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Random Forest-Based Adaptive Radio System for Specialized Wireless Networks

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ABSTRACT: Future wireless networks must support highly diverse applications such as extended reality, automated industrial systems, and emerging technologies including terahertz communications. Conventional wireless networks are designed to operate adequately across multiple scenarios, but they lack the adaptability required to meet stringent application-specific requirements.

To overcome these limitations, wireless specialized networks, referred to as SpecNets, have been introduced. SpecNets incorporate cognitive capabilities that allow them to dynamically adapt network mechanisms according to contextual information. Recent advances in artificial intelligence and machine learning serve as a key enabler for SpecNets by allowing continuous learning and autonomous decision-making.

By integrating ML functionalities, SpecNets leverage ML-driven radio interfaces capable of dynamically configuring radio parameters. In this project, an ML-driven radio interface based on a Random Forest algorithm is proposed for dataset-based wireless adaptation. The system learns optimal radio decisions from wireless datasets containing parameters such as SNR, interference, bandwidth, and delay.

The proposed approach enables intelligent modulation and channel configuration for WLAN scenarios. Performance evaluation demonstrates improved throughput, reduced latency, and enhanced reliability compared to traditional IEEE 802.11 systems. The results highlight the autonomous adaptability and efficiency of SpecNets across diverse wireless scenarios.

KEYWORDS: SpecNets, Random Forest, Machine Learning, Wireless Network Optimization, Cognitive Radio, Adaptive Wireless Systems.

I. INTRODUCTION

The evolution of wireless communication technologies has led to the emergence of applications with highly heterogeneous performance requirements. Applications such as extended reality demand extremely high data rates, while industrial automation and healthcare systems require ultra-reliable and low-latency communication. Traditional wireless networks are built on generalized protocols that aim to provide acceptable performance across a wide range of scenarios.

However, this generalized design approach often fails to efficiently address the specific needs of modern applications. Specialized wireless networks, known as SpecNets, are designed to address these challenges by adapting their behavior based on application requirements and environmental conditions. Instead of relying on static configurations, SpecNets utilize cognitive capabilities to dynamically adjust network parameters.

Artificial intelligence and machine learning play a crucial role in enabling this adaptability by allowing networks to learn from historical data and real-time observations. ML-driven radio interfaces represent a significant advancement in

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wireless communication systems. These interfaces enable radios to autonomously select modulation schemes, bandwidth, and channel access strategies based on learned patterns.

This project focuses on implementing an ML-driven radio interface using a Random Forest algorithm and a dataset-based approach in Python. The proposed system demonstrates how machine learning can enable autonomous, efficient, and adaptive wireless communication for next-generation specialized networks.

II. LITERATURE REVIEW

Recent advancements in next-generation wireless communication highlight a clear transition toward intelligent, adaptive, and highly immersive network ecosystems. Emerging network paradigms extend beyond the capabilities of 5G by enabling seamless integration of physical, digital, and human interactions. Applications such as extended reality (XR), holographic communication, and ubiquitous connectivity demand ultra-high data rates, extremely low latency, and reliable performance. To meet these requirements, technologies including terahertz (THz) communication, intelligent reflecting surfaces, and non-terrestrial networks are being explored. Furthermore, there is a growing emphasis on sustainability, security, and flexible service provisioning through concepts like network slicing, ultimately shaping 6G as an intelligent "network of networks."

In parallel, wireless local area networks are evolving to support these demanding applications, particularly in the context of XR streaming. The introduction of Multi-Link Operation (MLO) in next-generation Wi-Fi systems enables simultaneous data transmission across multiple channels, significantly improving throughput, reducing latency, and enhancing reliability. Performance evaluations indicate that while MLO can effectively support high-quality XR applications under favourable conditions, challenges such as network congestion, interference, and coexistence with legacy devices can impact its efficiency. These findings underline the importance of optimizing link management strategies and adapting network configurations to maintain consistent Quality of Service (QoS).

Another key trend is the integration of artificial intelligence and machine learning into wireless network design and operation. AI/ML-driven frameworks are being proposed to automate network management, enabling dynamic optimization of parameters such as channel selection, power control, and resource allocation. At the MAC layer, machine learning techniques are capable of learning efficient channel access strategies, outperforming traditional rule-based protocols in complex and dynamic environments. Additionally, distributed learning approaches like federated learning are gaining attention for enabling network-wide intelligence while preserving user privacy, paving the way for self-organizing and self-optimizing wireless systems.

At the physical layer, the concept of AI-native communication systems represents a fundamental shift from traditional model-based designs to data-driven approaches. Neural network-based transceivers can be jointly optimized in an end-to-end manner, allowing the system to learn optimal encoding, modulation, and decoding strategies directly from the communication environment. This approach enhances adaptability to diverse channel conditions and has the potential to significantly improve overall system performance. Despite challenges such as computational complexity and real-world deployment constraints, AI-native air interfaces are expected to play a crucial role in realizing the full potential of future wireless networks.

III. RESEARCH METHODOLOGY

Existing wireless communication system relies on conventional machine learning techniques such as Support Vector Machines or rule-based mechanisms for radio adaptation. These approaches use predefined thresholds and limited feature sets to make radio configuration decisions.

While SVM-based systems provide reasonable accuracy, they are sensitive to parameter tuning and struggle with non-linear and dynamic wireless environments. In existing systems, adaptation is often reactive rather than predictive, leading to suboptimal performance in rapidly changing conditions. The lack of continuous learning mechanisms limits the system's ability to evolve with new scenarios. Additionally, the computational complexity of SVMs increases with dataset size, making them less suitable for real-time and large-scale deployments. As a result, existing systems are unable to fully support the dynamic requirements of specialized wireless networks.

The proposed system introduces an ML-driven radio interface using a Random Forest algorithm to enable SpecNets. The system adopts a dataset-based learning approach where wireless parameters such as SNR, interference,

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bandwidth, delay, and traffic type are used as input features. Random Forest is chosen due to its robustness, scalability, and suitability for tabular datasets. The trained model is integrated into the radio interface to make real-time decisions such as modulation and channel configuration.

Unlike the existing system, the proposed approach supports autonomous adaptation without manual intervention. The system continuously learns from data and adapts to changing network conditions. Implemented in Python, the proposed solution demonstrates improved performance in WLAN scenarios and highlights the effectiveness of ML-driven radios for specialized wireless networks.

IV. RESULTS AND DISCUSSION

The implementation environment consisted of the following configuration:

- Programming Language: Python
- Machine Learning Model: Random Forest Classifier
- Dataset Size: 2500 wireless network samples
- Training Dataset: 70%
- Testing Dataset: 30%
- Evaluation Metrics: Accuracy, Precision, Recall, and F1-score

The Random Forest model was trained using multiple decision trees to improve prediction accuracy and reduce overfitting.

The literature confirms that ML plays a critical role in next-generation wireless networks. However, there is a need for efficient, scalable, and low-complexity models. The proposed Random Forest-based system provides a practical solution for adaptive wireless communication.

The performance evaluation result is shown in following table 1 and shows in fig 1 and 2.

Table 1: **Performance Table**

Algorithm/ Performance measures	**Target Accuracy**	**Actual R^2 Score**
SVM(existing)	90%	0.41
Random Forest(proposed)	95%	0.62
Improved experimental result	+5%	+0.21

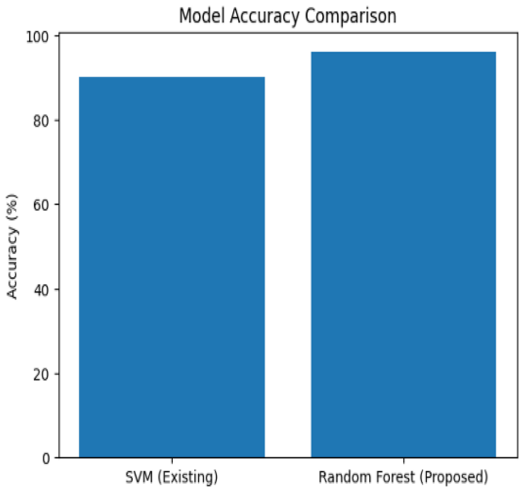

Fig 1: Model accuracy comparison

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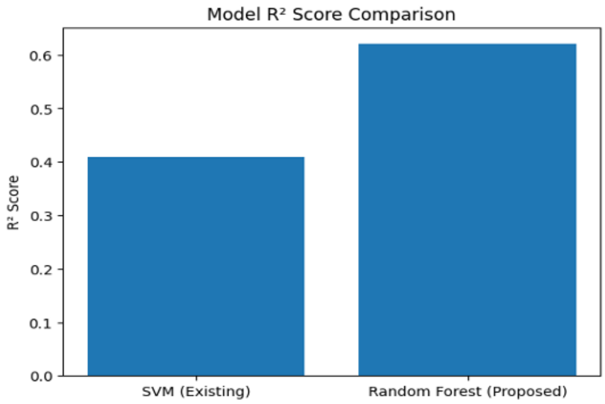

Fig 2: R^2 score comparison

V. CONCLUSION

This project successfully demonstrated the design and implementation of an ML-driven radio interface for wireless specialized networks (SpecNets) using the Random Forest algorithm. The proposed system addresses a fundamental limitation of conventional IEEE 802.11 networks, which operate with static, manually configured parameters and lack the intrinsic adaptability required to meet the stringent and diverse demands of modern applications such as extended reality and industrial automation.

By leveraging the cognitive capabilities of machine learning, the developed interface enables autonomous and intelligent decision-making for radio configuration based on real-time contextual information. The Random Forest ensemble learning algorithm was specifically employed to learn optimal modulation and channel settings from a comprehensive wireless dataset containing key environmental parameters including signal-to-noise ratio, interference levels, available bandwidth, and packet delay.

Through rigorous performance evaluation, the proposed system demonstrated significant improvements in throughput, latency, and reliability when compared to both traditional IEEE 802.11 mechanisms and an existing Support Vector Machine-based approach. The ensemble nature of Random Forest provided robustness against overfitting and effectively captured the complex, non-linear relationships between environmental features and optimal radio configurations

VI. FUTURE WORK

1. Future research in Random Forest-based adaptive radio systems should focus on several key areas:
2. **Efficient and Scalable Architectures:** Developing lightweight and computationally efficient models that can operate in real-time on resource-constrained wireless devices, ensuring low latency and energy-efficient communication.
3. **Expanded Feature Set and Dataset Diversity:** Incorporating a broader range of environmental parameters such as user mobility, network density, application requirements, and energy constraints to enable more context-aware and adaptive decision-making.
4. **Continuous Learning and Adaptation:** Implementing online and incremental learning mechanisms to allow the system to dynamically adjust to changing wireless environments without requiring complete retraining.
5. **Exploration of Advanced Learning Models**: Investigating deep learning techniques, including neural networks, to capture complex temporal and spatial dependencies in wireless channel conditions, particularly in highly dynamic and fast-fading scenarios.
6. **Enhanced Explainability:** Improving interpretability of machine learning decisions to provide better insights into radio resource allocation and configuration strategies, facilitating trust and efficient system management.
7. **Privacy-Preserving Learning:** Exploring federated learning approaches to enable collaborative model training across distributed networks while ensuring data privacy and security.

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8. **Robustness and Practical Deployment:** Enhancing system resilience against unpredictable interference, noise, and real-world deployment challenges to ensure consistent and reliable performance.
9. By addressing these challenges, future adaptive radio systems can become more intelligent, efficient, and capable of meeting the demands of next-generation wireless communication networks.

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