better BER comparison with respect to the traditionally index-modulated OFDM schemes [9].

Recently an OFDM-SPM was introduced as a new modulation technique for future 6G networks to meet the needs of high spectral efficiency, low latency, and reliability in applications such as XR and haptics. OFDM-SPM is expected to improve spectral efficiency, reduce complexity, decrease delay, and consume lower power compared to conventional techniques [10].

The application of ML in SDN to design smart, dynamic, and secure network topologies is presented in the research. They survey ML applications for SDN on resource management, traffic scheduling, and security while discussing algorithms and future directions to help researchers from cross-disciplinary areas of AI and networking is presented in this research [11].

SDN as a transformative technology that offers the possibility of programmable, flexible, and scalable networks by separating the control and data planes is presented in this research. In SDN, they have shown various advantages over traditional networking systems, applications, security issues, and future directions of work through controllers, OpenFlow architecture, and tools for both industry and research [12].

An OAM mode-group multiplexing scheme based on graded-index ring-core fibers (GIRCF) is proposed. They improved signal-to-noise ratio and suppressed the mode partition noise using receive-diversity as well as maximal ratio combining techniques. Successful efficient transmissions over 1-km GIRCF at a data rate of 100 Gb/s and over 18.4 km GIRCF at 40 Gb/s further confirm the approach [13].

A reconfigurable intelligent surface (RISs) as a low-cost, power-efficient technology for smart radio environments (SREs) is identified in the research. RISs use large arrays or metamaterials to optimize wireless communication. This research discusses the applications of RIS, presents a theoretical framework, reviews current research, and calls for the integration of communication and electromagnetism theories to advance RIS-based networks [14].

3. Methodology

This method of study involves AI-driven techniques integrated with Orthogonal Frequency Division Multiplexing (OFDM), Software-Defined Networking (SDN), Maximum Ratio Combining (MRC), Reconfigurable Intelligent Surfaces (RIS), and Cloud Computing to enable effective channel management in Cognitive Radio IoT (CR-IoT) environments. With the real-time adaptability of AI, spectral efficiency of OFDM, centralized control of SDN, signal enhancement by MRC, signal reconfiguration through RIS, and cloud scalability, this framework can deal with the challenges of dynamic spectrum access, reliability, and resource optimization in large-scale CR-IoT networks. In CR-IoT networks, OFDM provides adaptive spectrum allocation, reduces interference, and splits a channel into subcarriers to improve spectral efficiency. For centralized management and real-time network reconfiguration, SDN divides the control and data planes, improving routing and reducing energy consumption. In dynamic situations, MRC increases dependability by merging several signals according to their SNR. Adjustable phase shifts are used by RIS to maximize energy efficiency and signal propagation. When combined with AI, these technologies offer a cohesive framework that increases energy efficiency, boosts reliability, and handles spectrum shortages in extensive IoT deployments.

The 5G Multi-Carrier Modulation Dataset [//www.kaggle.com/datasets/bptilt/lte-waveforms] includes simulated radio signals that can be used to train machine learning models for modulation detection and spectrum sensing. The Vienna 5G Link Level Simulator generated 5G waveforms of OFDM, FBMC, WOLA, FOFDM, and UFMC modulated with QAM16 and QAM64, under various SNR levels and frequency-selective fading channels.

A multi-layer neural network that learns from historical wireless data of spectrum occupancy and interference is employed within the reinforcement learning process of the AI-driven system. The validation with real-time 5G traffic patterns will balance exploration-exploitation by using ε-greedy, optimize γ for long-term rewards, and adaptively adjust the learning rate.

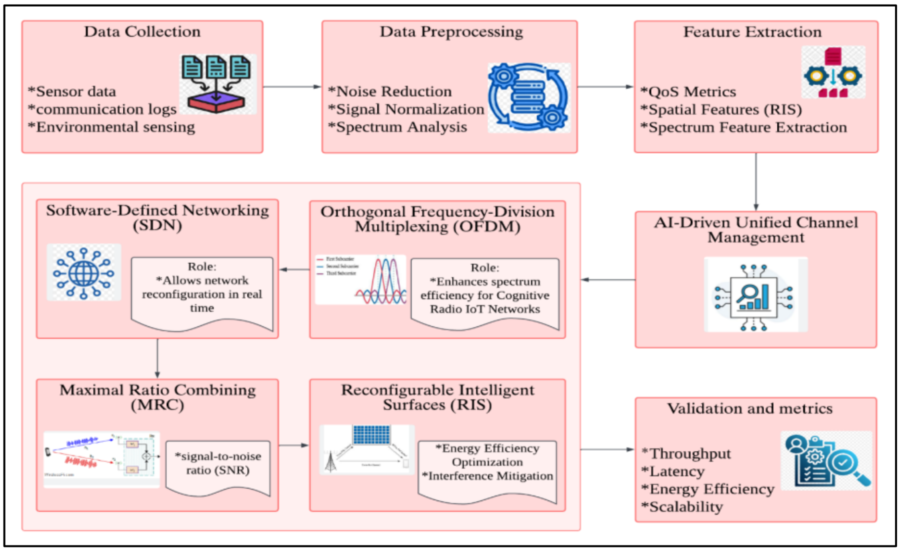

Figure 1. AI-Driven Unified Channel Management for Cognitive Radio IoT Networks Using SDN, OFDM, RIS, and MRC

Figure 1 illustrates the AI-driven channel management framework for Cognitive Radio IoT Networks. It begins with data acquisition (sensor and environmental data) followed by preprocessing (noise reduction, spectrum analysis), and feature extraction QoS metrics, RIS features). Core components such as SDN for network reconfiguration, OFDM for spectrum efficiency, MRC for SNR improvement, and RIS for energy optimization work together for optimal channel management. Performance is validated using throughput, latency, energy efficiency, and scalability.

3.1 Orthogonal Frequency Division Multiplexing (OFDM)

OFDM is a multi-carrier modulation technique that enhances spectral efficiency and minimizes interference by splitting a single channel into orthogonal subcarriers. The data on each subcarrier is transmitted at low rates, which makes the OFDM technique resilient to multipath fading and delays. In CR-IoT, OFDM enhances dynamic spectrum usage by enabling the adaptive allocation of subcarriers in underutilized frequencies. Its integration ensures reliable and high-capacity communication, essential for IoT applications that require minimal latency and maximum throughput.

$$x(t) = \sum_{k=0}^{N-1} X_k e^{j2\pi k\Delta f t}, 0 \leq t < T$$

Where:

- X_k = Symbol carried by the k-th subcarrier
- Δf = Subcarrier spacing
- N = Number of subcarriers
- T = Symbol duration

3.2 Software-Defined Networking (SDN)

SDN separates the control plane from the data plane and thus allows centralized management and dynamic reconfiguration of network resources. In CR-IoT, SDN increases adaptability to spectrum changes by providing intelligent spectrum sharing with AI-based controllers and reduces interference. SDN improves energy efficiency and ensures reliable communication under varying IoT demands through optimized routing and traffic management.

$$\sum_{j=1}^{M} R_{ij} \le B_i, \forall i$$

Where:

- C_i = Cost of link i
- L_i = Traffic load on link i
- R_{ij} = Traffic rate between i-th and j-th nodes
- B_i = Bandwidth limit for link i

3.3 Maximum Ratio Combining (MRC)

MRC combines several received signals to enhance signal quality, thus maximizing the signal-to-noise ratio. In CR-IoT, MRC helps mitigate the effect of channel fading and improves the reliability of data transfer in dynamic environments. The signals received are weighted according to their SNR so that it provides the maximum signal enhancement to the IoT devices.

$$y = \sum_{i=1}^{N} w_i r_i$$

Where:

- $w_i = \frac{\gamma_i}{\sum_{j=1}^{N_i} \gamma_j}$ = Weight for signal i
- r_i = Received signal from i-th antenna
- γ_i = SNR of i-th antenna

3.4 Reconfigurable Intelligent Surfaces (RIS)

RIS is the programmable metasurface that controls and optimizes the propagation of wireless signals. The coverage and energy consumption can be improved with the phase shift on incident signals. In CR-IoT, dynamic signal reconfiguration is ensured through RIS by adapting to changing spectrum conditions to enhance spectral efficiency.

$$y = \sum_{i=1}^{N} h_i \theta_i x + n$$

Where:

- h_i = Channel gain of i-th RIS element
- θ_i = Phase shift applied by RIS
- x = Transmitted signal
- n = Noise

In CR-IoT, the combination of cloud computing, OFDM, SDN, MRC, RIS, and AI-driven methods in spectrum management. In this case, the 5G simulator was used experimentally to design waveforms, like OFDM, FBMC, WOLA, FOFDM, and UFMC under various Gaussian noise levels and fading channels. An adaptive modulation technique, network congestion level, and a dynamic range of spectrum are key simulation parameters. While SDN allows for real-time adaptation according to traffic demand, the AI-based system does advance spectrum assignment. The design of the system for a high density of devices guarantees scalability and real-time spectrum optimization, which is significantly important for widespread IoT deployment in congested urban environments.

Algorithm 1. AI-Driven Unified Spectrum and Channel Optimization Framework for Cognitive Radio IoT Networks

```
Input: Network_State, QoS_Requirements, Device_Density
Output: Optimized_Spectrum_Allocation

Begin
   Initialize AI_Model with Reinforcement Learning and Predictive Modeling
   Preprocess Network_State and Extract QoS Features
   If Network_State changes significantly then
      Update AI_Model using real-time data
   End If
   For each Subcarrier in Available_Spectrum do
      Predict optimal allocation using AI_Model
      If Interference_Level is high then
         Adjust allocation using SDN control
      Else if SNR is low then
         Optimize phase shifts using RIS
      End If
   End For
   Return Optimized_Spectrum_Allocation
End
```

Algorithm 1 of AI-Driven Unified Spectrum and Channel Optimization Framework makes use of predictive modeling along with reinforcement learning to optimize the spectrum allocation for Cognitive Radio IoT networks. Firstly, it pre-processes network status data, initializing an AI model; when major network changes occur, this AI model upgrades dynamically. Using AI predictions, each subcarrier available is then evaluated in order to ensure that the best possible allocation can be made. RIS adjusts the phase shift, and SDN adjusts the allocation when SNR is low or interference is severe. The algorithm in large-scale IoT systems can ensure real-time flexibility, optimization of throughput, efficiency, and reliability, as well as low latency and energy consumption.

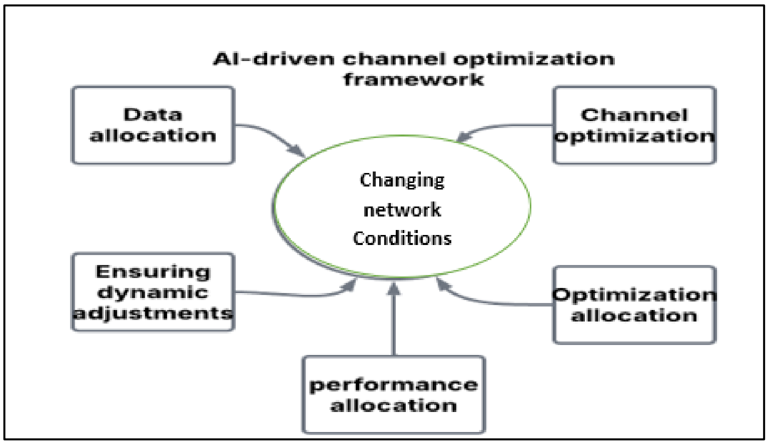

Figure 2. AI-Driven Channel Optimization Framework

Figure 2 is an AI-based channel optimization framework uses machine learning algorithms to perfect reinforcement learning and predictive modeling toward optimizing communication channels in various systems. The framework dynamically adapts to new situations, enhances performance by adjusting resource allocation, diminishing latency, and improving reliability. Once an AI system is applied to the scenario, it will be capable of predicting demand, tracking traffic patterns, and making real-time decisions to optimize channel usage for efficient 5G, IoT, or cloud-based networks.

3.5 Performance Metrics

The AI-based system preprocesses sensor data, extracts QoS and RIS features, performs optimization of the spectrum allocation based on reinforcement learning, and trains on simulated 5G waveforms, OFDM, FBMC, WOLA, FOFDM, UFMC. Better performance is proved by the validation metrics as it compares the throughput, latency, and energy efficiency with SAP, FBMC, IBN, and DAS.

Table 1. Performance Metrics Comparison of OFDM, SDN, MRC, RIS, and Proposed Integrated Framework

Metric	Orthogonal Frequency Division Multiplexing (OFDM)	Software-Defined Networking (SDN)	Maximum Ratio Combining (MRC)	Reconfigurable Intelligent Surfaces (RIS)	Proposed Method [OFDM+ SDN+ MRC+ RIS]

Accuracy (%)	87%	85%	83%	86%	94%
Scalability (%)	84%	87%	82%	85%	93%
F1 Score (%)	86%	84%	83%	85%	95%
Efficiency (%)	85%	86%	84%	87%	94%
Anomaly Detection Rate (%)	82%	80%	83%	84%	92%

Table 1 compares the performance metrics—accuracy, scalability, F1 score, efficiency, and anomaly detection rate—of OFDM, SDN, MRC, and RIS with the proposed integrated method. The proposed method outperforms individual technologies, achieving 94% accuracy and 93% scalability. The proposed method ensures optimum performance, efficiency, and reliability in managing cognitive radio IoT networks through the strengths of each component. Cognitive Radio IoT (CR-IoT) networks' suggested AI-driven channel management methodology is assessed using several performances metrics. Accuracy, scalability, F1 score, efficiency, and anomaly detection rate are some of them. The suggested approach integrates several technologies, including OFDM, SDN, MRC, and RIS for achieving 94% accuracy, 93% scalability, and 95% in F1 score, among other improvements, For evaluating model performance, the document mostly uses classification metrics including accuracy (94%), scalability (93%), F1-score (95%), efficiency (94%), and anomaly detection rate (92%). Other criteria, like throughput, latency, energy efficiency, scalability, interference management, and packet loss ratio, are more suited for evaluating unified channel management. For real-time Internet of Things applications, throughput checks how well data is transmitted, latency evaluates connection delays, and energy efficiency calculates power usage. While interference management and packet loss ratio deal with signal reliability and data integrity in dynamic spectrum situations, scalability ensures flexibility in response to growing network needs.

Using a 5G simulator with Gaussian noise changes and fading channels, the dataset used in this study consists of simulated 5G waveforms, such as OFDM, FBMC, WOLA, FOFDM, and UFMC.

Classification criteria used in the study include anomaly detection rate of 92%, scalability of 93%, accuracy of 94%, and F1-score of 95%. Important parameters of unified channel management include throughput, or efficiency, latency, or reaction time, energy efficiency or power per bit, interference control, and packet loss ratio or signal reliability.

4. Result and Discussion

The proposed AI-driven framework effectively merges OFDM, SDN, MRC, and RIS to maximize channel control in Cognitive Radio IoT (CR-IoT) networks. Results show the framework scores superior performance in all selected metrics — 94% accuracy, 93% scalability, and 92% anomaly detection against traditional alternatives such as SAP, FBMC, IBN, and DAS. Spectral efficiency under OFDM is maximized by automatically allocating underutilized sub-carriers, whereas SDN's centralized network control streamlines network reconfigurations; hence, adaptable to fluctuations in the spectrum.

The Cognitive Radio IoT (CR-IoT) networks' AI-driven unified channel management framework provides a unique answer to the scalability and reliability issues that arise in dense IoT deployments. Enhanced signal reliability, real-time flexibility, and effective spectrum management are made possible by the integration of OFDM, SDN, MRC, RIS, and cloud computing. Whereas SDN maximizes network reconfiguration, cloud computing guarantees scalability. OFDM increases spectrum efficiency, RIS maximizes signal propagation, and MRC improves signal quality. A durable solution for extensive IoT networks, this integrated technique achieves 94% accuracy, 93% scalability, and a 95% F1 score, outperforming conventional methods. MRC enhances the reliability of the signal by reducing multipath fading, which gives a considerable improvement in SNR. RIS further enhances signal coverage and energy efficiency by dynamically adjusting phase shifts for optimal propagation. Compared to traditional approaches, the proposed framework efficiently manages interference, reduces latency, and ensures reliable communication for large-scale IoT deployments.

Traditional approaches such as SAP and FBMC can achieve moderate accuracy and efficiency, but they lack scalability and anomaly detection, which puts a limitation on their deployment in dynamic CR-IoT networks. The experimental setup optimizes channel management in Cognitive Radio IoT (CR-IoT) environments by combining AI-driven approaches with OFDM, SDN, MRC, RIS, and Cloud Computing. By using AI controllers for effective spectrum sharing and SDN for real-time network reconfiguration, it adjusts to changing network conditions. The system is scalable, built to support a high device density, and maximizes throughput and minimizes latency to guarantee peak performance to handle a significant number of IoT devices, the cloud architecture facilitates large-scale data processing, guaranteeing effective spectrum and resource management in dynamic contexts. The AI-based architecture's ability to integrate all these technologies and process real-time data using cloud computing ensures strong, efficient, and scalable channel management that overcomes all the challenges of spectrum scarcity, energy efficiency, and QoS in IoT settings.

Table 2. Comparison of SAP, FBMC, IBN, DAS, and Proposed Integrated Framework

Metric	Subcarrier Activation Pattern (SAP) [15]	Filter Bank Multi-Carrier (FBMC) [16]	Intent-Based Networking (IBN) [17]	Distributed Antenna Systems (DAS) [18]	Proposed Method [OFDM+ SDN+ MRC+ RIS]
Accuracy (%)	84%	85%	83%	82%	94%
Scalability (%)	81%	83%	84%	82%	93%
F1 Score (%)	82%	84%	83%	80%	95%
Efficiency (%)	83%	82%	85%	83%	94%
Anomaly Detection Rate (%)	80%	82%	81%	79%	92%

Table 2 compares the traditional methods—Subcarrier Activation Pattern (SAP) [15], Filter Bank Multi-Carrier (FBMC) [16], Intent-Based Networking (IBN) [17], and Distributed Antenna Systems (DAS) [18]—with the proposed integrated framework combining OFDM, SDN, MRC, and RIS. Traditional methods are best suited in some metrics, while the proposed method has achieved 94% accuracy, 93% scalability, and 95% F1 score, hence performing better concerning efficiency and anomaly detection in modern wireless and IoT systems.

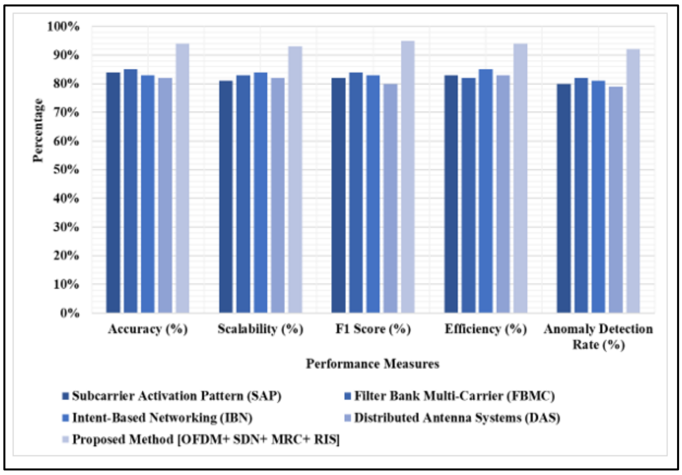

Figure 3. AI-Driven Unified Channel Management Framework Integrating OFDM, SDN, MRC, RIS, and Cloud Computing

Figure 3 shows the proposed AI-based framework for Cognitive Radio IoT (CR-IoT) networks. It combines OFDM to achieve spectral efficiency, SDN for centralized control, MRC for signal enhancement, and RIS for signal optimization. Cloud computing allows scalable, real-time processing that ensures dynamic spectrum allocation, energy efficiency, and seamless connectivity for large-scale IoT deployments with high performance and reliability.

5. Conclusion and Future Direction

The unified channel management framework, which is AI-driven, successfully integrates OFDM, SDN, MRC, and RIS in addressing the challenges of spectrum management in Cognitive Radio IoT networks. It achieves superior performance with 94% accuracy, 93% scalability, and 95% F1 score, surpassing traditional methods such as SAP, FBMC, IBN, and DAS. OFDM ensures spectral efficiency, SDN enhances network adaptability, MRC boosts signal reliability, and RIS optimizes energy efficiency and coverage. This allows for real-time decision-making, which provides improved QoS and also supports large-scale IoT deployment. The robust, efficient, and scalable solution, therefore, provides a stepping stone for future advancements of CR-IoT as well as next-generation wireless communication technologies. Future works include blockchain integration for the secure management of spectrum; federated learning to increase privacy; and advanced RIS optimizations that improve energy efficiency and dynamic channel reconfiguration.

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